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WATER TEST DEVELOPMENT OF THE FUEL PUMP FOR THE MSRE

P. G. Smith

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ORNL-TM-79

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Contract No. W-7405-eng-26

Reactor Division

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DATE ISSUED

MAR 27 1962

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Oak Ridge, Tennessee
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CONTENTS

LIST OF FIGURES

ABSTRACT

A vertical centrifugal sump-type pump utilizing commercially available impeller and volute designs was selected to circulate the fuel salt in the Molten Salt Reactor Experiment (MSRE). Tests were conducted in water to determine the adequacy of the pump design, to assist design of the prototype fuel pump, and to investigate the effectiveness of xenon removal with high velocity liquid jets contacting sweep gas in the pump tank. Hydraulic head characteristics were within +1 to -3 ft of manufacturers data for a given constant speed. Adequate and necessary provisions were devised to control the liquid and gas bubble behavior in the pump tank. The results of priming and coastdown tests are reported. During the gas removal tests, the fuel, xenon, and helium in the MSRE were simulated with distilled water, carbon dioxide, and air, respectively. The best configuration removed carbon dioxide from water at approximately 99% of the ideal removal rate when the stripping flow was 65 gpm and the sweep gas flow rate was 4 scfm.

WATER TEST DEVELOPMENT OF THE FUEL PUMP FOR THE MSRE

P. G. Smith

INTRODUCTION

The Molten Salt Reactor Experiment (MSRE) is to be a low-pressure, high-temperature, graphite moderated circulating fuel nuclear reactor using fissile and fertile materials dissolved in molten fluoride salts and is designed for a heat generation rate of 10 Mw (1, 2, and 3). Its goals include proving the safe and reliable operation of this nuclear reactor concept and demonstrating the maintainability of molten salt machinery. The investigation reported herein is concerned with the pump required to circulate the fuel salt in the MSRE.

A centrifugal sump-type pump consisting of a rotary element and pump tank was selected for this application. The rotary element includes the vertical shaft and underhung impeller, the shaft bearings, and the means for lubricating and cooling the bearings. The pump tank includes the volute (casing), suction and discharge nozzles, other nozzles for accommodating inert gas purge, fuel sampling and enrichment, liquid level sensing devices, a flange for mounting the rotary element, and various liquid bypass flows for degassing and removing xenon poison from the circulating fuel salt. The device used for removal of xenon will be referred to as a "stripper". Much of the design of the fuel pump was derived from the past experience with similar pumps for elevated temperature service which were developed during the Aircraft Nuclear Propulsion Program at Oak Ridge National Laboratory (4, 5, and 6).

The initial phase of development and testing of the fuel pump was conducted with water to ascertain the capability of the pump to meet the hydraulic requirements of the fuel circuit and to remove from the circulating fuel the xenon which will be generated by the fissioning process. Data were taken on the head-flow-power-speed performance of the pump for two impeller outside diameters, 13 and 11 inches. Various baffles were devised to control splash, spray, and gas bubbles caused by the operation of the bypass flows in the pump tank. The ability of the pump to prime was determined at various liquid levels of interest. The coastdown characteristics of the pump were measured from various speeds and flows. Attempts were made to measure indirectly the effectiveness with which xenon poison might be removed from the circulating fuel using high velocity liquid jets in contact with gas in the pump tank. During this particular test the fuel and xenon were simulated, respectively, with distilled water and carbon dioxide; this gas is much more soluble in water than xenon is in molten salts of interest and in addition provides for convenient measurement of solubility.

Pertinent information from these water tests were incorporated in the design of the prototype fuel pump and will be subjected to elevated temperature testing at MSRE design conditions.

EXPERIMENTAL APPARATUS

The experimental apparatus includes the pump, the test loop, and the stripper configurations. A description of each follows:

Pump

The pump is shown in Fig. 1 and includes a centrifugal impeller and volute with the impeller supported at the lower end of a vertical shaft, grease-lubricated bearings for supporting the shaft, bearing housing, pump tank bowl, and volute support. The pump tank bowl was fabricated of plexiglas to permit visual observation of the behavior of the liquid and the gas bubbles. Labyrinth-type seals were utilized on the impeller inlet shroud and on the impeller support shroud. The impeller support shroud labyrinth seal was supported on the impeller cover plate, which was sealed to the volute by an elastomeric O-ring. The volute discharge was connected to the pump tank discharge nozzle through a flexibly mounted bridge tube. The connection arrangement is shown in Fig. 2.

Test Loop

The test loop is shown in Fig. 3, which consists of the pump, piping, venturi flowmeter, throttle valve (globe type), stripper flow circuits

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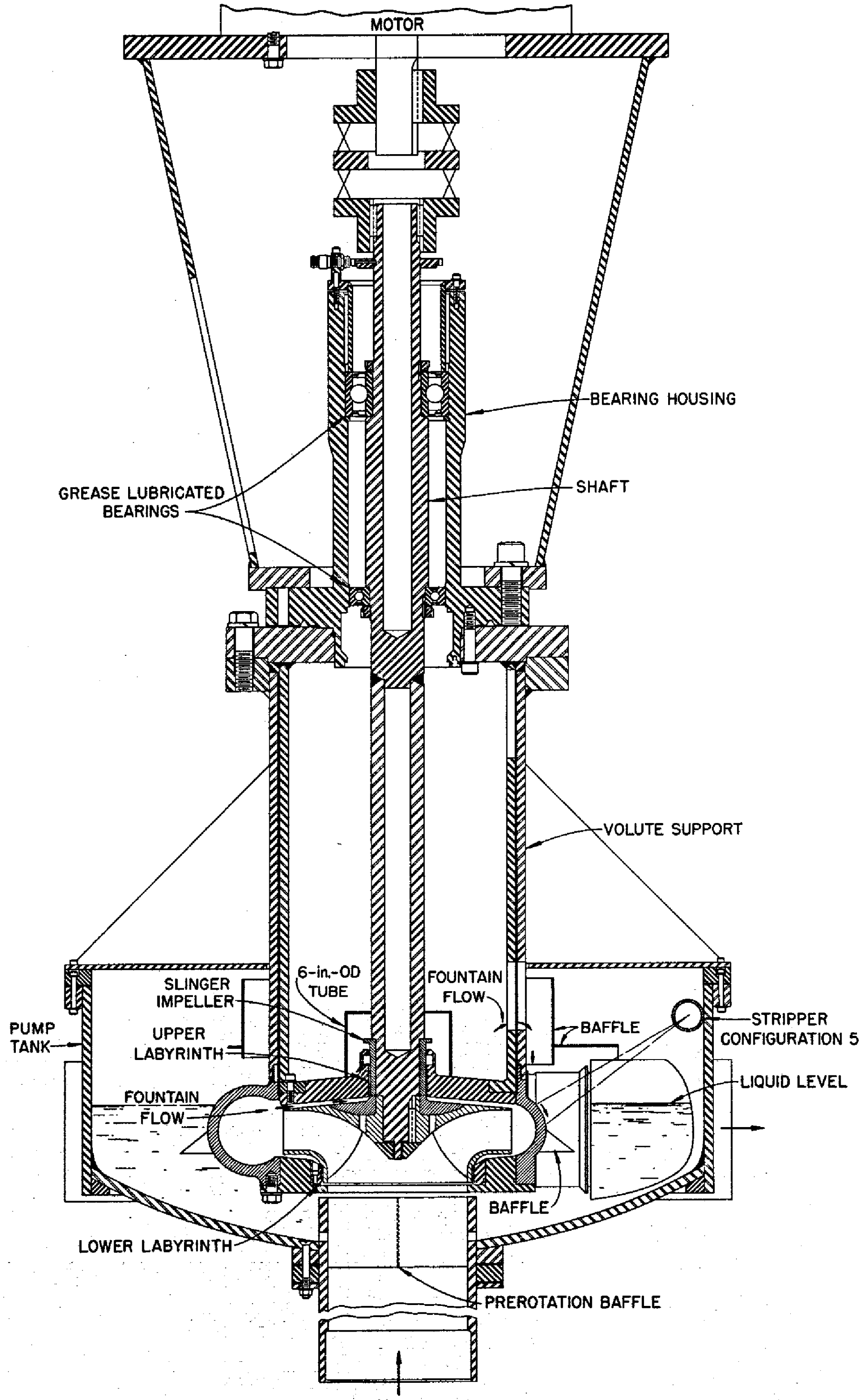

Fig. 1. Cross Section of Pump.

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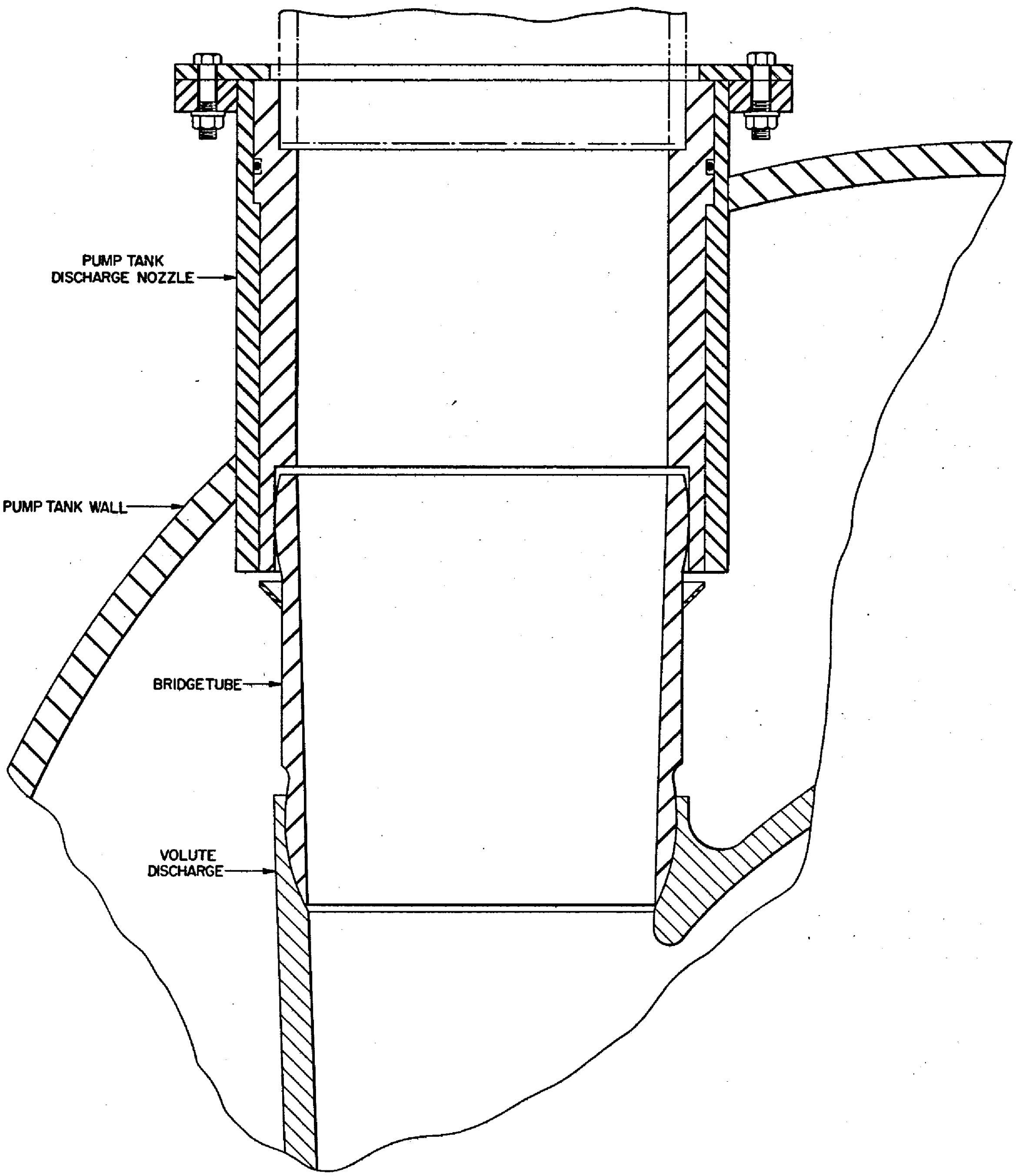

Fig. 2. Discharge Connection to Loop.

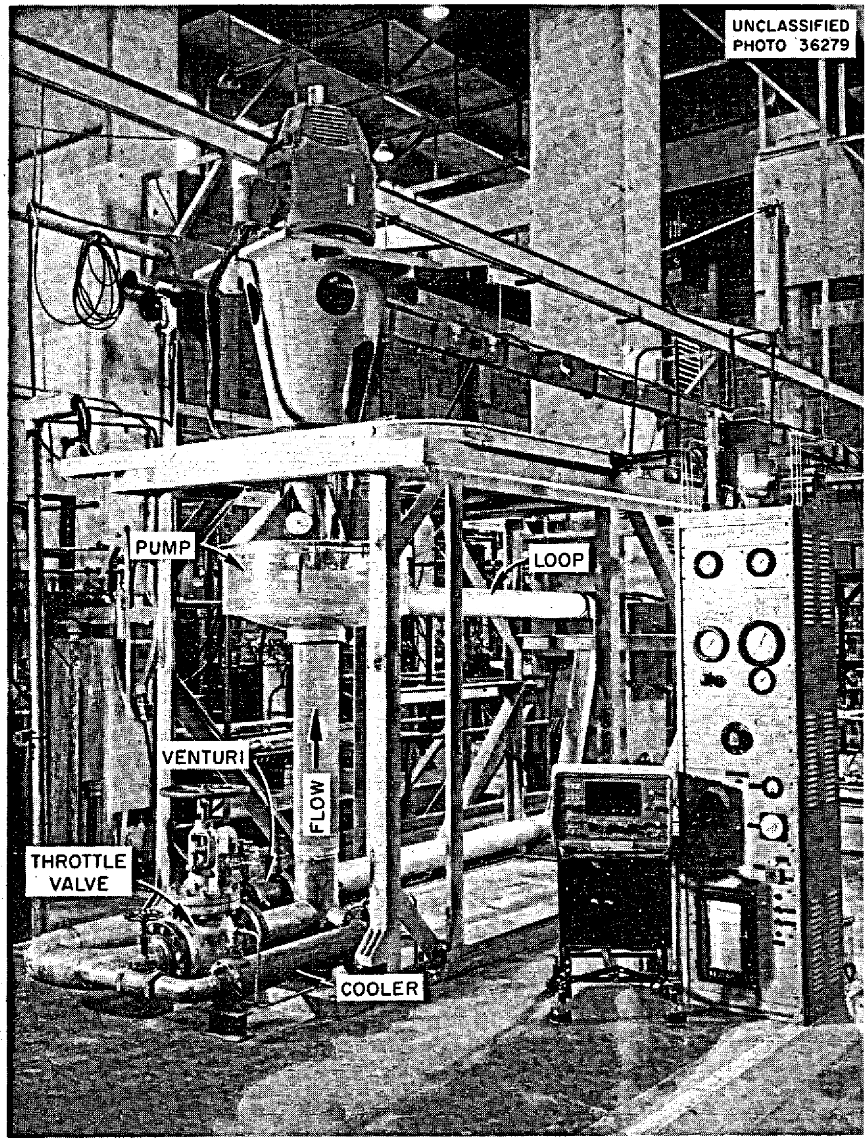

Fig. 3. Photo of Test Loop.

(not shown), and a cooler. The pump was driven with a 60 hp d.c. variable speed motor. The vertical inlet pipe to the pump was fabricated of plexiglas to permit visual observation of the inlet flow conditions. A bundle of 1-in. diameter thin-wall tubes, 6-in. long, was added to the lower end of this pipe to reduce rotation of the water column. The cooler was installed in parallel with the main loop throttle valve. A part of the main loop flow was bypassed through the cooler to control the system temperature. The bypass flow was controlled by a throttle valve located in the bypass flow circuit. Stripper configuration flow was supplied through a tap located just downstream of the pump tank discharge nozzle. The stripper flow as well as the flow from the impeller upper labyrinth passed through the pump tank and re-entered the system at the impeller inlet. Throttle valves were used to control the stripper flow. Following the initial tests an orifice was added to the nearly vertical section of the loop between the discharge and the venturi flow meter to decrease the pressure drop through the main throttle valve.

Carbon Dioxide Stripping Devices

Tests were conducted wherein a portion of the pump discharge flow was introduced into the gas volume of the pump tank through high velocity jets (strippers). A number of configurations were investigated, starting with a single stream and progressing to configurations which gave increasingly more fresh liquid-gas interface.

The strippers tested and identified in Table I (Appendix) are described as follows (in each test two strippers were used):

1. Configuration 1 is shown in Fig. 4. The flow discharged from one side of the can through 1/4-in. holes. For this test the holes were submerged below the liquid surface in the pump tank.

2. Configuration 2 is shown in Fig. 5. The lower end of the entry tube was closed and the beaker was packed with Inconel wool. The stripping flow entered the pump tank gas space in tangential direction as a spray. One beaker contained 84 spray holes, 1/8-in. in diameter, and the other contained 30 spray holes, 1/4-in. in diameter.

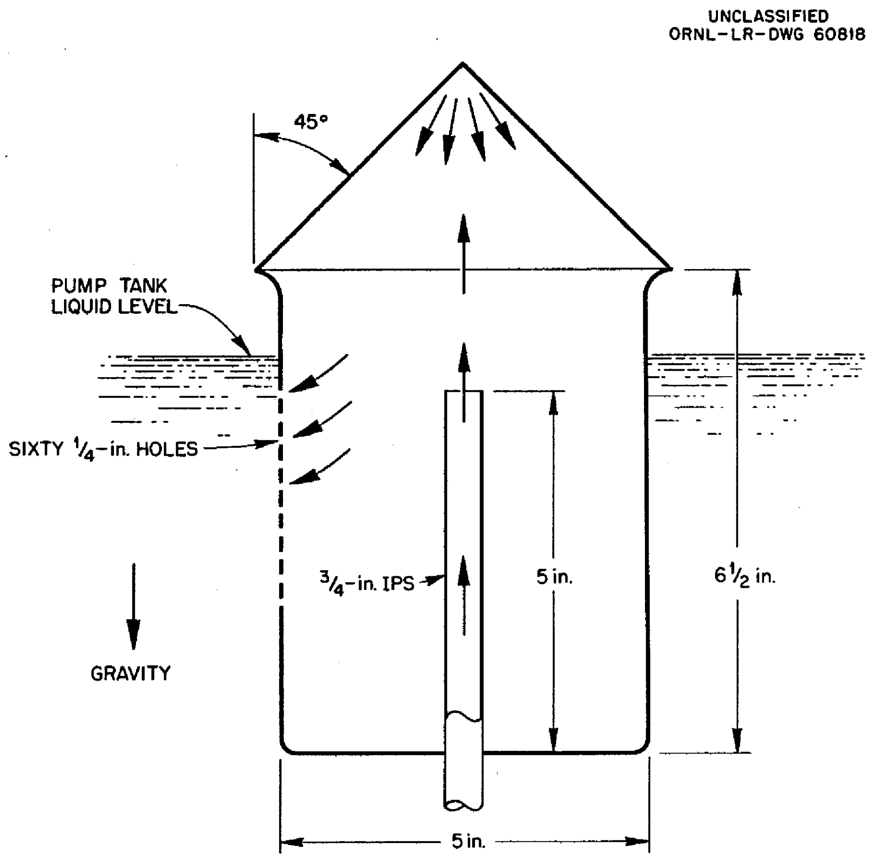

Fig. 4. Stripper Configuration 1.

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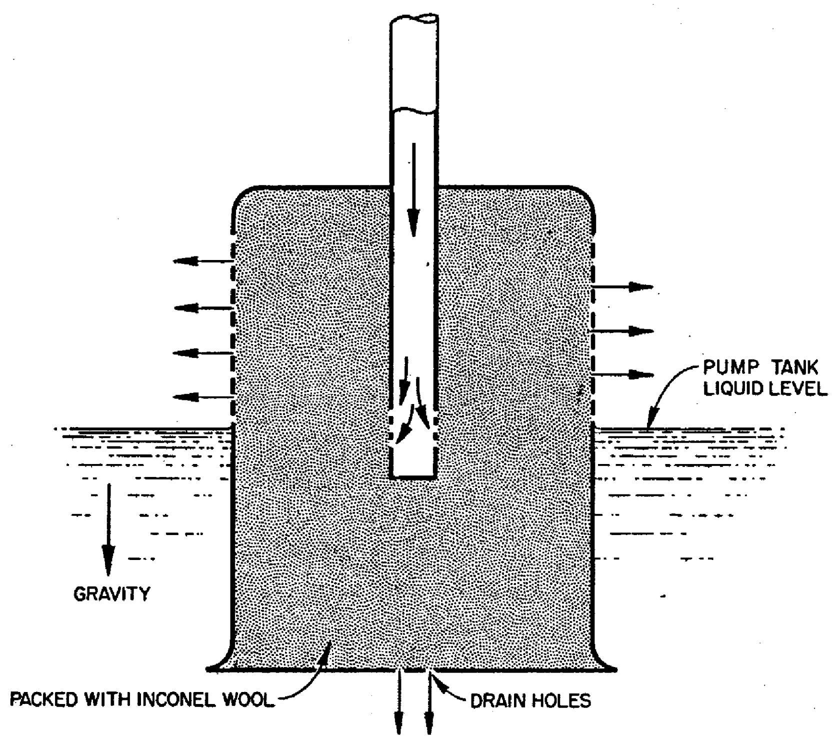

Fig. 5. Stripper Configuration 2.

3. Configuration 3 was the same as No. 2, except for the size of spray holes, and the number of holes. Each stripper contained 162 spray holes, 1/16-in. in diameter, with the beaker suspended such that the spray was circumferential.

4. Configuration 4 was the same as No. 3, except the number of holes was reduced by a factor of two and the spray was directed radially inwards toward the pump shaft.

5. Configuration 5 was a toroid constructed of pipe as shown in Fig. 6, and located in the pump tank as shown in Fig. 1. Each stripper contained two rows of 80 holes each, 1/16-in. in diameter.

INSTRUMENTATION

Instrumentation was provided to measure venturi pressure drop, discharge pressure, pump shaft speed, water temperature, motor input power, fountain flow, stripper flow, pH value of the water, and pump tank liquid level.

Three different methods were used in measuring the venturi pressure drop: mercury manometer, difference between individual pressures measured at the inlet and throat, and by differential pressure transmitter. Calibration of the venturi was provided by the vendor, and it is shown in Fig. 7. Individual pressures at the inlet and throat were indicated on Bourdon tube gages, 0-30 psi range, 1/8 psi subdivision, and 1/4% accuracy. The differential pressure transmitter was read out on a differential gage, 0-50 psi range, 1/2 psi subdivision, 1/4% accuracy. The flow is estimated to be accurate within ± 3%.

The discharge pressure was measured on a Bourdon tube gage, 0-100 psi range, 1/2 psi subdivision, and 1/4% accuracy.

The pump shaft speed was measured by use of a 60-tooth gear mounted on the shaft, a magnetic pickup, and a counter which indicated directly in rpm.

The water temperature was measured with a dial-type thermometer, 0 to 240 F range, 2 F subdivision.

Motor input power data was obtained by two methods: power recorder, 0 to 40 kw range, 0.8 kw subdivision and power analyzer which indicated

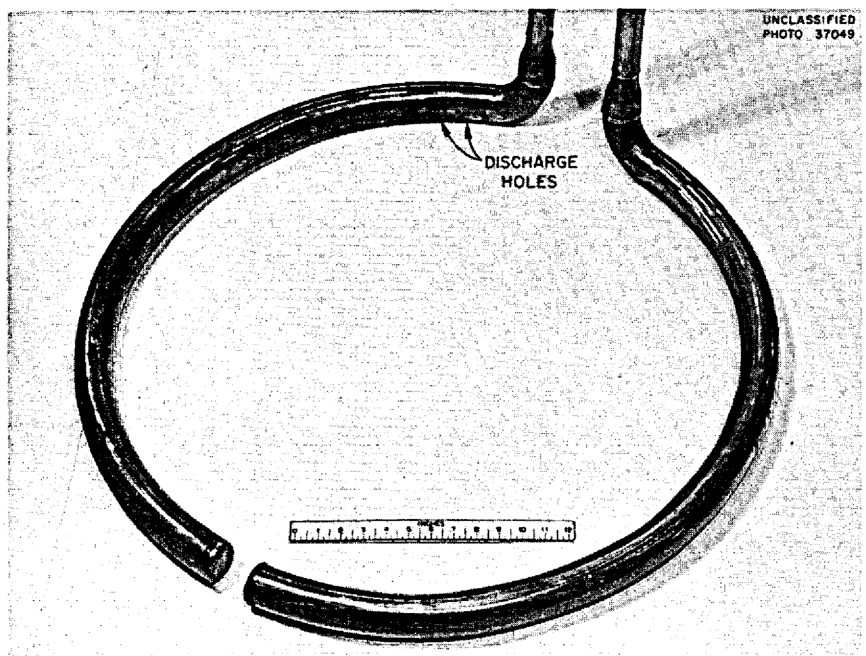

Fig. 6. Stripper Configuration 5.

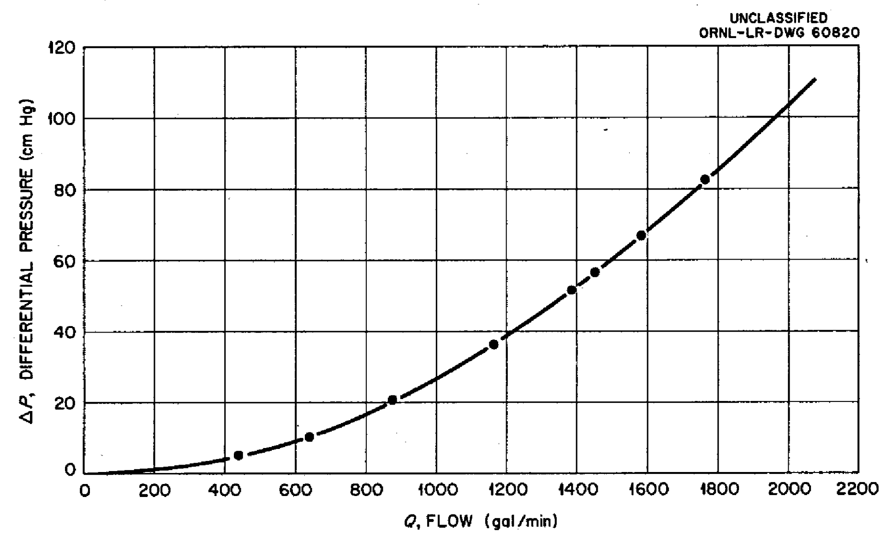

Fig. 7. Venturi Calibration.

current and voltage. The power measurements were in error during most of the testing with the 13-in-o.d. impeller which preceded tests with the 11-in. impeller. During this period, investigations were conducted to locate and correct the source of error. Satisfactory power measurements were obtained with the 11-in. impeller. The motor calibration curve is shown in Fig. 8.

The fountain flow was measured by directing the flow through 90° V-notch weirs and measuring the height of the flow column.

The stripper flow was measured by use of rotameters.

The pH value of the water was indicated with a Beckman pH meter, Model H-2, range 0 to 14 pH with an accuracy of 0.03 pH.

The pump tank liquid level was indicated with a scale marked off in 0.1-in. divisions. Zero level corresponded with the center line of the volute.

DESCRIPTION OF TESTS

Head-Flow-Power-Speed Performance

Hydraulic performance data were obtained over a wide range of operating conditions with impellers of 11- and 13-in. outside diameter. Two methods of operation were used: speed was varied (700 to 1300 rpm) at constant system resistance for several values of resistance with the 13-in. impeller, and system resistance was varied at constant speed for several values of speed (700 to 1300 rpm) with the 11-in. impeller. Data were obtained for computing head, flow, brake horsepower, and efficiency.

Carbon Dioxide Stripping Tests

A number of tests were performed with both impeller diameters to ascertain the change in effectiveness of CO_2 removal caused by various stripper configurations, flow rates, jet velocities, and sweep gas flow rates. Carbon dioxide in dry-ice form was added to the circulating distilled water in the system until saturation was achieved, after which time the stripper flow was started. Readings of pH of the water were taken versus time to determine the time required to reduce the CO_2 concentration by a factor of two. A total of 37 tests were performed.

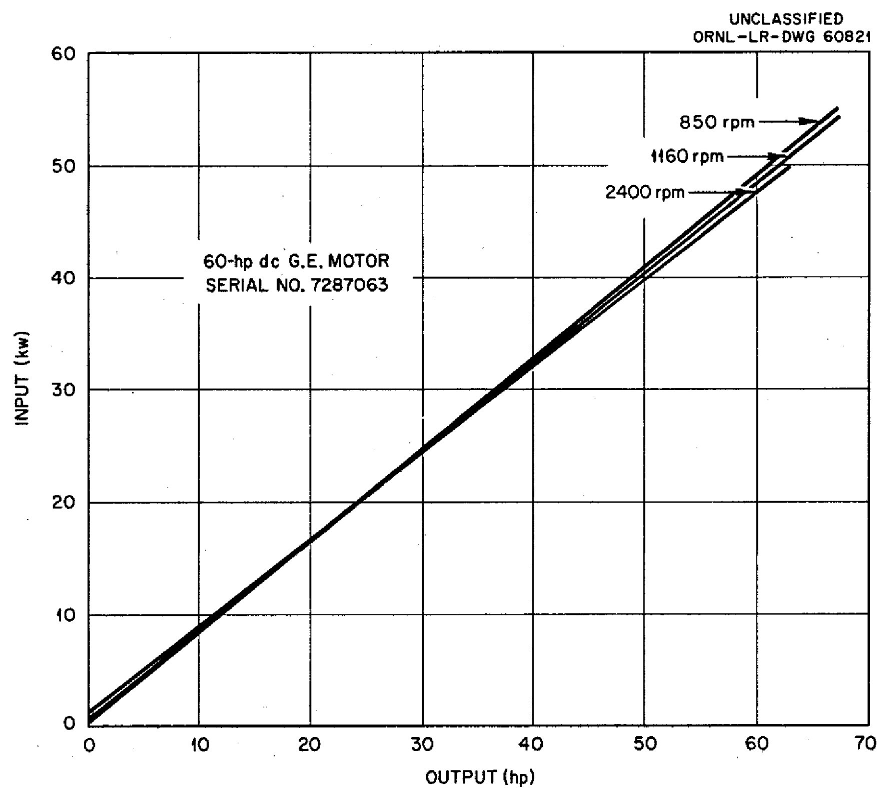

Fig. 8. Motor Calibration.

An expression was derived to give the theoretical time required to reduce the CO_2 concentration by one half. Comparison of the theoretical and experimental data is reported as relative effectiveness of the stripper.

Pump Tank Liquid and Gas Behavior

Fountain Flow

Considerable testing was performed to observe the flow of water from the impeller upper labyrinth (flow up the shaft and return to the system through the pump tank volume) and to develope adequate control of the return of this flow into the pump tank liquid, keeping the splatter of water and gas bubble formation to a minimum (see Fig. 1).

Clearances were varied between the shaft and the impeller upper labyrinth and the impeller upper shroud and seal plate. The corresponding fountain flows were measured.

Stripper Flow

The flow through the various stripper configurations was measured and baffling was developed to control splatter and gas bubble formation.

Gas Bubble Behavior in the Pump Tank Volume

Throughout all of the testing the formation and behavior of gas bubbles were observed in the pump tank volume. Baffling was devised to prevent entry of gas bubbles into the pump inlet from the pump tank volume.

Priming

The priming characteristics of the pump were checked at various static liquid levels in the pump tank. The ability of the pump to hold prime as the liquid level in the pump tank was being lowered was investigated. Data were obtained of head-flow-speed performance and of change in starting level for various starting levels as the pump was accelerated from zero to design speed.

Coastdown Characteristics

A number of coastdown tests were made from various pump operating conditions. The power supply to the pump drive motor was interrupted while the pump was operating at specific speed and flow conditions, and the time required to reach reduced system flow and pump speed was determined.

TEST RESULTS

Head-Flow-Power-Speed Performance

Hydraulic performance data were obtained over a wide range of head and flow conditions at several speeds for the 8 in. x 6 in. volute, using impellers of 13- and 11-in. outside diameter. These tests with the 13-in. diameter impeller were conducted without a baffle in the pump inlet. The 13-in. impeller performance is presented in Fig. 9, which is a plot of head versus flow at various speeds. The flow is total flow consisting of system flow, fountain flow, and stripper flow. The corresponding data are tabulated in Table II (Appendix). Allis-Chalmers data are also shown for comparison. The heads obtained are increasingly lower than Allis-Chalmers data with decreasing flow at constant speed.

The performance obtained with the 11-in. diameter impeller is presented in Fig. 10, which is a plot of head versus flow at various speeds. The flow is total flow consisting of system flow, fountain flow, and stripper flow. The corresponding data are tabulated in Table III (Appendix). Data for three different inlet configurations are shown: in two configurations a prerotation baffle was located at the inlet to the impeller; and the other configuration had none. The baffle consisted of two plates arranged in a cross as shown in Fig. 11; it had the effect of increasing the head at the lower range of flows on a constant speed line. There was essentially no difference in the results obtained with the two

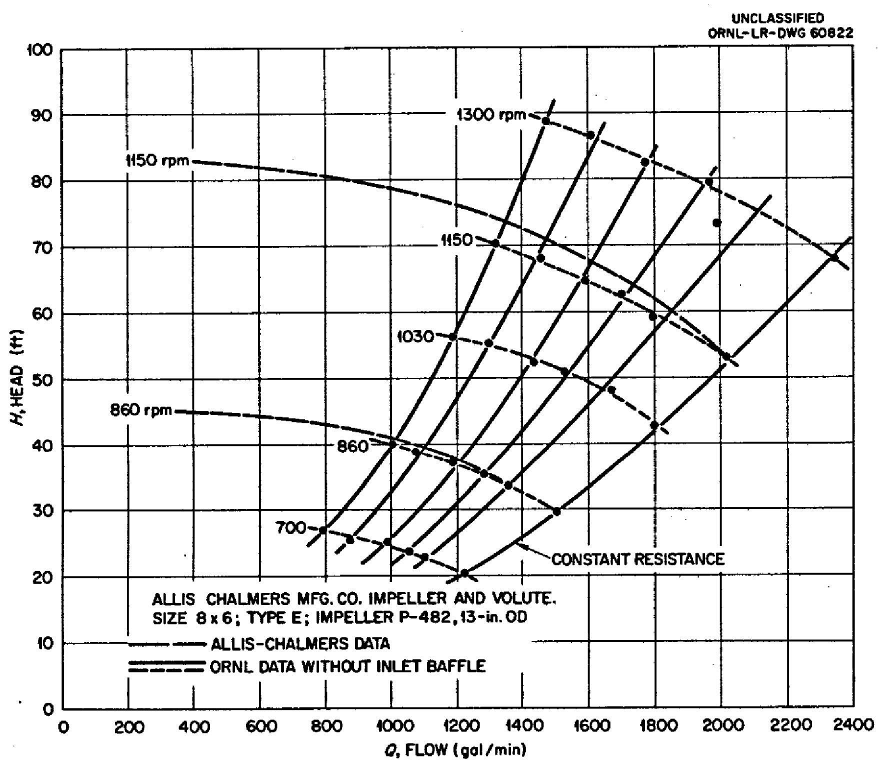

Fig. 9. Hydraulic Performance, 13-in. Impeller.

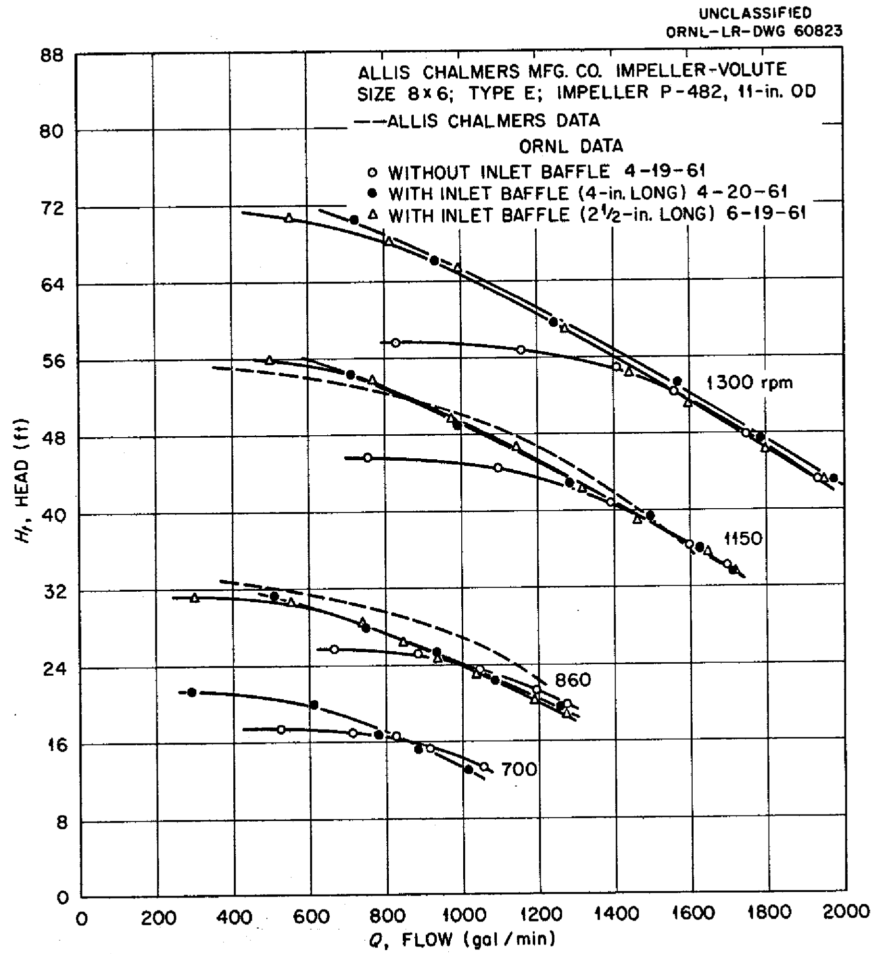

Fig. 10. Hydraulic Performance, 11-in. Impeller.

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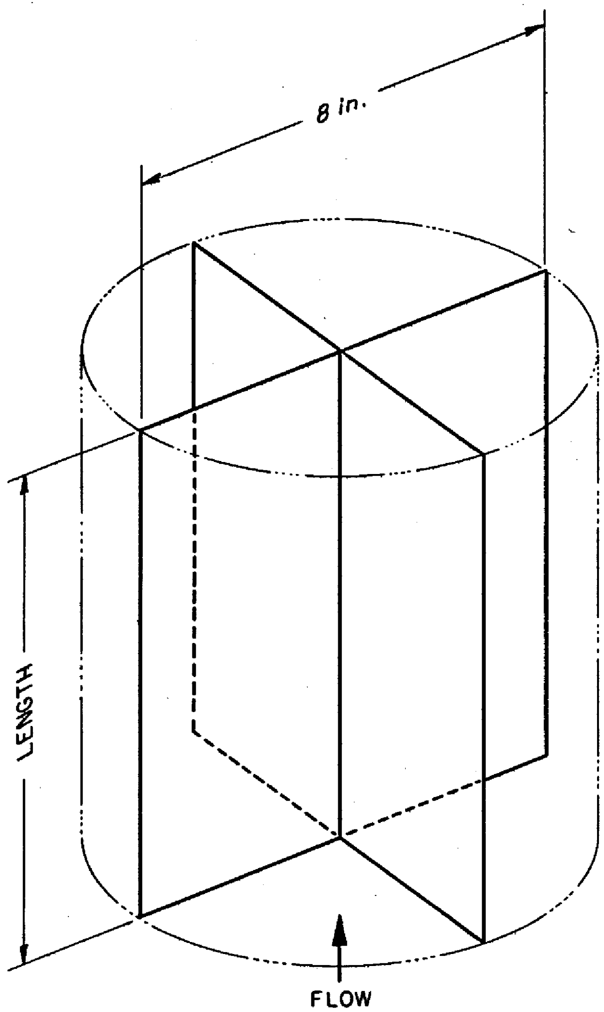

Fig. 11. Prerotation Baffle.

sizes of baffles. Curves of head and pump input power versus flow at various speeds are shown in Fig. 12. The input power change versus flow for constant speed operation is slight.

The prerotation baffle was not fully tested with the 13-in. impeller. Were such a baffle used with the 13-in. impeller, performance would be more nearly coincident with the published Allis-Chalmers data.

From the power data obtained with the 11-in. diameter impeller, efficiency contours were computed which are shown in Fig. 13, superimposed on a plot of head-flow-speed data.

Carbon Dioxide Stripping Effectiveness

In the stripping tests, data were obtained to determine the time required to reduce the CO_2 concentration by one half (half-life). The change in pH value of the distilled water was measured over a range from 4 to 6 versus time. For plotting purposes the pH values were converted to the logarithm of the molarity of CO_2 to determine the half-life.

Theoretical half-life ($t = 0.69\ V/Q_s$) was computed for each test and compared with the experimental half-life to give relative effectiveness.

The results of the carbon dioxide stripping tests are presented in Table I (Appendix). Related in the table are data pertaining to the stripper configurations, by-pass flows, liquid level in the pump tank, sweep gas flow rate, system volume, jet velocity, experimental half-life, ideal half-life, and relative effectiveness.

The first six tests were preliminary; the flow was simply bypassed through the pump tank without passing through strippers. These tests were performed to provide a base from which to proceed with strippers. Values of relative effectiveness ranged from 10 to 40 percent.

Tests 7 through 16 were concerned mainly with varying the stripper configuration. Other variables may be noted in the data shown in the table. Values of effectiveness ranged from 15 to 68 percent.

From the results of tests through No. 16, configuration 5 (Fig. 6) was derived and used for the remainder of the tests, 17 through 39.

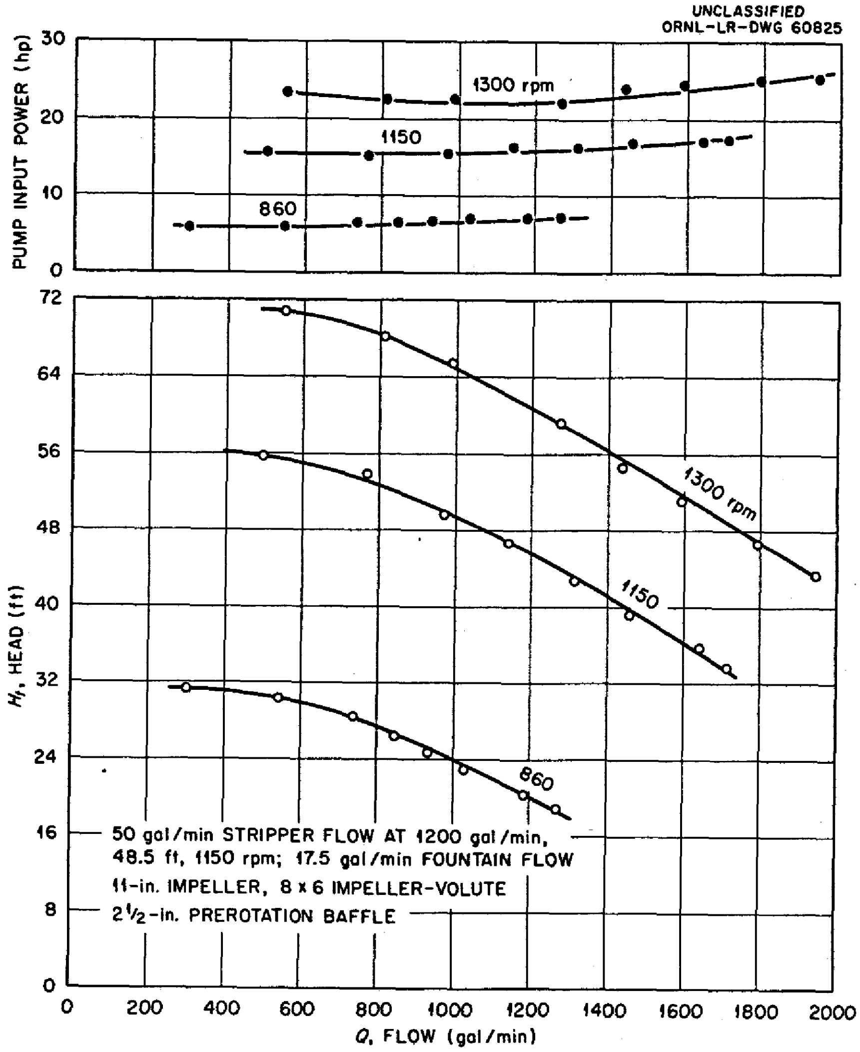

Fig. 12. Head, Input Power, and Speed Versus Flow, 11-in. Impeller.

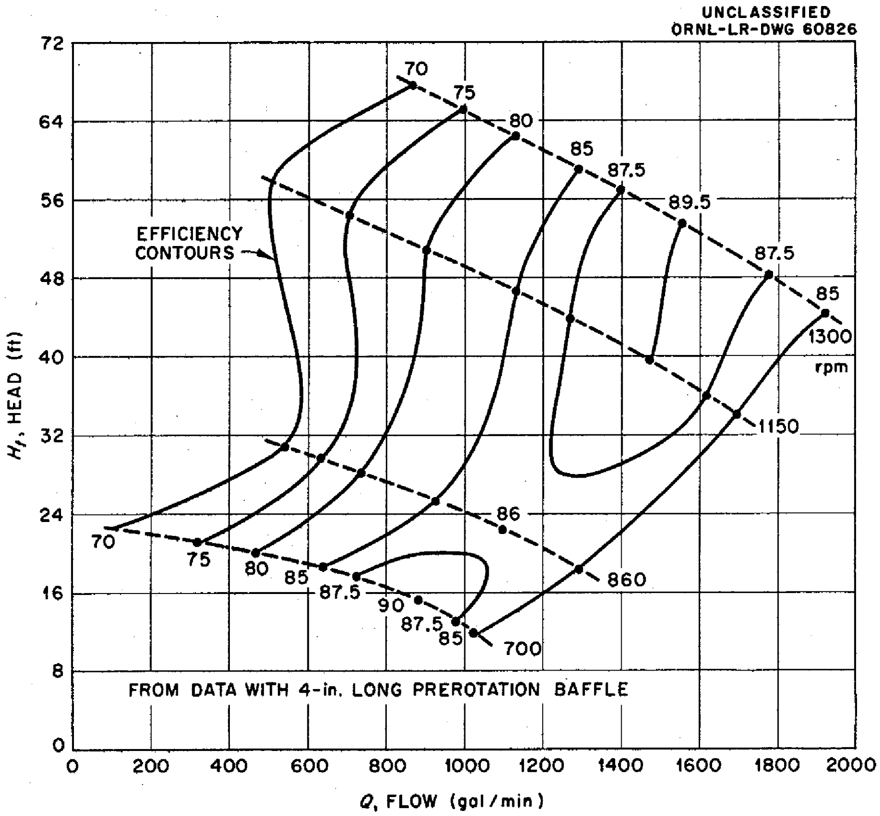

Fig. 13. Hydraulic Performance, 11-in. Impeller, Efficiency Contours Superimposed.

In tests 17 through 24, the flow and jet velocity were varied simultaneously at a constant sweep gas flow rate. The relative effectiveness varied from 27 to 99 percent.

In tests 10, 13, 14, 17, 18, and 25 through 29, sweep gas flow rate was varied with the other variables held constant, and two stripper configurations were used. The relative effectiveness varied from 47 to 72 percent. These data are plotted in Fig. 14, Relative Effectiveness Versus Sweep Gas Flow, for two configurations.

In tests 30, 32, 33, 35, and 39, the stripping flow was varied with the other variables held constant. The relative effectiveness varied from 70 to 90 percent. The results from these tests are shown in Fig. 15, Half-Life (defined on page 18) Versus Stripping Flow. Experimental and theoretical curves are shown.

In tests 30, 31, 34, and 36, the jet velocity was varied with the other variables held constant. The relative effectiveness varied from 27 to 90 percent. The results are shown in Fig. 16, Relative Effectiveness Versus Jet Velocity.

Configuration 5 was selected for the MSRE fuel pump, and was incorporated in the design of the prototype fuel pump. Tests 37 and 38 yielded effectiveness values of 52 and 55 percent, respectively. These tests were performed at the following conditions, reasonably attainable in the MSRE: stripping flow rate of 65 gpm, and sweep gas flow rates of 0.05 and 0.07 scfm, respectively.

Pump Tank Liquid and Gas Behavior

Fountain Flow

Observations of the fountain flow from the impeller upper labyrinth (Fig. 17) revealed the need to control it; the slinger impeller was causing an undesirable spray. This spray was contained and controlled by use of a cover enclosing the labyrinth and slinger impeller, and having drain ports located at its lower end.

Approximate measurements of the fountain flow were made using weirs located in the windows carrying the flow from the fountain into the pump

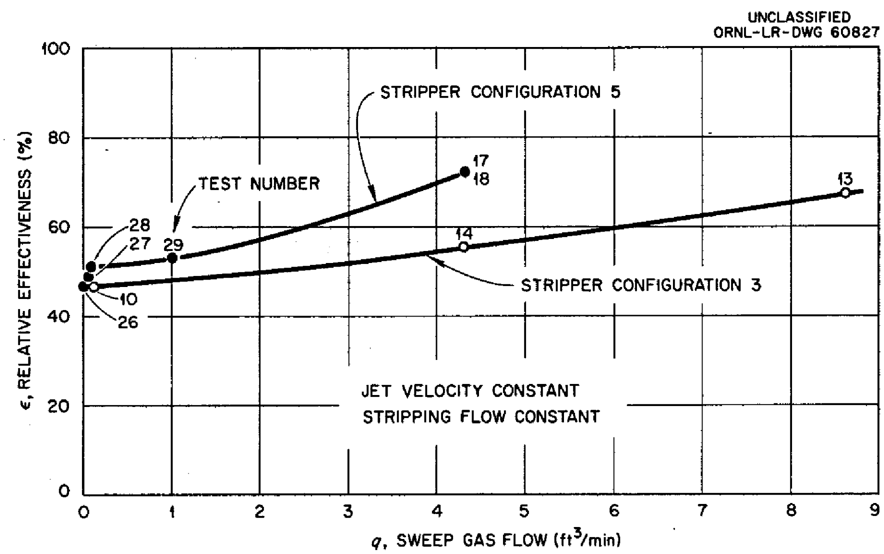

Fig. 14. Relative Effectiveness Versus Sweep Gas Flow.

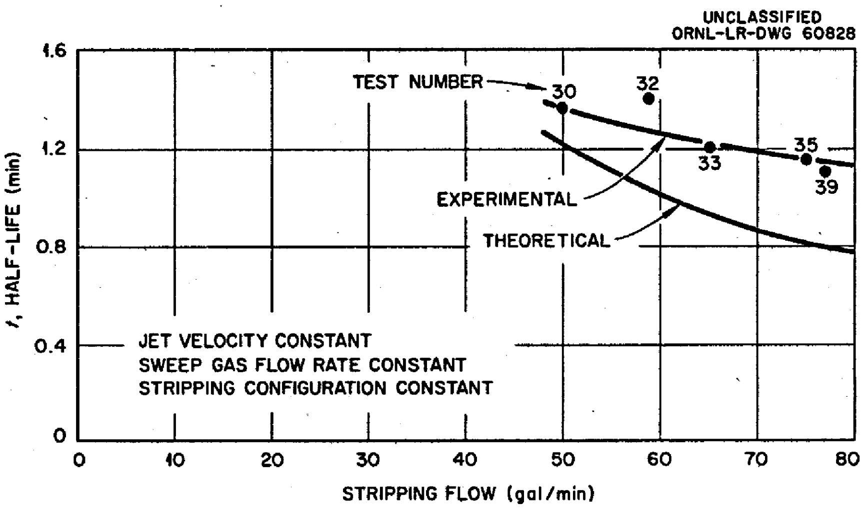

Fig. 15. Half-Life Versus Stripping Flow.

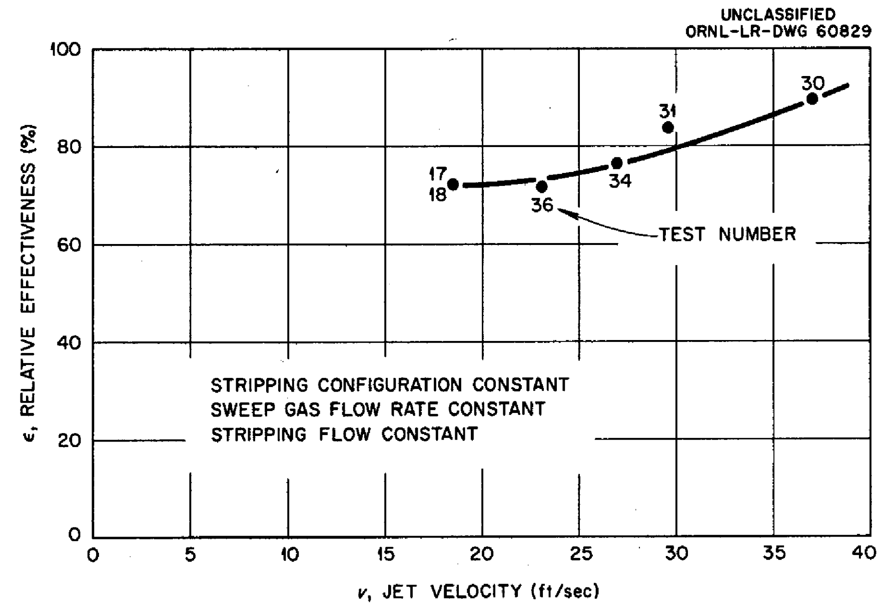

Fig. 16. Relative Effectiveness Versus Jet Velocity.

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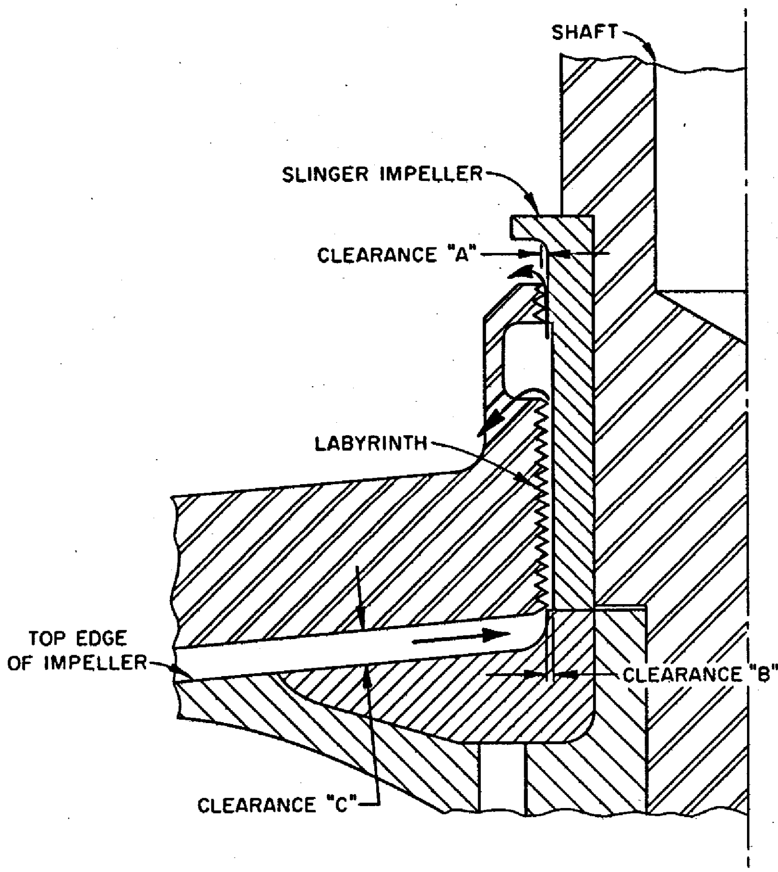

Fig. 17. Cross Section of Upper Labyrinth.

tank. Values of fountain flow for several labyrinth clearances are as follows:

13-in. Diameter Impeller, 1450 gpm, 1030 rpm, 50 ft Head

Configuration Number*	Clearance "A"	Clearance "B",	Clearance "C",	Flow, gpm
1	0.015	0.015	0.090	7.5 - 10
2	0.015	0.040	0.090	10 - 12
3	0.015	0.040	0.250	10 - 12
4	0.015	0.060	0.250	15 - 17.5

Configuration 4 was used with the 11-in. diameter impeller and the fountain flow was measured at various speeds along a constant resistance line defined by 1300 gpm and 45 ft. The fountain flow versus speed is shown in Fig. 18. Configuration 4 was adopted for use on the prototype MSRE fuel pump.

The direction of the fountain flow was observed over the range of conditions from which head-flow-speed data were obtained with both the 11-in. and 13-in. impellers. The flow of liquid was found always to be outward from the shaft annulus into the pump tank, which is the desired direction.

Stripper Flow

Considerable splatter of liquid resulted from impingement of this flow onto the volute and volute support. Control of this splatter was obtained through use of baffles installed on the stripper and on the volute support.

Gas Bubble Behavior in the Pump Tank Volume

Entrance of the fountain and stripper flows into the pump tank liquid caused gas bubble formation in the liquid. Control was obtained through use of a baffle installed on the volute which deflects bubbles radially

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*Each configuration was basically the same. Only the clearances were different.

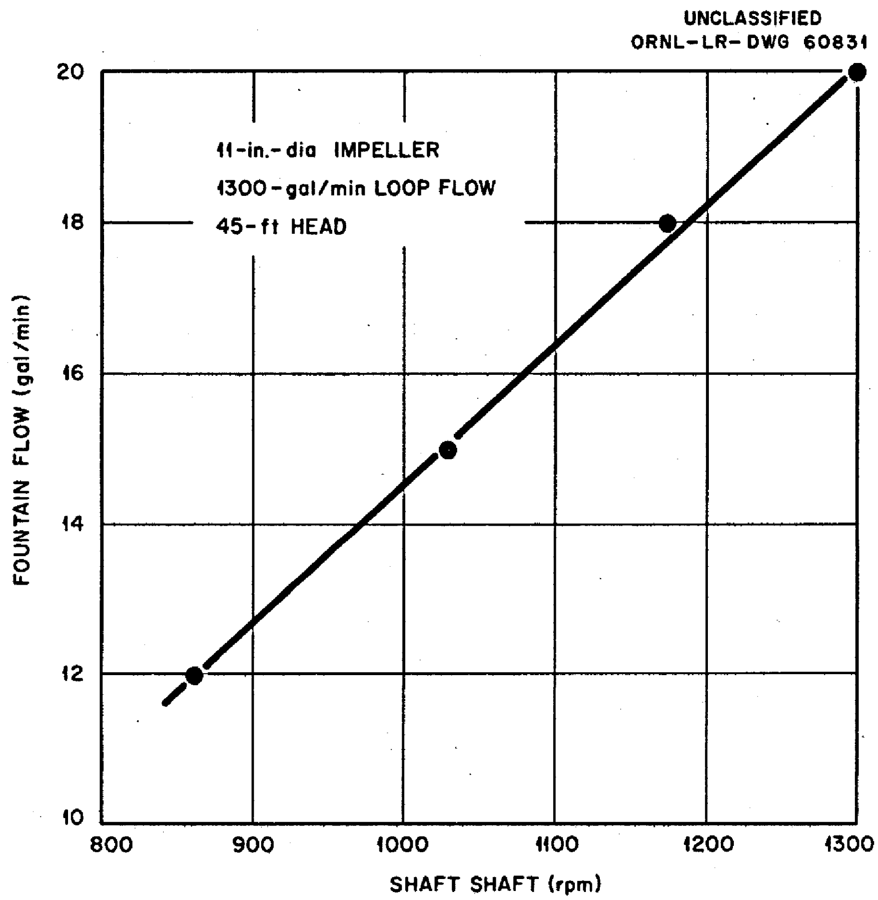

Fig. 18. Fountain Flow Versus Speed, 11-in. Impeller.

outwards in the tank and by forcing these two flows to enter the impeller inlet at the lowest elevation in the tank as shown in Fig. 19, which may be compared to Fig. 1.

Priming

Priming tests were conducted with the 13-in. impeller in which the pump was accelerated from zero to 1030 rpm in approximately 30 seconds, noting the change in pump tank liquid level and observing attainment of normal pump head and flow performance. The following operating levels were noted for the listed starting levels:

Static Liquid Level* (in.)	Operating Liquid Level* (in.)
13-in. impeller	
+2	+1.2
+1.5	+0.6
+1	-0.9
+0.5	-2.1
11-in. impeller	
+2	+1
+1	-1.5
0	would not prime

Normal hydraulic performance was achieved at the end of pump acceleration for all runs except the 0.5-in. starting level with the 13-in. impeller and the zero level with the 11-in. impeller. The 13-in. impeller required an additional minute for priming at the 0.5-in. level and the 11-in. impeller would not prime at the zero level. These data should not be used for reactor system computations unless differences in volumes of system trapped gas are accounted for.

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*Reference level is center line of the volute. + is above center line.

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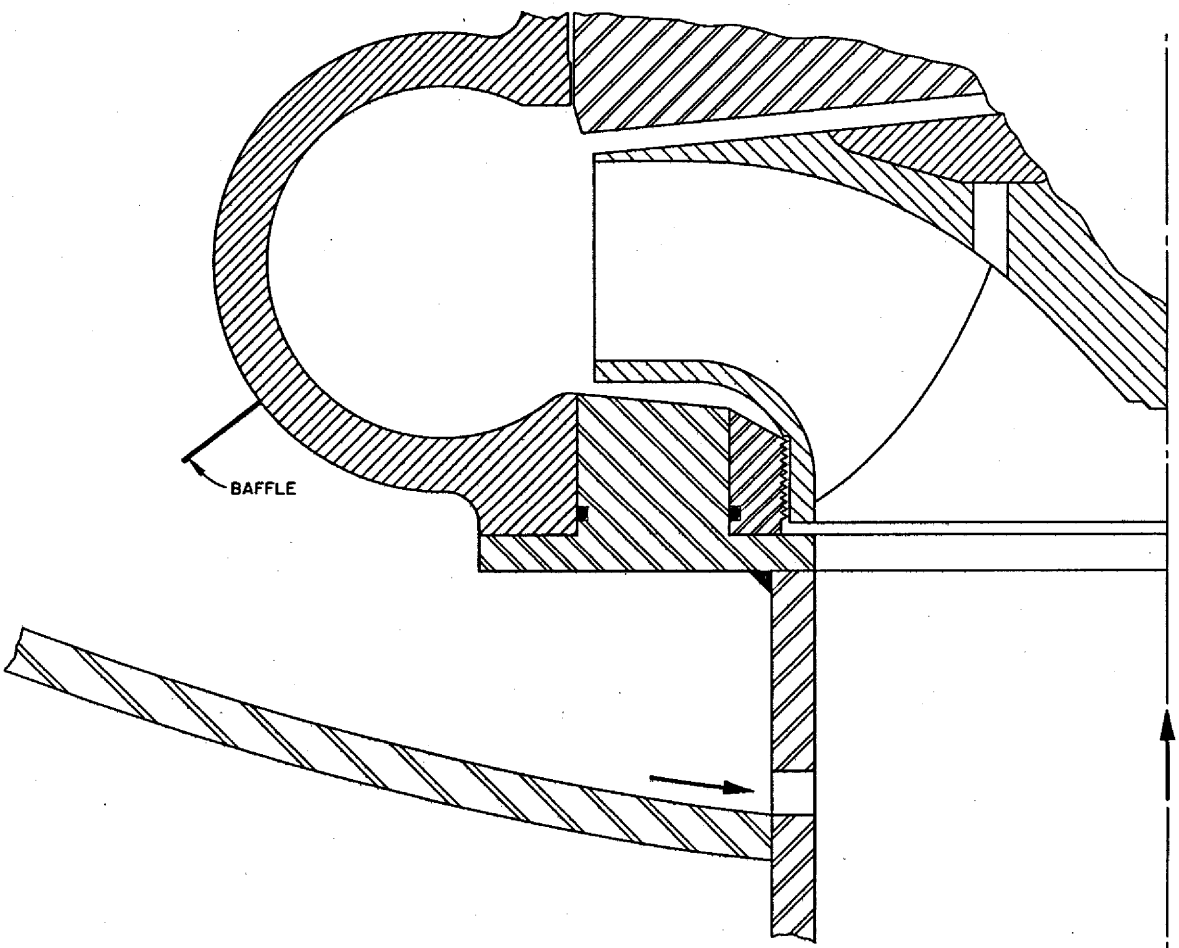

Fig. 19. Pump Inlet X-Section.

Other priming tests were performed by lowering of the liquid level in the pump tank slowly with the pump running. A test was performed with the 13-in. diameter impeller operating at 1450 gpm, 50 ft head, and starting liquid level at 1 1/2-in. above center line of the volute. Ingassing began at approximately 4 1/2-in. below the center line of the volute. At 5 1/2 in. below the center line of the volute, the system flow dropped to 700 gpm, and 6 1/2 in. below the center line of the volute, the flow reduced to zero.

A test was performed with the 11-in. impeller operating at 1250 gpm, 45 ft and starting liquid level at 1 1/2 in. above the center line of the volute. Ingassing began at approximately 3 in. below the center line of the volute. Vigorous ingassing and loss of head and flow began at 3 1/2 in. below the volute center line.

Coastdown Characteristics

Coastdown tests were performed on the drive motor and pump with the 13-in. impeller to determine the time required for the unit to stop after opening the drive motor circuit from the electric supply. Tests were performed on the same flow resistance line for operating speeds of 1150, 1030, and 860 rpm at flow rates of 1630, 1450, and 1210 gpm, respectively. Coastdown times to zero speed ranged from 10.1 to 10.4 sec., and for flow reduction to 540 gpm, the times ranged from 1.5 to 2.0 sec.

CONCLUSIONS

From the experimental hydraulic characteristics, the total head was found to deviate from reported data by +1 to -3 ft. It was found necessary to insert a prerotation baffle in the inlet to improve the head at reduced flows.

Based on the water test results, a 11.5-in. diameter impeller will be required to meet the reactor design head and flow (48.5 ft and 1200 gpm). This dimension will be more precisely determined during the prototype fuel pump tests.

Fountain flow was observed over the whole range of operation and found to be outward from the upper labyrinth into the pump tank, which is the desired direction. Gas bubbles created by the fountain and stripping flows were removed in the pump tank with assistance from the various baffles.

With regard to priming, the pump would prime (full head and flow) instantaneously with speed at static levels of 1 in. or more above the center line of the volute.

Gas stripping was accomplished in the pump tank with a relative effectiveness of up to 99 percent. Sweep gas flow rate, stripping flow, and jet velocity were found to have quite pronounced effects on the stripping rate of a given stripper configuration. It was concluded that the zenon removal rate will be primarily dependent on the fraction of fuel processed rather than on improved stripper configurations.

The hydraulic characteristics were found to be adequate for the anticipated requirements of the fuel circuit of the MSRE. The required control of liquid and gas behavior in the pump tank was accomplished by the use of baffles.

ACKNOWLEDGMENTS

The following specific contributions are acknowledged which comprise the main talents required to complete the investigations: L. V. Wilson, design; F. F. Blankenship, devised stripping tests; R. F. Apple, chemical aspects of stripping tests; and J. M. Coburn, test operation, data taking, and computations.

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APPENDIX

NOMENCLATURE

t, Half-life, min.

V, System volume, gal.

Q_s, Stripping flow, gal/min.

C, CO_2 concentration, pH reading

q, Sweep gas flow rate, ft^3/min.

ϵ, Relative effectiveness, dimensionless

Q, Total flow, gal/min.

H, Total head, ft.

v, Jet velocity, ft/sec.

Table I. CO_2 Stripping Tests of MSRE Primary Pump Circulating H_2O

Impeller Diameter: 13 in. for tests 1 through 24
Impeller Diameter: 11 in. for tests 25 through 39
System Water Flow: 1450 gpm
Head: 50 ft
Water Temperature: 65 F

1[a]	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	Stripper Configuration			By-Pass Flow (gpm)								Half-Life, t (min)		
Test No.	No.	Number of Holes	Diameter of Holes (in.)	Stripper	Fountain	Liquid Level[b] (in.)	Sweep Gas (Air) Flow (cfm)	Direction of Stripper Flow	Jet Velocity (ft/sec)	System Volume (gal)	Total By-Pass Flow (gpm)	Experimental[c]	Theoretical	Relative Effectiveness (%)
1				35	8	4.0	0	Submerged		96	42	15.0	1.57	10.5
2				35	8	4.0	0	"		96	42	16.0	1.57	9.8
3				18	15	4.0	0	"		96	32	12.0	2.06	17.2
4				18	15	4.0	0.1	"		96	32	8.0	2.06	24.2
5				35	15	4.0	0.1	"		96	50	10.0	1.34	13.4
6				0	15	4.0	0.1	"		96	15	11.0	4.45	40.5
7	1	60	1/4	26	15	2.5	0.1	"	4.6	91	41	10.0	1.55	15.5
9	2	84 } 30 }	1/8 } 1/4 }	35	15	1.5	0.1	Circumferential	8.9 } 6.2 }	88	50	3.0	1.22	40.6
10	3	324	1/16	35	15	1.5	0.1	"	18.5	88	50	2.6	1.22	46.9
12	3	324	1/16	35	15	3.8	0.1	"	18.5	96	50	3.2	1.32	41.7
13	3	324	1/16	35	15	1.5	8.6	"	18.5	88	50	1.8	1.22	67.7
14	3	324	1/16	35	15	1.5	4.3	"	18.5	88	50	2.2	1.22	55.4
15	5	324	1/16	0	15	1.5	0.1	"	0	88	15	6.8	4.06	59.7
16	4	162	1/16	35	15	1.5	0.1	Radially in-ward	37.0	88	50	2.0	1.22	61.0
17	5	320	1/16	35	15	1.5	4.3	"	18.5	88	50	1.7	1.22	72.8
18	5	320	1/16	35	15	1.5	4.3	"	18.5	88	50	1.7	1.22	71.8
19	5	200	1/16	50	15	1.5	4.3	"	46.2	88	65	1.0	0.94	98.9
20	5	200	1/16	50	15	1.5	4.3	"	46.2	88	65	0.9	0.94	99.0
21	5	320	1/16	70	15	1.5	4.3	"	40.5	88	85	0.9	0.72	80.8
22	5	320	1/16	70	15	1.5	4.3	"	40.5	88	85	0.9	0.72	82.7
23	5	215	1/16	44	15	1.5	4.3	"	37.8	88	59	1.1	1.03	96.8
24	5	215	1/16	44	15	1.5	4.3	"	37.8	88	59	1.0	1.03	98.0
25	5	320	1/16	35	15	1.5	0	"	18.5	88	50	2.5	1.22	48.8
26	5	320	1/16	35	15	1.5	0	"	18.5	88	50	2.6	1.22	46.9
27	5	320	1/16	35	15	1.5	0.05	"	18.5	88	50	2.5	1.22	48.8
28	5	320	1/16	35	15	1.5	0.07	"	18.5	88	50	2.4	1.22	50.8
29	5	320	1/16	35	15	1.5	1.0	"	18.5	88	50	2.3	1.22	53.0
30	5	160	1/16	35	15	1.5	4.3	"	37.0	88	50	1.4	1.22	89.6
31	5	200	1/16	35	15	1.5	4.3	"	29.6	88	50	1.5	1.22	83.6
32	5	200	1/16	44	15	1.5	4.3	"	37.0	88	59	1.4	1.04	73.8
33	5	228	1/16	50	15	1.5	4.3	"	37.0	88	65	1.2	0.94	78.3
34	5	240	1/16	35	15	1.5	4.3	"	27.0	88	50	1.6	1.22	76.3
35	5	274	1/16	60	15	1.5	4.3	"	37.0	88	75	1.2	0.81	70.2
36	5	280	1/16	35	15	1.5	4.3	"	23.1	88	50	1.7	1.22	71.7
37[d]	5	290	1/16	50	15	1.5	0.05	"	28.8	88	65	1.8	0.94	52.2
38[d]	5	290	1/16	50	15	1.5	0.07	"	28.8	88	65	1.7	0.94	55.3
39	5	300	1/16	62	15	1.5	4.3	"	34.8	88	77	1.1	0.79	72.2

[a]See appendix for computations relative to indicated columns.

[b]Level referred to centerline of volute.

[c]Data from R. G. Apple, Reactor Chemistry Division.

[d]System flow, 1200 gpm; head, 48.5 ft.

Table II. Head-Flow-Speed-Power Data for 13-in. Impeller on MSRE Primary Pump Circulating H_2O

1[a]	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Speed (rpm)	Motor Input Power Recorder		Motor Input Power Analyzer			Discharge Pressure		Venturi					Stripper Flow				Fountain Flow (gpm)	Total Flow (gpm)	Change in Velocity Head (ft)	Total Head (ft)
											Δp Gage Flow		Circuit 1		Circuit 2					
	Reading	kw	v	amp	kw	psig	ft	Inlet (psig)	Throat (psig)	Δp (psi)	psi	gpm	%	gpm	%	gpm				
700	1.30	5.2				11.0	24.4	8.0	4.2	3.8	3.2	840	74	13.0	74	13.0	9	875	0.98	25.38
860	2.45	9.8				16.2	37.4	11.6	6.1	5.5	5.2	1032	88	14.4	88	14.4	12	1073	1.47	38.87
1030	4.25	17.0				23.1	53.3	16.4	8.4	8.0	7.4	1248	100	17.5	100	17.5	15	1298	2.15	55.45
1150	5.95	23.8				28.5	65.4	20.0	10.2	9.8	9.3	1375	100	17.5	100	17.5	17	1427	2.61	68.01
1300	8.65	34.6				36.1	83.4	25.5	13.0	12.5	12.2	1550	100	17.5	100	17.5	20	1605	3.35	86.75
700	1.40	5.6				9.2	21.2	8.2	2.4	5.9	5.5	1070	68	11.9	68	11.9	9	1103	1.58	22.78
860	2.65	10.6				13.6	31.4	12.0	3.1	8.9	8.5	1315	84	14.7	84	14.7	12	1356	2.35	33.75
1030	4.65	18.6				19.4	44.8	16.9	4.2	12.6	12.3	1620	100	17.5	100	17.5	15	1670	3.56	48.36
1150	6.60	26.4				23.9	55.2	20.6	5.0	15.6	15.4	1745	100	17.5	100	17.5	17	1797	3.93	59.13
1300	9.50	38.0				30.2	69.6	22.9	9.0	18.9	15.4	1930	100	17.5	100	17.5	20	1985	3.74	73.34
700	1.50	6.0	86	71	6.1	7.9	18.2				7.3	1185	45	15.7	45	15.7	9	1225	1.92	20.17
860	2.70	10.8	108	106	11.4	11.7	27.0				11.0	1450	56	19.5	56	19.5	12	1501	2.88	29.88
1030	4.75	19.0	130	150	19.5	16.7	38.6				15.5	1735	70	24.5	70	24.5	15	1799	4.15	42.75
1150	6.70	26.8	145	187	27.1	20.7	47.8				19.5	1950	76	26.6	76	26.6	17	2021	5.22	53.02
1300	9.90	39.6	164	245	40.2	26.5	62.2				25.0	2270	86	30.0	86	30.0	20	2340	5.81	68.01
700	1.30	5.2				10.3	23.8	6.5	2.0	4.5	4.2	955	69	12.0	69	12.0	9	988	1.25	25.05
860	2.55	10.2				15.2	35.2	9.4	2.6	6.8	6.5	1145	85	14.9	85	14.9	12	1187	1.81	37.01
1030	4.40	17.6				21.6	49.9	13.1	3.4	9.8	9.5	1380	100	17.5	100	17.5	15	1430	2.59	52.49
1150	6.10	24.4				26.6	61.4	16.1	4.0	12.1	11.8	1535	100	17.5	100	17.5	17	1578	3.23	64.63
1300	9.00	36.0				34.0	78.5	20.4	4.8	15.6		1710	100	17.5	100	17.5	20	1765	4.00	82.50
700	1.25	5.0				11.3	26.1	6.8	3.8	3.0	2.7	760	72	12.6	72	12.6	9	794	0.81	26.91
860	2.35	9.4				16.8	38.8	9.9	5.1	4.8	4.2	960	90	15.9	90	15.9	12	1004	1.29	40.09
1030	4.00	16.0				23.6	54.5	13.8	7.1	6.6	6.1	1135	100	17.5	100	17.5	15	1185	1.79	56.29
1150	5.70	23.5				29.4	68.2	17.0	8.8	8.2	7.6	1265	100	17.5	100	17.5	17	1317	2.22	70.42
1300	8.60	34.4				37.3	86.2	21.2	11.0	10.2	10.0	1412	100	17.5	100	17.5	20	1467	2.75	88.95
700	1.40	5.6	82	68	5.6	9.6	22.2	5.1			5.3	1010	48	16.8	48	16.8	9	1052	1.42	23.62
860	2.60	10.4	105	101	10.6	14.4	33.3	7.4			7.8	1225	69	24.1	69	24.1	12	1285	2.11	35.41
1037	4.61	18.4	130	143	18.6	20.8	48.1	10.2			11.1	1460	70	24.5	70	24.5	15	1524	2.97	51.07
1154	6.40	26.4	146	176	25.7	25.5	58.9	12.5			13.7	1625	80	28.0	80	28.0	17	1698	3.68	62.58
1300	9.40	37.6	164	228	37.4	32.4	74.9	15.6			17.5	1875	92	32.2	92	32.2	20	1959	4.92	79.82

[a]See appendix for computations relative to indicated columns.

Table III. Head-Flow-Speed-Power Data for 11½-in. Impeller on MSRE Primary Pump Circulating H_2O

1[a]	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Speed (rpm)	Motor Input Power Recorder		Motor Input Power Analyzer			Discharge Pressure		Venturi		Stripping Flow					Fountain Flow (gpm)	Total Flow (gpm)	Change in Velocity Head (ft)	Total Head (ft)	Pump Power Input (hp)	Water Horsepower (hp)	Efficiency (%)
										Circuits (%)											
	Reading	kw	v	amp	kw	psig	ft	ΔP (cm Hg)	Flow (gpm)	1	2	3	4	gpm							
Prerotation Baffle: Not Used																					
1300	3.90	15.6	156	100	15.6	24.6	56.8	15.8	770	56	58	59	59	41.0	20.0	831	0.88	57.68	18.3	12.10	66.1
	4.50	18.0	156	116	18.1	23.9	55.2	32.5	1100	55	56	57	58	39.9	20.0	1160	1.73	56.93	21.7	16.67	76.8
	4.80	19.2	156	125	19.5	22.8	52.7	49.3	1350	53	56	53	57	39.0	20.0	1409	2.54	55.24	23.5	19.65	83.6
	5.00	20.0	156	129	20.1	21.4	49.4	60.8	1500	51	53	54	55	37.8	20.0	1558	3.10	52.50	24.4	20.65	84.6
	5.10	20.4	156	132	20.6	19.1	44.1	76.2	1690	48	51	51	52	35.7	20.0	1746	3.90	48.05	25.1	21.20	84.5
	5.30	21.2	156	138	21.5	16.8	38.8	93.2	1880	45	46	47	48	32.5	20.0	1932	4.77	43.57	26.3	21.28	80.9
1150	2.60	10.4	144	77	11.1	19.5	45.0	12.8	700	46	51	52	52	35.2	17.4	753	0.73	45.73	13.2	8.70	65.9
	3.15	12.6	144	89	12.8	18.6	43.0	29.2	1045	45	50	51	51	34.8	17.4	1097	1.55	44.55	15.5	12.35	79.7
	3.40	13.6	144	96	13.8	16.7	38.6	48.7	1340	42	47	48	48	32.7	17.4	1390	2.47	41.07	16.5	14.28	86.5
	3.55	14.2	144	100	14.4	14.4	33.2	64.7	1550	39	43	44	45	30.3	17.4	1598	3.26	36.51	17.2	14.74	85.7
	3.60	14.4	144	103	14.8	13.3	30.8	73.0	1650	37	41	42	42	28.7	17.4	1696	3.68	34.48	17.7	14.78	83.5
860	1.20	4.8	102	48	4.9	11.0	25.3	10.1	630	33	37	38	38	25.5	12.0	667	0.57	25.87	5.5	4.37	79.5
	1.30	5.2	102	56	5.7	10.5	24.2	19.4	850	32	36	38	37	25.5	12.0	887	1.01	25.26	6.7	5.67	84.6
	1.40	5.6	102	58	5.9	9.6	22.2	27.1	1005	31	35	35	35	24.1	12.0	1641	1.38	23.58	7.0	6.19	88.5
	1.50	6.0	102	61	6.2	8.5	19.6	35.2	1145	28	32	33	33	22.5	12.0	1179	1.78	21.42	7.3	6.39	87.5
	1.55	7.2	102	62	6.3	7.7	17.8	41.6	1240	27	30	31	31	21.3	12.0	1273	2.07	19.87	7.4	6.39	86.4
700	.65	2.6	80	34	2.7	7.4	17.1	6.7	500	26	30	30	30	20.3	8.9	529	0.36	17.46	2.8	2.34	84.2
	.75	3.0	80	39	3.1	7.1	16.4	12.3	690	25	29	30	29	19.8	8.9	719	0.66	17.06	3.6	3.10	84.7
	.80	3.2	80	42	3.4	6.8	15.7	17.1	800	24	28	29	28	19.1	8.9	828	0.88	16.58	3.8	3.47	91.9
	.80	3.2	80	43	3.4	6.2	14.3	21.3	890	23	26	27	27	18.0	8.9	917	1.08	15.40	4.0	3.57	89.2
	.85	3.4	80	45	3.6	5.3	12.2	28.2	1025	20	24	25	25	16.5	8.9	1050	1.42	13.67	4.3	3.64	84.7
Prerotation Baffle: 2 1/2 in. Long																					
860	1.20	4.8	101	51	5.2	13.5	31.2	2.9	250	57	60	57	57	40.4	12.0	302	0.12	31.32	5.9	2.40	40.1
	1.25	5.0	101	53	5.4	13.0	30.1	6.8	500	55	59	55	56	39.5	12.0	551	0.38	30.48	6.0	4.24	70.7
	1.30	5.2	101	56	5.7	12.0	27.7	12.5	690	53	55	55	54	38.0	12.0	740	0.70	28.40	6.5	5.31	81.8
	1.35	5.4	101	57	5.8	11.0	25.4	17.2	800	50	54	53	51	36.4	12.0	848	0.92	26.32	6.6	5.64	85.5
	1.40	5.6	101	58	5.9	10.2	23.6	21.4	890	48	53	50	49	35.0	12.0	937	1.12	24.72	6.7	5.85	87.2
	1.40	5.6	101	59	6.0	9.4	21.7	26.4	990	45	50	48	47	33.3	12.0	1035	1.37	23.07	7.0	6.20	88.5
	1.45	5.8	101	61	6.2	8.0	18.5	35.5	1145	41	47	45	44	31.0	12.0	1188	1.81	20.29	7.1	6.10	85.8
	1.45	5.8	101	62	6.3	7.3	16.9	41.0	1230	38	45	40	42	29.0	12.0	2171	2.06	18.92	7.2	6.07	84.3
1150	3.25	13.0	142	92	13.1	24.2	55.5	5.2	430	77	79	77	76	55.0	17.4	502	0.32	55.78	15.6	6.70	42.9
	3.20	12.8	142	89	12.6	23.0	53.2	11.8	645	74	77	75	75	54.6	17.4	770	0.76	53.96	15.2	10.48	68.9
	3.25	13.0	141	91	12.9	21.0	48.5	22.3	910	68	74	70	71	50.0	17.4	977	1.22	49.72	15.4	12.26	79.7
	3.30	13.2	141	95	13.5	19.5	45.1	31.3	1080	65	73	67	68	47.5	17.4	1145	1.68	46.78	16.3	13.52	83.0
	3.40	13.6	141	97	13.8	17.4	40.2	42.8	1255	61	68	63	64	45.0	17.4	1317	2.21	42.41	16.4	14.28	87.1
	3.40	13.6	141	99	14.1	15.8	36.5	53.0	1400	57	66	62	61	43.0	17.4	1460	2.73	39.23	16.8	14.48	86.2
	3.50	14.0	141	101	14.4	14.0	32.4	66.6	1575	54	62	58	56	40.5	17.4	1643	3.46	35.81	17.1	14.88	87.0
	3.60	14.4	141	103	14.6	13.0	30.0	73.5	1655	50	59	55	55	38.5	17.4	1711	3.75	33.75	17.5	14.57	83.3

Table III. (continued)

1[a]	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
	Motor Input Power Recorder		Motor Input Power Analyzer			Discharge Pressure		Venturi		Stripping Flow											
										Circuits (%)											
Speed (rpm)	Reading	kw	v	amp	kw	psig	ft	ΔP (cm Hg)	Flow (gpm)	1	2	3	4	gpm	Fountain Flow (gpm)	Total Flow (gpm)	Change in Velocity Head (ft)	Total Head (ft)	Pump Power Input (hp)	Water Horsepower (hp)	Efficiency (%)
Prerotation Baffle: 2 1/2 in. Long																					
1300	4.80	19.2	159	122	19.4	30.6	70.4	6.2	480	83	88	85	85	59.5	20.0	599	0.40	70.75	23.4	9.98	42.6
	4.65	18.6	159	116	18.4	29.3	67.4	14.3	740	80	77	83	82	57.0	20.0	817	0.85	68.20	22.7	14.10	62.2
	4.60	18.4	159	115	18.3	27.8	64.2	22.8	915	77	82	79	80	56.0	20.0	991	1.26	65.46	22.5	16.38	72.8
	4.70	18.8	159	121	19.2	24.7	57.1	39.0	1200	73	78	75	76	53.0	20.0	1273	2.07	59.17	23.3	19.00	81.5
	4.80	19.2	159	124	19.7	22.5	52.0	50.8	1370	70	75	70	77	50.0	20.0	1440	2.61	54.61	24.0	19.88	82.8
	4.90	19.6	158	126	20.7	20.7	47.8	63.0	1530	65	72	65	68	47.0	20.0	1597	3.26	51.11	24.5	20.62	84.2
	5.00	20.0	158	129	20.5	18.3	42.3	80.0	1730	62	70	63	65	45.5	20.0	1795	4.12	46.42	25.1	21.10	84.0
	5.10	20.4	158	132	21.0	16.3	37.6	93.0	1880	58	60	60	60	43.0	20.0	1943	4.82	43.47	25.5	21.32	82.0
Prerotation Baffle: 4 in. Long																					
1300	4.25	17.0	162	104	16.8	30.2	69.8	11.0	655	67	65	66	64	46.0	20.0	721	0.67	70.47	20.0	12.83	64.1
	4.40	17.6	162	107	17.4	28.2	65.2	20.2	870	65	63	63	61	44.1	20.0	934	1.12	66.32	21.5	15.64	72.2
	4.65	18.6	162	115	18.6	25.0	57.8	38.0	1185	58	59	59	58	41.0	20.0	1246	1.98	59.78	22.5	18.83	83.7
	4.85	19.4	162	121	19.6	21.8	50.4	57.6	1460	55	55	55	54	48.3	20.0	1562	3.12	53.52	23.6	21.12	89.5
	5.00	20.0	161	125	20.2	18.9	43.6	79.6	1725	51	52	53	50	36.0	20.0	1781	4.06	47.71	24.5	21.45	87.5
	5.15	20.6	160	128	20.8	16.7	38.6	94.5	1895	47	48	47	46	32.9	20.0	1974	4.98	43.58	25.3	21.70	85.8
1150	2.95	11.8	138	86	11.9	23.2	53.6	11.1	655	56	57	56	55	39.2	17.4	711	0.65	54.25	13.0	9.75	75.0
	3.10	12.4	138	91	12.6	20.7	47.8	23.9	940	53	53	53	52	36.8	17.4	994	1.27	49.07	15.0	12.32	82.1
	3.30	13.2	138	98	13.6	17.8	41.1	41.3	1235	48	50	49	48	34.2	17.4	1287	2.12	43.22	16.5	14.5	85.2
	3.40	13.6	138	101	14.0	15.9	36.7	56.2	1445	44	45	46	44	31.4	17.4	1494	2.85	39.55	16.7	14.93	89.4
	3.50	14.0	138	103	14.2	14.2	32.8	67.0	1580	43	44	43	42	30.0	17.4	1627	3.35	36.15	17.0	14.86	87.5
	3.55	14.2	138	104	14.4	13.1	30.3	73.6	1660	40	42	41	41	28.7	17.4	1706	3.72	34.02	17.3	14.67	84.9
860	1.20	4.8	107	48	5.1	13.5	31.2	6.0	470	43	43	42	41	29.7	12.0	512	0.33	31.53	6.0	4.08	68.0
	1.30	5.2	107	52	5.6	11.8	27.2	13.4	710	40	40	40	38	27.7	12.0	750	0.72	27.97	6.5	5.30	81.5
	1.40	5.6	107	55	5.9	10.2	23.6	21.6	895	36	37	36	36	25.7	12.0	933	1.05	24.65	6.9	5.81	84.2
	1.40	5.6	107	57	6.1	9.0	21.0	29.8	1050	34	35	34	33	23.8	12.0	1086	1.51	22.51	7.2	6.19	86.0
	1.50	6.0	107	59	6.3	7.7	17.8	40.7	1225	31	32	31	30	21.7	12.0	1259	2.02	19.82	7.4	6.31	85.3
700	.65	2.60	78	36	2.8	9.2	21.2	3.1	260	34	34	34	33	23.7	8.9	293	0.12	21.37	3.0	2.22	74.0
	.70	2.80	78	39	3.0	8.0	18.5	8.6	580	32	32	32	31	22.2	8.9	611	0.48	18.94	3.5	2.92	83.5
	.75	3.00	78	43	3.4	6.9	15.9	14.9	750	29	29	29	28	20.8	8.9	780	0.87	16.72	3.7	3.29	88.9
	.80	3.20	78	44	3.4	6.2	14.3	19.5	855	27	28	27	26	18.9	8.9	883	1.00	15.33	3.8	3.42	90.0
	.80	3.20	78	45	3.5	5.2	12.0	26.3	990	24	25	24	24	17.3	8.9	1016	1.32	13.32	4.0	3.42	85.5

[a]See appendix for computations relative to indicated columns.

COMPUTATIONS

Table I.

Col. (10), Jet Velocity, ft/sec.

$Q = v_j A_j$ $\quad v_j = .98\ v$ Where v is Velocity through hole.

$A_j = .62\ A$ A is area of hole

V_j is Velocity of jet

$Q = .98\ v\ (.62A) = .61\ vA$ $\quad A_j$ is area of jet

$$v = \frac{Q}{.61\ A}$$

$$\text{Test 17, } v = \frac{35\ \frac{gal}{min} \times 144\ \frac{in^2}{ft^2}}{.61\ (321\ \text{holes})\ \frac{\pi}{4}\ (\frac{1}{16})^2\ in.^2 \times 7.5\ \frac{gal}{ft^3} \times 60\ \frac{sec}{min}}$$

$v = 18.5$ ft/sec.

Col. (12), Total By-Pass Flow, gpm

Col. (10) = Col. (5) + Col. (6)

Col. (13), Experimental Half-Life, min.

Col. (13), Data obtained from Reactor Chemistry Division

Col. (14), Ideal Half-Life, min.

$$C = C_1\ e^{-Q_s t/V}$$

C = CO_2 Concentration, pH reading

Q_s = Stripping Flow, gpm.

t = Half-Life Time, min.

V = System Volume, gal.

$$0.5 = e^{-Q_s t/V}$$

$$\ln 0.5 = -Q_s t/V$$

$$0.694 = Q_s t/V$$

$$t = 0.694\ V/Q_s$$

Test 17, $t = \frac{0.694(88)}{50} = 1.22$ min.

Col. (15), Relative Effectiveness, %

$$\text{Col. (15)} = \frac{\text{Col. (14)}}{\text{Col. (13)}}$$

Table II.

Col. (3), Motor Input Power, Kw

$$\text{Col. (3)} = 4\left[\text{Col. (2)}\right]$$

Col. (6), Motor Input Power, Kw

$$\text{Col. (6)} = \frac{[\text{Col. (4)}]\ [\text{Col. (5)}]}{1000}$$

Col. (8), Discharge Head, ft.

$$\text{Col. (8)} = \text{Col. (7)}\ \frac{\text{lbs}}{\text{in}^2} \times \frac{144\ \text{in}^2/\text{ft}^2}{62.4\ \frac{\text{lbs}}{\text{ft}^3}} = \text{Col. (7) (2.31)}$$

Col. (11), Venturi Pressure Drop, psi

$$\text{Col. (11)} = \text{Col. (9)} - \text{Col. (10)}$$

Col. (13), Venturi Flow, gpm

Col. (13) obtained from Fig. 7, using Col. (11) or (12)

Col. (15) and (17), Stripper Flow, gpm

$$\text{Cols. (15) and (17)} = \frac{[\text{Cols. (14) and (16)}]}{100}\quad 17.5$$

Col. (18), Fountain Flow, gpm

Col. (18) obtained from Fig. 18

Col. (19), Total Flow, gpm

$$\text{Col. (19)} = \text{Col. (13)} + \text{Col. (15)} + \text{Col. (17)} + \text{Col. (18)}$$

Col. (20), Change in Velocity Head, ft.

Col. (20) = $1.28 \times 10^{-6} Q^2$ Where Q = Total Flow, gpm.

$$1.28 \times 10^{-6} Q^2 = \frac{v_d^2}{2g} - \frac{v_s^2}{2g} = \frac{(Q/A_d)^2}{2g} - \frac{(Q/A_s)^2}{2g}$$

$$= \frac{Q^2}{2g}\left[\frac{1}{\left(\frac{\pi d_d^2}{4}\right)^2} - \frac{1}{\left(\frac{\pi d_s^2}{4}\right)^2}\right]$$

$$= \frac{16\ Q^2}{2(32.2)\pi^2}\left[\frac{1}{d_d^4} - \frac{1}{d_s^4}\right]$$

Where d_d = discharge diameter

d_s = suction diameter

d_d = 0.505 ft.

d_s = 0.666 ft.

Q = $ft^3/sec.$

$$= \frac{\frac{16\ Q^2}{(7.5 \times 60)^2}}{2(32.2)\pi^2}\left[\frac{1}{(.505)^4} - \frac{1}{(.666)^4}\right]$$

Col. (20) = $1.28 \times 10^{-6} Q^2$ Where Q = gpm.

Col. (21), Total Head, ft.

Col. (21) = Col. (8) + Col. (20)

Table III.

Col. (3), Motor Input Power, Kw.

Col. (3) = 4 [Col. (2)]

Col. (6), Motor Input Power, Kw.

$$\text{Col. (6)} = \frac{[\text{Col. (4)}]\,[\text{Col. (5)}]}{1000}$$

Col. (8), Discharge Head, ft.

$$\text{Col. (8)} = \text{Col. (7)}\,(2.31)$$

Col. (10), Venturi Flow, gpm.

Col. (10) is obtained from Fig. 7 using Col. (9)

Col. (15), Stripping Flow, gpm.

$$\text{Col. (15)} = \left[\frac{\text{Col. (11)} + \text{Col. (12)} + \text{Col. (13)} + \text{Col. (14)}}{100}\right] 17.5$$

Col. (16), Fountain Flow, gpm.

Col. (16) is obtained from Fig. 18.

Col. (17), Total Flow, gpm.

Col. (17) = Col. (10) + Col. (15) + Col. (16).

Col. (18), Change in Velocity Head, ft.

Col. (18), Same as Col. (20), Table II.

Col. (19), Total Head, ft.

Col. (19) = Col. (8) + Col. (18).

Col. (20), Pump Power Input, hp.

Col. (20) obtained from Fig. 8, using Col. (6).

Col. (21), Water Horsepower, hp.

$$\text{Col. (21)} = \frac{Q\,H}{3960}$$

Q is in gpm.

H is in ft.

Col. (22), Efficiency, %

$$\text{Col. (22)} = \left[\frac{\text{Col. (21)}}{\text{Col. (20)}}\right] 100$$

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