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EXPERIMENT DATA REPORT FOR SINGLE- AND TWO-PHASE STEADY STATE TESTS OF THE 1-1/2-LOOP MOD-1 SEMISCALE SYSTEM PUMP

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**EXPERIMENT DATA REPORT FOR SINGLE- AND TWO-PHASE STEADY STATE
TESTS OF THE 1-1/2-LOOP MOD-1 SEMISCALE SYSTEM PUMP**

by

D. J. Olson

AEROJET NUCLEAR COMPANY

Date Published - May 1974

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ABSTRACT

Steady state tests using both single-phase and two-phase fluid as the working medium were conducted on a small centrifugal pump. The purpose of this report is to present the data obtained from the single- and two-phase tests together with the system description, test procedures, and error analysis so that those interested in determining pump response to single- and two-phase fluid conditions can perform an independent analysis of the results.

SUMMARY

The behavior of centrifugal pumps when such pumps are subjected to single-phase service with fluids of low viscosity such as water has been well established for a number of years; however, the corresponding behavior for two-phase fluid conditions is not well defined. Current reactor safety analyses are based on the assumption that centrifugal pumps respond to a two-phase fluid in much the same manner as they do to a single-phase fluid. Although extensive high pressure two-phase data have not been obtained on which to base an understanding of the behavior of centrifugal pumps when two-phase fluid is passing through them, limited high pressure pump cavitation data available for low void fractions indicate this assumption may not be valid. A proper assessment of pump behavior under two-phase conditions is necessary to the understanding of the thermal-hydraulic response of a pressurized water reactor (PWR) system to a postulated loss-of-coolant accident (LOCA), particularly in regard to the influence of pump performance on the magnitude and direction of core flow.

The tests described were performed on the small centrifugal pump which is being used as the operating loop primary pump in the 1-1/2-loop Mod-1 semiscale blowdown facility. The tests were conducted by Westinghouse Canada Limited under contract to Aerojet Nuclear Company as part of the Semiscale Blowdown and Emergency Core Cooling (ECC) Project which is conducted by Aerojet Nuclear Company for the United States Atomic Energy Commission. The purposes of the tests were to:

- (1) Determine the performance characteristics of the pump for normal operation with both single-phase (subcooled water) and two-phase (steam-water mixture) fluids flowing through the pump.
- (2) To determine the losses across the pump for abnormal operation (reverse flow, reverse rotation, negative head) with both single- and two-phase fluids flowing through the pump.
- (3) To determine the cavitation characteristics of the pump at specified saturation pressures with low void fraction steam-water mixtures.

This report presents the test results from the single- and two-phase tests performed on the subject pump. The intent is to present the data, with sufficient supporting information concerning the test system, procedures, and instrumentation used, for use in subsequent analyses.

The data presented represent a beginning toward achieving an understanding of centrifugal pump behavior under two-phase fluid conditions. Although the data were

obtained with a small pump and are not considered directly applicable to large pumps, they are considered appropriate for evaluation of theoretical predictions of centrifugal pump behavior in general and for establishment of criteria for possible future pump tests with large scale systems.

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EXPERIMENT DATA REPORT FOR SINGLE- AND TWO-PHASE STEADY STATE

TESTS OF THE 1-1/2-LOOP MOD-1 SEMISCALE SYSTEM PUMP

I. INTRODUCTION

The behavior of centrifugal pumps, when such pumps are used in single-phase service for fluids of low viscosity such as water, is well established. Even in cases of abnormal operation such as loss of power when fluid is being pumped to an elevated reservoir, the application of the pump affinity laws and available experimental information allows determination of the subsequent behavior of the pump in terms of the head, flow, and speed relationships. Contrariwise, the behavior of centrifugal pumps, when such pumps are used under conditions which would subject them to two-phase fluids, is less well defined. A primary coolant pipe rupture [loss-of-coolant accident (LOCA)] in a pressurized water reactor (PWR) system in which the system fluid rapidly decompresses from nominal conditions of 2250 psig, 577°F to near atmospheric conditions represents a situation in which the pump could be subjected to two-phase fluids. In water reactor safety analyses of the LOCA, basic assumptions are necessary for evaluation of the contribution of the primary coolant pumps to the consequences of this accident. In these analyses, the primary coolant pumps are assumed to be susceptible to operation in all possible normal and abnormal modes such as impeller speed coastdown, reverse pump operation, turbine operation, and energy dissipation with the pump retarding flow. Current analyses assume that the pumps respond to the rapidly decompressing two-phase fluid passing through them in a manner similar to that in which they respond to single-phase fluid. Although extensive high pressure-two-phase data defining the behavior of centrifugal pumps are not available on which to base the current assumptions, limited, high pressure pump cavitation data available for low void fractions indicate that the assumption may not be valid. Therefore, data are needed that provide not only an understanding of the single-phase normal and abnormal pump characteristics, but also an understanding of the characteristics under two-phase conditions.

A pump test project that represents a beginning toward achievement of the needed understanding of pump behavior under two-phase fluid conditions has been completed. The work accomplished, however, is only an initial step in investigating a complex area of centrifugal pump behavior. The tests were performed with a small pump to meet specific needs of an experimental program involving hardware that is small in scale relative to commercial power plants. Although the resultant data should not be interpreted as being directly applicable to the large pumps used in the commercial plants, they are expected to be helpful in evaluating theoretical predictions of centrifugal pump behavior in general and for establishing criteria for possible future pump tests with larger scale hardware.

The purpose of this report is to present the results, and other pertinent information, relating to the single- and two-phase performance and head loss tests performed on the

subject pump. The intent is to present the data obtained and the associated information required for subsequent analysis to the scientific community without attempting to relate the single- and two-phase behavior in this report. A subsequent report is to contain an analysis of the data.

The tests had a three-fold purpose as follows:

- (1) To determine the performance characteristics of the pump for normal operation with both single-phase (subcooled water) and two-phase (steam-water mixture) fluid flowing through the pump.
- (2) To determine the losses across the pump for abnormal operation (reverse flow, reverse rotation, negative head) with both single- and two-phase fluid flowing through the pump.
- (3) To determine the cavitation characteristics of the pump at specified saturation pressures with low void fraction steam-water mixtures.

The tests were conducted at the Atomic Power Division Laboratory of Westinghouse Canada Limited (WCL) in Hamilton, Ontario, Canada. Single-phase testing of the pump was performed at that facility during January 1973. The single-phase test conditions included a pressure range of 0 to 200 psig coincident with a temperature range of 75 to 125°F required to maintain a relatively constant density fluid through the tests, a flow rate of -200 to +200% of rated and an impeller speed range of -100 to +100% of rated. Two-phase testing was performed in February and March 1973. Test conditions were essentially the same as for the single-phase tests with the most significant differences being that tests were also performed at three saturated pressure levels (900, 500, and 200 psia) and fluid void fractions ranging from 0 to 100%. The pump tested in these investigations is the same pump employed in the operating loop of the 1-1/2-loop Mod-1 semiscale test system used in a portion of the Semiscale and Emergency Core Cooling (ECC) Project performed by Aerojet Nuclear Company for the U. S. Atomic Energy Commission. The pump was modified prior to the single- and two phase testing for service in the Mod-1 semiscale system. The modifications resulted in rated conditions of 180 gpm against 192 ft of head at 3560 rpm with a specific speed of 926. The rated torque on the pump shaft at these conditions is 417.6 in.-lb.

Sufficient data points were obtained during the single-phase tests to establish the operating characteristics of the subject pump in all regions of pump operation. Data points during the two-phase tests were obtained in corresponding regions of pump operation to provide a basis for comparison between the two test series. All pertinent test data are included in this report together with specific descriptions of the test systems, test conditions, procedures, and instrumentation.

II. FACILITY, TEST PROCEDURES, AND DATA ACQUISITION

The test systems and procedures and the instrumentation and measurements for the single- and two-phase flow tests on the 1-1/2-loop Mod-1 semiscale pump are described.

1. PUMP TEST SECTION

The configuration of the test section, including the pump assembly and associated peripheral equipment such as the bearing oil supply, dc motor, and speed controller and inlet and outlet spool pieces, was the same for the single- and two-phase test sequences. As shown in Figure 1, the discharge line extended horizontally for a distance of about 38 inches from the pump discharge to connect with the loop piping, and the suction line extended horizontally from the pump suction port for a distance of about 40 inches to the spool elbow at which point the suction line extended vertically for a distance of about 36 inches to connect with the loop piping. The discharge and suction lines consisted of piping spools which were three-inch Schedule 160 pipe. All loop piping in the vicinity of the test section was three-inch Schedule 80 pipe.

The pump test assembly is shown in Figure 2. The pump is a two-inch heavy duty, horizontally mounted centrifugal pump, manufactured by Lawrence Pumps Inc. Figure 3 presents a sectional side view of the pump assembly. The pump is the 1-1/2-loop semiscale Mod-1 system pump which was modified in accordance with the philosophy outlined in Reference 1. These modifications consisted of a 7-3/4-inch-diameter impeller (instead of the original 11-inch-diameter impeller) and a venturi in the pump discharge port. Figure 4 presents the details of the 7-3/4-inch-diameter impeller and the venturi.

2. LOOP DESCRIPTION AND TEST PROCEDURES

The test loops and the test procedures for the single- and two-phase tests were basically similar with only slight changes for the two-phase tests.

2.1 Single-Phase Tests

The single-phase test loop is shown isometrically in Figure 5. Briefly, the test flow loop contained a deaerator tank, recirculation pumps (one shown for illustration), loop bypass, throttle valve, venturi flowmeter, and the necessary piping arrangements to provide forward and reverse flow through the test pump. Two recirculation pumps, each with a capacity of 145,000 lb/hr, were available to drive the fluid through the loop and test section. The two pumps could be operated either in parallel (total flow 290,000 lb/hr at 150 psi pressure rise) or in series (total flow 145,000 lb/hr at 300 psi pressure rise). Included in

Fig. 1 Test pump and adjacent flow piping.

Fig. 2 Pump test assembly (top view).

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Fig. 3 1-1/2-loop Mod-1 semiscale pump - section view.

Fig. 4 1-1/2-loop Mod-1 semiscale pump impeller and venturi details.

Fig. 5 Single-phase test loop.

Figure 5 are pertinent elevations, lengths, and pipe sizes describing the single-phase test loop.

The single-phase tests were performed in the simple closed loop recirculating water circuit described which permitted pressure and temperature control and operated with subcooled water at about 90°F in the pressure range of 20 to 250 psia. The test pump was operated at various speeds in the forward and reverse directions of rotation, with subcooled water flowing through the test pump from the recirculation system in either the normal or reverse flow direction, which allowed investigation of pump behavior in all modes of operation (normal pump operation, turbine operation, reverse flow operation, and energy dissipation operation). A flow schematic of the single-phase test loop is shown in Figure 6. Subcooled water was supplied from a deaerator tank by the recirculation pumps to the test pump at controlled pressure, temperature, and flow rate. The discharge from the test pump passed through a venturi flowmeter and back into the deaerator tank. Cold water was injected into the recirculation pump inlet piping to control the water temperature. The pressure in the deaerator tank was controlled by venting water to a drain. The loop bypass was used to ensure reasonably high flows through the recirculation pump in all tests, which assisted in providing stable system temperatures and pressures. The direction of fluid flow through the test pump was controlled by the insertion of blanking plates (solid metal discs) in the appropriate flanges as illustrated in Figures 5 and 6. The direction of rotation of the test pump impeller, except for cases of free wheeling, was controlled by changing the electrical leads at the dc motor to obtain the desired direction of rotation.

Several different venturi flowmeters were used in order to provide an accurate measurement of the loop flow rate for the various test conditions. Because of the time required to interchange the flowmeters, the flow range of the desired test points had to be treated as a test variable in order to keep the required number of flow changes to a minimum. The sequence in which the test data were obtained, therefore, was based on the sequence which resulted in the least number of changes to, first, the flow range; second, the flow direction; and third, the direction of rotation of the test pump impeller.

For all tests, the direction of rotation of the test pump impeller and the direction and magnitude of flow were specified in advance, thus allowing advance preparation of the system for each group of tests. The primary control parameters during each group of tests were the pump speed and fluid flow rate except for tests for which zero head or torque was specified making head or torque the control parameters. For the former, test conditions were established by first setting the test pump impeller rotation at the desired speed and then the flow at the desired magnitude. Flow to the test pump was adjusted by the loop throttle valve in the recirculating pump discharge line. When the required flow, pressure, and temperature were reached, all pertinent experimental data were recorded on the instrumentation systems described in Section II-3.

2.2 Two-Phase Tests

The two-phase test loop, shown isometrically in Figure 7, consisted of a steam-water mixer, a steam-water separator, a recirculation pump, throttling valves, venturi flowmeters

Fig. 6 Single-phase test system flow schematic.

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Fig. 7 Two-phase test loop.

and orifices, and the necessary piping to provide forward and reverse flow through the test pump. The two-phase test loop included a high-pressure, oil-fired boiler of sufficient capacity to supply the test loop with up to 30,000 lb/hr of superheated steam or saturated water, or a combined total 30,000 lb/hr of superheated steam and saturated water at 1000 psia. The recirculation pump was capable of recirculating the high pressure water at up to 145,000 lb/hr. Included in Figure 7 are pertinent piping elevations and lengths describing the two-phase test loop.

In the two-phase test series the test loop was operated at steady state conditions over a range of saturation pressures with various steam-water mixtures flowing through the system. The test pump was operated in the various operating regions described for the single-phase tests (normal, turbine, and energy dissipation). As in the single-phase tests, the test procedure was such that the flow range to be tested minimized the number of times that venturi flowmeters had to be interchanged. Steam was supplied by the steam boiler and liquid was supplied by either the recirculation system or the steam boiler. The test procedure for the two-phase flow tests was such that, for a given flow range, the liquid source was selected to minimize system changes.

A flow schematic of the two-phase test loop is shown in Figure 8. The boiler steam, boiler water, and recirculating water flows were separately controlled and measured by the use of a system of control valves, venturi flowmeters, orifices, and differential pressure transducers before the flows entered the steam-water mixing device upstream of the test pump inlet. The discharge leaving the test pump entered a steam-water separator. Steam from the separator passed through the automatic pressure control valve and was condensed and returned to the boiler from the storage tank by means of the feed pump. The water from the separator was recirculated to the steam-water mixer. High-pressure cold water, supplied from the boiler feed pump, was injected at the inlet of the recirculating water pump for control of recirculating water temperatures and to prevent cavitation. Steam entering the mixing device was superheated by 10 to 20 Btu/lb and water was subcooled by 20 to 40 Btu/lb. When the required test section inlet temperature and pressure had been reached, the loop flow control valves were adjusted to obtain the required total flow and inlet quality to the test pump. All pertinent experimental data were recorded on the instrumentation systems described in Section II-3.

3. DATA ACQUISITION SYSTEMS AND INSTRUMENTATION

The data acquisition systems and instrumentation used during the pump tests were provided jointly by Aerojet Nuclear Company and Westinghouse Canada Limited. Westinghouse Canada Limited provided the data acquisition systems and instrumentation necessary to control the test loop and to obtain the initial operating conditions. Aerojet Nuclear Company provided the data acquisition systems and instrumentation for obtaining the measurements at the test section. The data acquisition systems, instrumentation, and measurement locations were identical for both the single- and two-phase tests, with the

Fig. 8 Two-phase test system flow schematic.

exception of additional loop measurements required at the boiler inlet to the test loop for the two-phase tests. Complete measurement characteristics and maximum error limits are given in Section IV.

3.1 Test Section Measurements and Data Acquisition

Following establishment of the steady state loop conditions for each data point as determined from the loop data acquisition and measurement systems, the test section measurements were taken. Figure 9 illustrates the relative location of each of the measurements taken at the test section, and Figures 10 and 11 present detailed drawings of the physical location of the various detectors within the instrumented spool pieces. A complete listing of the test section measurements is given in Table I, and Figure 12 presents a block diagram of the test section data acquisition system (DAS). The DAS basically consisted of a transducer, signal conditioner, amplifier, and visual readout. All measurements were manually recorded from a digital voltmeter, a digital counter, or a 15-inch precision pressure gage. Selected data were recorded on a strip chart recorder.

3.2 Loop Measurements and Data Acquisition

Measurements in the loop were used to control the test loop and to obtain initial operating conditions. Figure 13 shows the relative locations of the loop instruments near the test section which were used to establish initial operating conditions. Following establishment of the operating conditions, all pertinent loop data were recorded and immediately reduced to engineering units through use of a Wang 700 programmable calculator. The inlet qualities were calculated from knowledge of the mixer inlet steam and water enthalpies, the absolute pressure at the test pump inlet, and the heat loss between the mixer and the test pump (measured during a separate experiment). The test pump inlet and outlet mean specific volumes, used to calculate the pump head rise, were calculated assuming homogeneous flow with zero slip between the steam and water phases. Table II gives a complete listing of each type of loop measurement, and the test loop data acquisition system is described in block diagram form on Figure 14.

Fig. 9 Measurement locations at test section.

Fig. 10 Measurement locations in instrumented discharge spool piece.

Fig. 11 Measurement locations in instrumented suction pool piece.

TABLE I

TEST SECTION MEASUREMENTS

Measurement	Transducer Type
Pump suction fluid temperature	Chromel-Alumel thermocouple
Pump suction pressure	Flush diaphragm-bonded strain gages
Pump suction momentum flux	Strain-gaged cantilever beam with target
Pump suction fluid density	Gamma attenuation
Pump discharge fluid temperature	Chromel-Alumel thermocouple
Pump discharge pressure	Flush diaphragm-bonded strain gages
Pump discharge momentum flux	Strain-gaged cantilever beam with target
Pump discharge fluid density	Gamma attenuation
Pump discharge volumetric flow	Turbine flowmeter
Pump shaft torque	Strain gages and slip rings
Pump shaft speed	60-tooth gear and proximity detector
Pump differential pressure	Bonded strain-gaged diaphragm
System pressure (pump suction)	Bourdon tube

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Fig. 12 Test section data acquisition system.

- ① ΔP Tap Used For Forward Flow
- ② ΔP Tap Used For Reverse Flow

Fig. 13 Loop measurement locations adjacent to test section.

TABLE II
LOOP MEASUREMENTS

Measurement	Transducer Type
Pump differential pressure	Bonded strain-gaged diaphragm
Pump suction fluid temperature	Chromel-Alumel thermocouple
Pump suction pressure	Bonded strain-gaged diaphragm
Pump discharge fluid temperature	Chromel-Alumel thermocouple
Pump discharge pressure	Bonded strain-gaged diaphragm
Boiler feedwater flow	Venturi flowmeter
Recirculation water flow	Venturi flowmeter
Steam flow	Orifice
Loop pressure (6)	Bourdon tube
Loop temperature (6)	Chromel-Alumel thermocouples and iron-constantan thermocouples

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Fig. 14 Loop data acquisition system.

III. PRESENTATION AND DISCUSSION OF TEST RESULTS

The test data from both the single- and two-phase flow pump tests are presented in tabular form.

1. SINGLE-PHASE DATA

Data taken during the single-phase flow pump tests were sufficient to establish the complete single phase performance characteristics of the subject pump. The data, grouped as to test section measurements and loop measurements, are presented in Tables III and IV, respectively. The data presented in Table IV for the test loop were obtained by Westinghouse Canada Limited and were reproduced from Reference 2 with only slight changes in format of presentation. In some cases, such as flow rate and pump head, measurements are included in both tables because these variables were measured through use of both loop and test section instrumentation. The data are discussed on an individual basis in terms of consistency and in terms of differences between the loop and test section measurements. The measurements are discussed in the order in which they appear in Table III.

1.1 Pump Impeller Speed

The impeller speed of the test pump was measured only on the test section measurements system through use of a frequency counter. Measurement accuracy is to within ± 25 rpm.

1.2 Volumetric Flow Rate

Comparison of the volumetric flow rates as measured by the turbine flowmeter in the test section and the loop venturi flowmeter indicates correspondence on the average to within 2 to 3%. Maximum deviations in the measurements recorded from the two measurement systems are on the order of 4 to 5%. For the low flow tests, the output of the turbine flowmeter is to some degree a function of the forces on the blades, and greater inaccuracy is evident. In these tests, the flow rate obtained from the venturi flowmeter was included in Table III as the flow rate in the test section. The appropriate tests are identified in Table III.

1.3 Pump Head

The greatest difference between the results obtained from the test section and loop measurement systems is in the measurement of the differential pressure across the pump. The differences, in most cases, can be attributed to the difference in distances between transducer tap locations which were used for the test section and loop measurements of pump differential pressure.

TABLE III

RESULTS OBTAINED FROM TEST SECTION MEASUREMENTS DURING SINGLE-PHASE FLOW PUMP TESTS

Test	Impeller Speed (rpm)	Volumetric Flow Rate ^[a] (gpm)	Pump Head		Density ^[d] (lb/ft ³)	Torque (in./lb)	Fluid Temperature (°F)		Pressure (psig)	
			(psid) ^[b]	(ft of fluid) ^[c]			Pump Inlet ^[e]	Pump Outlet ^[e]	Pump Inlet ^[e]	Pump Outlet ^[e]
001	0	101	-9.1	-21.2	62.0	-44.2	100.3	100.7	59.4	47.6
002	0	164	-2.4	-55.7	62.1	-44.2	93.2	93.7	77.5	48.6
003	0	228	-45.3	-104.9	62.2	-45.6	90.6	91.0	100.7	51.6
004	0	341	-121.9	-282.5	62.2	-68.9	86.6	87.1	187.3	64.8
005	0	276	-69.0	-159.9	62.2	-65.1	86.2	87.1	120.8	50.6
006	0	67	-4.4	-10.2	62.2	-31.6	86.2	86.7	49.3	43.6
007	0	-68	8.4	19.4	62.4	50.7	86.6	86.2	66.8	58.4
008	0	-106	21.4	49.5	62.4	54.4	94.0	94.0	84.0	62.4
009	0	-154	44.1	101.8	62.3	81.0	97.6	98.0	110.3	66.5
010	0	-190	66.9	154.6	62.3	157.7	95.8	96.0	131.6	65.5
011	0	-255	121.6	280.8	62.4	305.2	94.5	94.0	191.3	70.5
012	0	-255	121.4	280.3	62.4	307.1	94.0	94.0	192.3	70.5
013	2700	168	40.7	94.1	62.3	270.8	77.4	77.8	17.7	57.0
014	2704	281	0.2	0.5	62.2	324.0	83.9	84.4	86.0	83.0
015	2710	326	-21.0	-48.7	62.2	345.0	86.1	86.6	107.0	84.0
016	2702	388	-85.0	-196.8	62.2	363.0	87.5	87.9	174.0	89.0
017	2705	135	47.2	108.9	62.4	249.0	86.2	86.6	9.1	54.0
018	2708	148	45.1	104.0	62.4	259.0	83.5	84.0	10.1	54.0
019	2707	0	56.8	131.1	62.4	163.0	76.9	77.4	2.0	59.0
020	3005	154	58.2	134.6	62.3	301.0	74.9	75.0	6.0	62.0
021	2995	311	1.0	2.3	62.2	392.0	80.0	80.5	73.0	73.0
022	1605	81	16.2	37.6	62.1	134.0	94.6	95.0	26.2	44.5

TABLE III (contd.)

RESULTS OBTAINED FROM TEST SECTION MEASUREMENTS DURING SINGLE-PHASE FLOW PUMP TESTS

Test	Impeller Speed (rpm)	Volumetric Flow Rate ^[a] (gpm)	Pump Head		Density ^[d] (lb/ft ³)	Torque (in./lb)	Fluid Temperature (°F)		Pressure (psig)	
			(psid) ^[b]	(ft of fluid) ^[c]			Pump Inlet ^[e]	Pump Outlet ^[e]	Pump Inlet ^[e]	Pump Outlet ^[e]
023	1604	99	13.4	31.1	62.1	137.0	92.8	93.2	39.3	55.7
024	1604	130	8.5	19.8	62.1	148.0	91.0	91.5	45.3	55.7
025	1598	164	0.1	0.2	62.2	152.0	91.9	92.3	62.4	63.8
026	1603	199	-9.4	-21.8	62.1	157.0	95.0	95.4	80.6	71.9
027	1599	241	-25.0	-57.9	62.1	159.0	95.4	95.9	104.7	82.0
028	1601	291	-49.7	-115.3	62.1	153.0	96.3	96.8	145.0	97.8
029	803	97.1	-2.8	-6.5	62.1	63.3	90.6	91.0	65.3	64.8
030	804	197	-27.8	-64.3	62.2	60.0	88.8	89.3	93.7	67.8
031	804	292	-65.1	-150.8	62.2	46.1	86.6	87.5	137.0	72.9
032	807	0	4.4	10.2	62.2	46.5	80.5	81.3	44.3	51.6
033	1602	0	20.4	47.3	62.2	93.5	79.1	79.6	29.2	51.6
034	2204	0	39.2	90.6	62.3	127.0	76.1	76.5	21.1	61.7
035	2705	51	54.7	126.8	62.1	202.4	91.0	91.5	8.1	61.7
036	2703	78	53.4	123.8	62.1	221.5	89.7	90.1	11.1	63.7
037	2698	120	49.9	115.7	62.1	349.4	88.8	89.3	19.1	67.8
038	2708	29 ^[f]	56.0	129.8	62.2	178.7	86.2	87.0	7.0	62.7
039	1600	16 ^[f]	19.5	45.3	62.1	78.2	90.1	90.6	43.3	62.7
040	1600	26 ^[f]	19.3	44.8	62.1	84.7	87.9	87.9	44.3	62.7
041	1600	46	18.8	43.7	62.1	96.8	87.9	88.4	45.3	62.7
042	1604	78	16.7	38.8	62.1	110.7	87.1	87.1	48.3	63.7
043	1608	92	15.5	36.0	62.2	118.7	85.3	85.7	50.4	64.8
044	1600	137	7.6	17.6	62.2	138.2	82.7	82.7	60.4	64.8

TABLE III (contd.)

RESULTS OBTAINED FROM TEST SECTION MEASUREMENTS DURING SINGLE-PHASE FLOW PUMP TESTS

Test	Impeller Speed (rpm)	Volumetric Flow Rate ^[a] (gpm)	Pump Head		Density ^[d] (lb/ft ³)	Torque (in./lb)	Fluid Temperature (°F)		Pressure (psig)	
			(psid) ^[b]	(ft of fluid) ^[c]			Pump Inlet ^[e]	Pump Outlet ^[e]	Pump Inlet ^[e]	Pump Outlet ^[e]
045	400	37	0.5	1.2	62.2	37.7	76.9	76.9	63.4	62.7
046	401	149	-16.5	-38.3	62.1	36.3	93.2	93.7	90.6	72.9
047	202	155	-19.8	-46.1	62.0	16.3	100.3	100.3	100.7	81.0
048	1603	58	18.3	42.5	62.0	122.8	97.2	97.2	46.3	63.8
049	2930	0	68.2	157.9	62.2	181.9	102.5	96.8	4.0	73.9
050	1168	0	10.9	25.3	62.1	57.7	92.8	95.0	52.4	62.7
051	2696	-28 ^[f]	61.3	142.6	61.9	148.4	107.3	106.9	120.4	62.4
052	2695	-52	64.5	150.0	62.0	148.9	105.1	104.7	126.5	65.5
053	2701	-79	65.1	151.4	62.0	154.0	103.8	103.8	130.5	68.5
054	2700	-110	60.2	140.0	62.0	172.6	103.4	103.4	130.5	72.5
055	2698	-135	70.6	164.1	62.0	185.2	102.9	102.9	147.8	79.6
056	2696	0	57.7	134.1	62.0	153.1	102.0	102.0	57.4	112.3
057	1599	-19	22.1	51.1	62.4	70.7	97.6	97.2	83.0	62.4
058	1603	-46	23.0	53.5	62.0	72.6	98.1	97.6	85.0	64.4
059	1606	-79	25.4	58.9	62.0	88.4	99.0	98.5	91.1	68.5
060	1602	-101	30.6	70.9	62.0	95.4	98.1	97.6	92.1	61.4
061	1606	-134	43.6	101.1	62.1	126.6	96.3	95.9	118.4	76.5
062	1607	-60	22.0	51.1	62.1	94.0	94.1	94.1	83.0	63.4
063	1609	-70	22.3	51.9	62.0	98.2	96.3	95.9	84.0	66.5
064	1610	-76	24.3	56.5	62.0	99.6	98.1	97.6	87.0	63.4
065	1598	-52	22.4	52.1	62.0	90.3	98.5	98.1	83.0	64.4

TABLE III (contd.)

RESULTS OBTAINED FROM TEST SECTION MEASUREMENTS DURING SINGLE-PHASE FLOW PUMP TESTS

Test	Impeller Speed (rpm)	Volumetric Flow Rate ^[a] (gpm)	Pump Head		Density ^[d] (lb/ft ³)	Torque (in./lb)	Fluid Temperature (°F)		Pressure (psig)	
			(psid) ^[b]	(ft of fluid) ^[c]			Pump Inlet ^[e]	Pump Outlet ^[e]	Pump Inlet ^[e]	Pump Outlet ^[e]
066	1599	-88	26.7	61.9	62.0	100.0	99.4	99.0	93.1	69.5
067	1602	0	20.0	46.5	62.0	87.9	97.2	99.4	58.4	75.9
068	798	0	5.0	11.6	62.0	46.5	94.1	97.2	56.4	58.7
069	798	-38	6.1	14.2	62.1	50.2	96.3	95.9	67.8	62.4
070	799	-48	7.3	17.0	62.0	52.6	97.6	97.2	73.9	66.5
071	801	-69	11.0	25.6	62.0	62.4	99.8	99.4	73.9	66.5
072	801	-101	21.3	49.5	62.0	90.3	99.8	99.4	92.1	73.5
073	800	-139	35.1	90.7	62.1	135.4	96.8	96.3	120.4	83.6
074	2204	-110	47.6	110.3	62.1	142.8	94.1	94.1	124.5	81.6
075	-802	-39	8.1	18.8	62.1	-39.1	95.4	94.6	68.8	63.4
076	-804	-66	12.8	29.8	62.0	-27.5	99.4	99.0	81.0	70.5
077	-802	-100.4	20.2	47.0	62.0	0.1	98.5	98.1	98.2	79.6
078	-390	-99	17.8	41.3	62.2	18.6	85.3	84.9	82.0	67.5
079	-206	-86	12.7	29.5	62.2	15.9	86.6	86.2	82.0	71.5
080	0	-64	7.2	16.7	62.2	11.6	89.7	89.3	68.8	64.4
081	-246	-92	14.5	33.7	62.1	16.8	92.3	91.9	86.0	74.5
082	-420	-102	19.5	45.3	62.1	18.6	94.6	94.1	96.1	79.6
083	-616	-113	55.9	129.7	62.1	22.3	96.3	95.9	100.2	78.5
084	-865	-121	29.7	68.8	62.1	20.5	97.6	97.6	110.3	84.6
085	-1194	-137	41.1	95.3	62.1	23.3	97.6	97.6	132.6	95.7
086	-397	-23.3 ^[f]	2.2	5.1	62.1	-21.4	96.3	95.9	60.7	61.4
087	-398	-61	7.6	17.7	62.1	-7.0	96.8	96.3	65.8	62.4

TABLE III (contd.)

RESULTS OBTAINED FROM TEST SECTION MEASUREMENTS DURING SINGLE-PHASE FLOW PUMP TESTS

Test	Impeller Speed (rpm)	Volumetric Flow Rate ^[a] (gpm)	Pump Head		Density ^[d] (lb/ft ³)	Torque (in./lb)	Fluid Temperature (°F)		Pressure (psig)	
			(psid) ^[b]	(ft of fluid) ^[c]			Pump Inlet ^[e]	Pump Outlet ^[e]	Pump Inlet ^[e]	Pump Outlet ^[e]
088	-398	-72	10.2	23.7	62.1	0	96.8	96.3	70.8	64.4
089	-399	-99	18.0	41.8	62.1	16.8	98.5	98.1	88.0	72.5
090	-800	-118	26.3	61.2	62.0	18.6	99.8	99.4	103.2	78.5
091	-800	0	4.0	9.3	62.0	-45.6	99.8	97.6	60.7	60.4
092	-403	0	1.0	2.3	62.0	-25.6	99.0	99.4	58.7	60.4
093	-1602	-31	21.2	49.2	62.2	-72.1	80.9	80.9	88.0	66.5
094	-1594	-47	24.4	56.7	62.1	-69.8	96.8	96.3	98.2	73.5
095	-1591	-80	31.9	73.9	62.1	-50.2	95.9	95.4	114.4	82.6
096	-1595	-101	38.3	88.8	62.1	-34.0	92.3	91.9	126.5	87.6
097	-1602	-134	53.0	122.7	62.2	-3.3	84.4	84.4	157.9	107.7
098	-1602	0	16.1	37.4	62.2	-92.1	84.9	84.4	72.9	58.4
099	-2197	0	29.9	69.1	62.2	-131.7	83.5	84.4	86.0	56.4
100	-2704	-29 ^[f]	52.1	120.7	62.2	-140.0	91.0	91.0	126.5	76.5
101	-2699	-47	58.9	136.6	62.1	-131.2	93.7	93.7	133.6	74.5
102	-2697	-78.4	70.3	163.2	62.1	-11.7	95.4	95.4	155.8	88.6
103	-2699	-109	81.0	187.8	62.1	-87.0	95.4	95.9	173.1	93.7
104	-2698	-133	92.9	215.1	62.2	-59.1	86.2	86.2	198.4	104.7
105	-2706	0	44.9	104.1	62.1	-168.0	97.6	103.4	99.2	50.4
106	-2208	-44	41.9	97.2	62.1	-90.7	98.5	98.5	112.3	68.5
107	-2210	-82	52.4	121.6	62.1	-67.9	93.7	93.7	135.6	80.6
108	-2208	-110	62.1	143.9	62.2	-46.1	90.1	90.1	152.8	88.6
109	-2206	-137	73.7	170.1	62.2	-20.0	87.5	87.5	174.1	99.7

TABLE III (contd.)

RESULTS OBTAINED FROM TEST SECTION MEASUREMENTS DURING SINGLE-PHASE FLOW PUMP TESTS

Test	Impeller Speed (rpm)	Volumetric Flow Rate ^[a] (gpm)	Pump Head		Density ^[d] (lb/ft ³)	Torque (in./lb)	Fluid Temperature (°F)		Pressure (psig)	
			(psid) ^[b]	(ft of fluid) ^[c]			Pump Inlet ^[e]	Pump Outlet ^[e]	Pump Inlet ^[e]	Pump Outlet ^[e]
110	-799	42	0.9	2.1	62.2	-79.1	78.7	78.7	58.4	60.7
111	-799	66	-3.0	-7.0	62.2	-94.9	82.2	82.2	69.5	67.8
112	-801	97	-9.4	-21.8	62.2	-112.6	85.3	85.3	88.6	79.9
113	-800	129	-19.8	-44.8	62.2	-136.8	88.8	88.8	90.6	71.9
114	-803	0	4.0	9.3	62.0	-53.0	92.8	95.9	54.4	58.7
115	-1609	35 ^[f]	12.0	27.9	62.0	-131.2	95.0	95.0	48.3	60.7
116	-1608	0	16.3	37.9	62.0	-99.6	95.9	97.2	43.3	59.7
117	-2196	0	29.4	68.1	62.1	-144.2	95.4	94.6	28.2	58.7
118	-2706	0	45.1	104.7	62.0	-175.8	101.2	95.0	11.1	56.7
119	-1601	49.8 ^[f]	10.6	24.7	62.0	-131.7	97.6	97.6	49.3	60.7
120	-2197	25 ^[f]	27.8	64.5	62.0	-155.9	99.0	99.4	32.2	58.7
121	-2199	48	23.1	53.6	62.0	-182.9	102.5	102.9	37.3	60.7
122	-2195	59	20.6	47.9	62.0	-204.7	99.8	100.3	37.3	57.7
123	-2199	83	15.2	35.4	62.0	-233.6	99.4	99.8	45.3	59.7
124	-2198	113	4.9	11.4	62.0	-269.9	98.5	99.0	56.4	62.7
125	-2703	28 ^[f]	40.5	94.0	62.0	-198.7	98.1	99.0	15.1	56.7
126	-2703	48	35.6	62.5	62.1	-240.6	96.3	96.8	20.1	57.7
127	-2706	77	30.5	70.7	62.1	-283.8	96.3	96.8	30.1	58.7
128	-2701	111	19.0	44.2	62.1	-330.4	96.3	96.8	43.3	62.7
129	-2698	125	13.8	32.1	62.1	-355.5	96.8	97.2	50.3	64.8
130	-2698	139	9.1	21.2	62.0	-381.1	97.2	97.6	57.4	65.8
131	-2197	126	0	0	62.0	-292.7	97.6	98.1	62.4	63.8

TABLE III (contd.)

RESULTS OBTAINED FROM TEST SECTION MEASUREMENTS DURING SINGLE-PHASE FLOW PUMP TESTS

Test	Impeller Speed (rpm)	Volumetric Flow Rate ^[a] (gpm)	Pump Head		Density ^[d] (lb/ft ³)	Torque (in./lb)	Fluid Temperature (°F)		Pressure (psig)	
			(psid) ^[b]	(ft of fluid) ^[c]			Pump Inlet ^[e]	Pump Outlet ^[e]	Pump Inlet ^[e]	Pump Outlet ^[e]
132	-2190	142	-5.1	-11.9	62.0	-313.6	97.6	98.1	71.5	64.8
133	-1604	81	3.3	7.7	62.1	-155.9	96.3	96.8	56.3	59.7
134	-1601	103	-2.6	-6.0	62.1	-188.0	96.8	96.8	65.5	62.7
135	-1599	137	-13.2	-30.7	62.1	-227.5	96.3	96.8	78.5	64.8
136	0	149	-18.8	-43.7	62.1	2.8	95.9	95.9	86.6	67.8
137	-796	196	-37.8	-87.5	62.2	-165.8	90.6	91.0	115.8	74.9
138	-794	195	-38.5	-88.9	62.4	-168.0	91.5	91.9	111.8	67.8
139	-1599	171	-25.3	-58.3	62.4	-279.2	95.0	95.9	92.6	63.8
140	-1595	207	-39.5	-91.2	62.4	-316.4	99.4	99.0	113.8	69.8
141	-1588	258	-66.7	-154.2	62.3	-384.3	98.1	98.5	153.1	81.0
142	-2704	159	0	0	62.2	-430.9	92.8	99.4	65.5	61.7
143	-2205	141	-6.2	-14.4	62.0	-327.6	91.9	92.8	72.5	62.7
144	-2197	186	-23.0	-53.2	62.3	-386.2	92.3	92.8	97.7	69.8
145	-2198	226	-42.7	-99.8	61.6	-446.2	92.8	93.7	126.9	79.9
146	191	238	-46.7	-107.9	62.3	-14.9	92.3	92.8	130.9	78.9
147	-2690	-156	100.4	231.9	62.3	-39.6	77.8	77.8	181.1	82.6
148	-2698	-202	131.7	304.1	62.4	26.5	80.9	80.5	210.5	81.6
149	-2204	-179	95.0	219.4	62.4	23.3	83.1	82.7	168.0	75.5
150	-1605	-154	59.1	136.8	62.2	23.3	84.4	83.5	125.5	66.5
151	-2197	-187	97.7	225.7	62.3	26.1	85.3	84.9	173.1	75.7
152	-2722	-207	134.0	310.0	62.2	31.6	86.6	86.2	216.6	84.6
153	801	-195	75.3	173.8	62.3	220.1	85.3	85.3	147.8	75.5

TABLE III (contd.)

RESULTS OBTAINED FROM TEST SECTION MEASUREMENTS DURING SINGLE-PHASE FLOW PUMP TESTS

Test	Impeller Speed (rpm)	Volumetric Flow Rate ^[a] (gpm)	Pump Head		Density ^[d] (lb/ft ³)	Torque (in./lb)	Fluid Temperature (°F)		Pressure (psig)	
			(psid) ^[b]	(ft of fluid) ^[c]			Pump Inlet ^[e]	Pump Outlet ^[e]	Pump Inlet ^[e]	Pump Outlet ^[e]
154	1597	-170	65.0	150.2	62.3	192.6	87.1	86.6	132.6	68.5
155	1595	-205	90.0	207.9	62.3	262.4	88.5	88.4	167.0	77.5
156	1603	-263	146.7	338.9	62.3	403.9	89.7	89.3	229.7	88.6
157	2706	-155.3	77.4	178.7	62.3	194.5	90.1	90.1	145.7	69.5
158	2730	-219	118.7	274.3	62.3	274.1	91.9	91.9	196.3	80.6
159	3201	0	81.5	188.2	62.4	92.2	98.1	94.6	63.4	142.7
160	3545	0	97.6	225.6	62.3	225.7	101.6	98.5	63.4	160.9

[a] Based on turbine flowmeter measurements.

[b] Positive pump ΔP represents higher pressure at discharge nozzle.

[c] Based on fluid density measurement at pump inlet.

[d] Fluid density at pump inlet (suction for normal operation, discharge for reverse flow).

[e] Inlet and outlet refer to locations with respect to direction of flow.

[f] Flow rate obtained from venturi flowmeter in test loop.

TABLE IV

RESULTS OBTAINED FROM LOOP MEASUREMENTS DURING SINGLE-PHASE FLOW PUMP TESTS

Test	Flow Rate		Temperature (°F)			Pump $\Delta P^{[a]}$		Pressure (psia)	
	(lb/hr)	(gpm)	At Flow Venturi	At Pump Inlet	At Pump Outlet	(ft of Inlet Fluid)	(psid)	Pump Inlet	Pump Outlet
1	51460.09	103.48	100.70	99.54	98.59	30.19	13.00	88.66	-
2	83205.06	167.10	94.19	92.02	90.85	68.20	29.40	104.44	76.24
3	116379.03	233.59	90.74	88.44	87.24	130.29	56.20	130.51	74.57
4	172958.66	347.00	86.98	84.59	83.67	317.42	137.00	219.29	81.51
5	142984.94	286.85	86.36	84.18	83.12	195.78	84.50	151.49	70.42
6	34031.20	68.27	86.45	84.50	83.12	13.90	6.00	77.11	71.53
7	33682.44	67.58	86.80	85.21	84.12	18.66	8.05	71.37	80.33
8	53717.87	107.91	96.36	94.39	93.03	50.31	21.68	72.63	95.66
9	78375.57	157.48	97.65	95.64	94.34	105.97	45.63	75.71	122.57
10	96112.76	193.09	96.54	97.48	93.12	160.52	69.17	75.29	148.23
11	129591.74	260.28	95.04	93.05	91.58	294.84	127.08	79.34	210.78
12	129600.04	260.26	94.24	92.33	90.72	294.81	127.08	79.34	210.50
13	86692.48	173.78	77.43	75.32	74.00	80.17	34.63	33.41	67.44
14	143821.80	288.48	84.68	82.48	81.36	21.73	9.38	98.43	87.75
15	167076.60	335.18	86.27	83.96	82.95	79.96	34.51	123.10	87.06
16	210348.50	422.07	87.87	85.39	84.67	237.33	102.40	192.94	85.54
17	69441.30	139.31	86.58	84.23	82.95	98.51	42.56	23.77	67.71
18	76171.30	152.76	83.62	81.36	80.05	92.44	39.90	26.35	67.37
19	0	0	76.85	72.01	70.20	124.86	53.93	14.33	73.26
20	79162.63	158.66	74.86	72.54	71.19	121.04	52.28	21.81	75.41
21	159203.70	319.27	82.51	80.51	70.42	24.05	10.38	90.95	78.18

TABLE IV (contd.)

RESULTS OBTAINED FROM LOOP MEASUREMENTS DURING SINGLE-PHASE FLOW PUMP TESTS

Test	Flow Rate		Temperature (°F)			Pump $\Delta P^{[a]}$		Pressure (psia)	
	(lb/hr)	(gpm)	At Flow Venturi	At Pump Inlet	At Pump Outlet	(ft of Inlet Fluid)	(psid)	Pump Inlet	Pump Outlet
22	41205.10	82.80	95.08	93.18	91.90	33.86	14.59	41.66	55.30
23	51949.80	104.31	93.31	91.35	90.00	27.61	11.95	54.25	65.98
24	67176.20	134.85	91.45	89.72	88.10	13.29	5.73	60.33	65.56
25	83147.90	166.93	92.16	90.27	89.10	5.24	2.26	76.76	72.84
26	101131.90	203.14	95.48	93.32	92.17	32.95	14.20	96.05	80.27
27	121860.00	244.81	96.10	94.03	93.07	71.52	30.82	121.98	88.87
28	148835.90	299.04	96.94	94.93	93.89	134.85	58.07	164.42	102.52
29	49996.20	100.36	90.97	88.84	87.56	7.39	3.18	80.74	75.20
30	100771.30	202.24	89.55	87.09	86.02	73.90	31.53	109.82	75.97
31	148868.90	298.69	87.34	85.12	83.94	184.08	79.43	154.21	76.87
32	0	0	81.19	78.95	77.70	10.58	4.57	58.37	62.86
33	0	0	79.37	77.29	75.85	44.64	19.28	43.69	62.86
34	0	0	75.97	73.75	72.55	85.73	37.03	35.02	72.56
35	27474.30	55.15	91.50	89.33	88.19	121.30	52.31	17.19	71.81
36	40468.82	81.22	90.04	87.85	86.74	117.49	50.68	15.37	65.70
37	60500.20	121.41	88.97	86.91	85.66	105.76	45.62	30.62	76.17
38	14548.30	29.19	87.51	84.23	83.44	124.14	53.57	15.94	72.00
39	7736.20	15.52	91.23	87.18	86.51	43.33	18.69	52.56	69.59
40	12995.30	26.07	87.64	86.24	84.85	42.64	18.39	52.35	70.41
41	25420.40	51.01	88.35	86.24	84.94	40.41	17.43	54.74	71.39
42	40917.50	82.10	87.25	85.26	83.94	35.14	15.16	57.81	72.29

TABLE IV (contd.)

RESULTS OBTAINED FROM LOOP MEASUREMENTS DURING SINGLE-PHASE FLOW PUMP TESTS

Test	Flow Rate		Temperature (°F)			Pump $\Delta P^{[a]}$		Pressure (psia)	
	(lb/hr)	(gpm)	At Flow Venturi	At Pump Inlet	At Pump Outlet	(ft of Inlet Fluid)	(psid)	Pump Inlet	Pump Outlet
43	47478.60	95.24	85.70	83.56	82.22	31.17	13.45	59.91	72.78
44	69048.60	138.47	82.60	80.42	79.11	9.95	4.29	71.44	73.12
45	18335.80	36.75	77.43	75.00	73.59	-1.15	0.50	73.75	71.80
46	74781.20	150.23	95.97	94.35	93.16	43.93	18.93	102.62	81.72
47	78304.60	157.42	100.35	98.42	97.32	51.70	22.26	113.88	89.14
48	30162.60	60.61	97.25	95.47	94.25	38.92	16.77	57.18	73.82
49	0	0	97.34	93.81	93.62	152.95	65.91	15.59	83.53
50	0	0	94.55	93.32	92.03	23.53	10.14	63.82	73.40
51	14041.46	28.26	107.25	105.36	104.15	138.23	59.44	74.87	135.32
52	26677.45	53.68	105.21	103.30	102.02	146.61	63.07	76.90	141.15
53	41394.14	83.27	104.02	102.14	100.80	149.97	64.53	79.90	146.56
54	55188.11	111.01	103.31	101.42	100.15	141.80	61.02	83.19	145.87
55	68536.62	137.85	103.00	101.20	99.81	169.28	72.85	89.97	164.45
56	0	0	101.23	99.31	98.59	130.11	56.02	70.04	127.21
57	16067.90	32.39	97.03	95.20	94.29	50.28	21.67	74.31	96.22
58	24264.50	48.76	97.56	95.69	94.79	52.25	22.51	75.85	98.64
59	40542.63	81.48	98.44	96.63	95.51	58.72	25.29	79.20	104.26
60	51540.00	103.57	97.87	95.87	94.84	70.72	30.47	77.80	121.25
61	67414.00	135.43	96.32	94.30	93.03	103.67	44.67	88.01	134.15
62	31469.00	63.19	93.53	91.62	90.50	49.90	21.51	75.29	97.46
63	36416.00	73.15	95.92	97.08	92.89	52.21	22.50	76.20	99.34

TABLE IV (contd.)

RESULTS OBTAINED FROM LOOP MEASUREMENTS DURING SINGLE-PHASE FLOW PUMP TESTS

Test	Flow Rate		Temperature (°F)			Pump $\Delta P^{[a]}$		Pressure (psia)	
	(lb/hr)	(gpm)	At Flow Venturi	At Pump Inlet	At Pump Outlet	(ft of Inlet Fluid)	(psid)	Pump Inlet	Pump Outlet
64	38898.00	78.17	97.65	95.78	94.79	55.79	24.03	77.24	101.90
65	27980.00	56.23	98.18	96.32	95.38	50.85	21.90	75.15	97.19
66	45046.00	90.54	98.93	97.08	96.06	62.04	26.72	80.25	106.90
67	0	0	99.28	97.21	95.97	44.67	19.24	69.35	89.00
68	0	0	98.27	95.56	94.20	10.30	4.44	68.50	72.43
69	20615.00	44.41	95.35	93.54	92.76	13.57	5.85	73.61	78.94
70	25591.00	51.42	97.16	95.42	94.47	16.15	6.96	74.73	81.10
71	34721.00	69.80	99.15	97.35	96.42	24.63	10.61	78.08	88.10
72	50614.00	101.74	99.55	97.57	96.46	50.78	21.87	84.24	106.34
73	69772.00	140.17	96.63	97.57	93.25	94.21	40.60	94.37	136.58
74	55109.00	110.67	94.11	92.11	90.68	110.81	47.77	90.39	140.04
75	20981.00	42.14	94.68	92.96	92.17	18.13	7.81	74.94	82.35
76	34689.00	69.70	96.76	95.15	94.25	30.14	12.99	81.44	99.20
77	50728.00	101.94	98.40	96.18	95.11	48.50	20.89	90.88	111.33
78	50917.00	102.13	85.04	82.75	81.37	42.35	18.28	77.25	96.49
79	44678.00	89.63	98.80	84.23	83.08	30.64	13.22	82.28	95.52
80	33414.00	67.06	89.24	87.71	86.29	16.74	7.22	74.38	81.79
81	46843.00	94.05	91.89	90.00	89.00	35.22	15.19	84.24	99.75
82	51822.00	104.08	94.15	92.33	91.36	45.16	19.47	89.48	109.53
83	56521.00	113.54	95.78	93.94	92.80	69.18	23.40	89.69	113.97
84	60914.00	122.40	97.25	95.47	94.38	67.95	29.28	95.28	114.79

TABLE IV (contd.)

RESULTS OBTAINED FROM LOOP MEASUREMENTS DURING SINGLE-PHASE FLOW PUMP TESTS

Test	Flow Rate		Temperature (°F)			Pump $\Delta P^{[a]}$		Pressure (psia)	
	(lb/hr)	(gpm)	At Flow Venturi	At Pump Inlet	At Pump Outlet	(ft of Inlet Fluid)	(psid)	Pump Inlet	Pump Outlet
85	68371.00	137.38	97.51	95.56	94.34	98.67	42.51	103.67	148.16
86	11585.00	23.27	95.79	93.94	93.12	3.98	1.71	71.65	73.05
87	31789.00	63.86	96.19	94.30	93.25	16.70	7.19	72.21	79.30
88	38205.00	76.76	96.45	94.62	93.44	23.38	10.07	74.45	84.63
89	50115.00	100.71	98.22	96.23	95.33	42.43	18.28	82.28	101.48
90	59088.00	118.77	99.50	97.61	96.55	62.87	27.07	88.85	117.43
91	0	0	100.26	98.11	96.69	8.20	3.53	70.60	74.30
92	0	0	98.80	97.21	95.70	1.30	.56	70.88	71.11
93	16593.00	33.27	80.97	79.00	77.66	47.43	20.48	78.78	21.98
94	24294.00	48.81	96.98	95.06	94.11	55.80	24.04	85.63	109.95
95	41192.00	82.75	96.00	94.03	92.80	75.52	32.55	94.02	127.35
96	51362.00	103.12	92.56	90.75	89.14	92.58	39.92	98.22	139.63
97	68014.00	136.41	84.38	82.87	80.69	126.10	54.40	119.05	172.64
98	0	0	84.55	82.57	81.23	35.07	15.14	69.14	84.01
99	0	0	83.35	81.32	80.10	66.30	28.63	70.00	99.00
100	14545.00	29.20	90.43	89.15	87.78	116.70	50.32	87.31	139.14
101	25274.00	50.75	93.62	91.84	90.45	134.80	58.11	86.75	145.73
102	41228.00	82.81	95.30	93.54	92.21	164.91	71.07	96.82	170.63
103	54877.00	110.24	95.79	93.90	92.62	193.20	83.26	100.94	187.06
104	68335.00	137.08	98.53	84.45	82.93	222.65	95.80	113.90	213.10
105	0	0	98.35	95.82	95.06	100.25	43.19	67.04	111.47

TABLE IV (contd.)

RESULTS OBTAINED FROM LOOP MEASUREMENTS DURING SINGLE-PHASE FLOW PUMP TESTS

Test	Flow Rate		Temperature (°F)			Pump $\Delta P^{[a]}$		Pressure (psia)	
	(lb/hr)	(gpm)	At Flow Venturi	At Pump Inlet	At Pump Outlet	(ft of Inlet Fluid)	(psid)	Pump Inlet	Pump Outlet
106	23126.00	46.48	99.50	96.99	95.65	93.92	40.45	83.40	124.65
107	43237.00	86.83	94.46	92.15	90.72	124.33	53.59	95.07	149.68
108	55874.00	112.13	89.86	87.68	86.16	147.13	63.46	101.71	165.84
109	69820.00	140.09	87.96	85.80	84.39	176.72	76.24	110.80	189.56
110	22579.40	45.26	77.34	75.81	74.13	1.98	.85	72.84	71.74
111	35035.70	70.26	82.43	80.56	79.20	7.52	3.25	83.54	79.99
112	51048.10	102.39	85.12	83.29	81.95	23.26	10.04	101.43	89.21
113	70257.70	140.99	88.58	86.74	85.57	47.41	20.45	105.91	83.59
114	0	0	89.46	87.63	86.20	7.61	3.28	68.57	70.33
114	0	0	96.05	94.12	92.71	8.20	3.53	68.58	71.30
115	17456.20	35.06	94.90	93.18	91.76	26.48	11.41	61.44	72.01
116	0	0	97.29	95.42	94.25	34.94	15.06	57.11	72.36
117	0	0	94.64	92.65	91.45	66.29	28.57	41.52	70.48
118	0	0	95.04	92.73	91.85	100.45	43.30	25.44	69.38
119	24790.20	49.81	97.29	95.69	94.43	20.54	8.85	64.31	72.98
120	12368.80	24.86	99.64	100.44	96.24	59.48	25.60	45.09	71.32
121	24045.40	48.36	102.38	100.70	99.67	48.90	21.05	51.10	71.80
122	33191.60	66.72	99.99	97.93	97.00	39.68	17.09	53.13	70.21
123	43420.00	87.28	99.59	97.66	96.64	26.26	11.31	61.24	72.29
124	56515.30	113.59	98.75	96.67	95.79	5.83	2.51	72.21	74.30
125	14088.70	28.31	97.96	94.97	94.70	90.25	38.88	31.11	70.00

TABLE IV (contd.)

RESULTS OBTAINED FROM LOOP MEASUREMENTS DURING SINGLE-PHASE FLOW PUMP TESTS

Test	Flow Rate		Temperature (°F)			Pump $\Delta P^{[a]}$		Pressure (psia)	
	(lb/hr)	(gpm)	At Flow Venturi	At Pump Inlet	At Pump Outlet	(ft of Inlet Fluid)	(psid)	Pump Inlet	Pump Outlet
126	26769.20	53.78	96.58	94.12	93.53	77.10	33.22	38.24	70.83
127	41084.10	82.54	96.67	94.30	93.57	59.72	25.73	45.86	71.67
128	55516.10	111.54	96.98	94.62	93.93	34.44	14.84	58.93	74.30
129	62506.50	125.59	97.29	94.88	94.20	21.97	9.47	66.41	76.11
130	68969.70	138.59	97.56	95.55	94.52	10.49	4.52	72.98	77.00
131	63150.00	126.90	97.87	95.69	94.84	3.09	1.33	78.50	75.27
132	70175.30	141.02	97.91	95.73	94.93	16.34	7.04	84.59	75.69
133	41667.90	83.71	96.36	94.48	93.30	3.07	1.32	71.02	70.76
134	51848.30	104.17	96.50	94.61	93.48	8.42	3.63	78.99	73.88
135	67746.80	136.10	96.50	94.44	93.44	33.72	14.53	92.27	76.38
136	74447.90	149.55	95.66	93.76	92.53	49.09	21.16	100.03	77.77
137	100432.60	201.61	91.41	89.29	88.01	96.92	41.80	129.18	85.95
138	100169.00	201.11	92.43	90.45	89.19	96.83	41.75	122.61	79.71
139	92309.00	185.43	95.92	93.90	92.71	65.34	28.16	105.35	75.27
140	104708.00	210.48	99.73	97.70	96.55	100.95	43.47	126.45	80.20
141	134198.00	269.66	96.69	95.24	94.57	170.45	73.44	167.07	89.00
142	80137.00	160.92	93.22	90.94	90.13	7.10	3.02	77.25	72.92
143	75394.00	151.37	92.43	90.18	89.23	19.50	8.41	84.24	72.36
144	94311.00	189.36	92.87	90.54	89.64	61.47	26.51	108.42	78.53
145	113323.00	227.57	93.62	91.35	90.50	110.52	47.65	138.10	87.41
146	122681.00	246.31	92.25	90.09	88.96	122.58	52.86	141.91	85.47

TABLE IV (contd.)

RESULTS OBTAINED FROM LOOP MEASUREMENTS DURING SINGLE-PHASE FLOW PUMP TESTS

Test	Flow Rate		Temperature (°F)			Pump $\Delta P^{[a]}$		Pressure (psia)	
	(lb/hr)	(gpm)	At Flow Venturi	At Pump Inlet	At Pump Outlet	(ft of Inlet Fluid)	(psid)	Pump Inlet	Pump Outlet
147	81107.70	162.59	77.43	75.50	73.82	245.61	106.10	88.43	195.94
148	104855.00	210.23	80.57	78.50	76.85	322.88	139.40	86.40	229.50
149	92173.00	184.84	82.74	80.74	79.29	231.84	100.10	82.35	185.26
150	80510.00	161.47	83.84	81.86	80.46	143.14	61.80	76.76	140.32
151	96303.00	193.17	84.86	82.88	81.50	238.40	102.90	84.52	190.60
152	106183.00	213.00	86.23	84.32	82.81	330.30	142.53	89.27	236.78
153	100733.00	202.05	84.90	82.97	81.50	181.53	78.35	84.23	165.50
154	88225.00	177.00	86.45	84.50	83.13	154.84	66.82	81.16	148.92
155	105685.00	212.06	88.18	86.24	84.71	218.76	94.38	88.01	185.54
156	134785.00	270.49	89.37	87.41	85.66	350.36	151.13	96.75	252.73
157	80922.00	162.40	90.04	88.12	86.61	182.28	78.62	78.85	158.98
158	112383.00	225.60	92.03	90.10	88.37	281.70	121.46	89.69	214.73
159	0	0	93.71	91.39	90.54	182.07	78.49	73.54	153.78
160	0	0	97.78	95.60	94.79	223.62	96.34	72.35	176.60

[a] All pump pressure drops are listed as positive numbers, the correct sign can be determined from the inlet and discharge absolute pressure.

The loop ΔP measurement includes the frictional losses due to a 17-foot equivalent length of pipe, plus the losses across the turbine flowmeter. The difference in the theoretical differential pressure reading as a function of single-phase flow rate for these extra losses is plotted in Figure 15. Depending on the flow direction and whether a head rise or head loss occurs across the pump, a certain value, obtained from Figure 15 for a given flow, must be added to, or subtracted from, the loop ΔP reading.

The locations of the pressure transducers for both the test section and loop were such that the elevation head of the ΔP sensing lines need not be considered for a liquid full system.

With consideration of the extra losses for the loop measurement, the majority of the ΔP data are in agreement to within $\pm 5\%$ of reading.

1.4 Density

The fluid density, established for the single-phase flow tests, is based on the measured fluid temperature and pressure and the corresponding specific volume stated in the ASME steam tables^[3]. The gamma attenuation density detectors were used for the single-phase flow tests primarily for system checkout in preparation for use during the two-phase flow tests. The output from the detectors (one at the pump suction and one at the pump discharge) was checked throughout the single-phase flow tests to determine linearity and equivalent density drift of the detectors. Data obtained indicate a drift of less than 0.5 lb/ft^3 and a noise band of approximately 0.1 lb/ft^3 as typical values.

1.5 Shaft Torque

Pump shaft torque was measured directly using a LEBOW 1100 series inline torque sensor. Prior to the single-phase flow tests, measurements were made of the breakaway torque, pump frictional torque, and frictional torque of the jack shaft and pulley assembly. The average of several breakaway torque measurements was about 49 in.-lb. To measure frictional torque of the pump, the jack shaft and pulley assembly were disconnected at the outboard flexible coupling (Figure 2). The average of several readings was 38.8 in.-lb. The same procedure was followed for the jack shaft and pulley assembly by disconnecting the inboard flexible coupling; the average of several measurements was 10 in.-lb.

1.6 Fluid Temperature

Fluid temperature measurements, with an accuracy to within $\pm 6^\circ\text{F}$, were obtained with Chromel-Alumel thermocouples.

1.7 Fluid Pressure

Fluid pressure measurements, with an accuracy to within $\pm 15 \text{ psig}$, were made using strain gage type pressure transducers.

Fig. 15 Single-phase differential pressure tap reading difference due to different tap locations.

2. TWO-PHASE DATA

Because of the large number of test variables (flow, direction of flow, speed, direction of rotation, system pressure, and void fraction) for the two-phase flow pump tests, test conditions were chosen which would produce two-phase data at the speed and flow conditions for which the majority of data were obtained during the single-phase tests. Pertinent data obtained from the two-phase tests are included in Table V for the test section and Table VI for the loop.

This section presents separate discussions of the various types of data with respect to consistency and identifies probable causes for differences between the results obtained from test section and loop measurements. A primary consideration is that comparison is generally between measured (test section) and calculated (loop) variables. The loop data (flow, head, density, and void fraction) were calculated from the primary measurement of mass flow rate and the local thermodynamic conditions, together with the results of heat loss experiments performed on the piping. The measurement of total mass flow rate is considered to be a reasonably accurate primary measurement because the steam and water flows were metered separately prior to mixing. Maximum errors in these measurements are defined in Section IV.

2.1 Fluid Density

The difference between the measured and calculated fluid densities is the basis for the majority of the differences in the data in Tables V and VI. The local average density at the test section was measured by use of the gamma attenuation technique which is discussed in Section IV.

To allow for compensation of the long-term drift of the detectors during the two-phase flow tests, pretest and posttest calibrations for each of the density measurement systems were performed each test day. A description of the calibration procedure and the data reduction methods is given in Section IV.

For the majority of the data, the measurements in the test section indicate a higher density at the test section than the homogeneous calculations of density at the test section based on loop measurements. This difference suggests that significant slip occurs between the two phases of the fluid during transit from the mixing location to the pump test section. For the greater flow rates (greater than about $\pm 35,000$ to $40,000$ lb/hr), the situation is reversed with the measured density being lower than the calculated density thus indicating that more phase separation may have occurred due to higher two-phase pressure gradients existing at the greater flows.

2.2 Void Fraction

The void fraction calculations reflect the differences in the measured and calculated densities which were discussed previously. Both void fractions listed for a given test in

TABLE V

RESULTS OBTAINED FROM TEST SECTION MEASUREMENTS DURING TWO-PHASE FLOW PUMP TESTS

Test	Nominal System Pressure (psia)	Pump Impeller Speed (rpm)	Flow Rate		Head		Density (lb/ft3)		Void Fraction ^[e]		Torque ^[f]	Temperature (°F)		Pressure (psig)	
			Test Section	Loop	(psid) ^[b]	(ft of fluid) ^[c]	Pump inlet ^[d]	Pump outlet ^[d]	Pump inlet ^[d]	Pump outlet ^[d]	(in./lb)	Pump inlet ^[d]	Pump outlet ^[d]	Pump inlet ^[d]	Pump outlet ^[d]
			(gpm) ^[a]	(lb/hr)											
001	900	0													
002	900	0													
003	900	0	207.1	60467	-23.3	-92.1	36.4	16.73	0.241	0.675	-3.67	527.6	525.8	910.9	881.3
004	900	0	228.1	58723	-23.5	-105.4	32.1	14.3	0.336	0.728	-4.37	527.5	525.8	914.9	877.2
005	900	2500	369.7	75302	-41.5	-235.3	25.4	9.52	0.483	0.832	112.6	527.6	521.8	905.9	846.9
006	900	2800	375.9	85614	-45.6	-231.0	28.4	13.5	0.419	0.746	120.9	525.8	522.3	902.9	844.8
007	900	2590	359.2	97086	-43.0	-183.9	33.7	21.2	0.300	0.577	137.26	528.9	523.6	917.9	864.6
008	900	1590	323.5	65121	-32.4	-185.9	25.1	16.5	0.490	0.680	71.2	527.2	524.0	895.9	854.2
009	900	1700	304.9	82157	-38.5	-164.9	33.6	24.8	0.303	0.498	78.2	527.1	523.2	896.9	848.0
010	900	1700	233.4	60084	-16.2	-72.7	32.1	30.2	0.336	0.379	76.7	527.1	525.8	900.9	877.2
011	900	1700	---	58193	-15.2	---	---	---	---	---	76.7	527.1	525.8	892.9	876.1
012	500	0	289.0	64193	-54.7	-284.2	27.7	10.2	0.464	0.316	-5.96	462.8	453.6	504.8	440.1
013	500	0	256.9	64899	-48.6	-222.1	31.5	11.3	0.387	0.794	-5.96	463.7	454.9	506.5	447.4
014	500	0	246.9	64350	-43.5	-192.9	32.5	13.5	0.367	0.751	-5.96	463.7	454.9	510.5	452.7
015	500	0	209.6	64871	-41.5	-154.8	38.6	14.6	0.245	0.728	-5.86	463.7	463.2	502.5	453.7
016	500	2690	291.7	78128	-76.4	-329.5	33.4	8.74	0.349	0.845	131.6	464.1	449.2	509.5	417.2
017	500	2670	338.6	78737	-81.0	-402.1	29.0	8.3	0.438	0.854	132.6	463.7	448.3	506.5	415.1
018															
019															
020															
021															
022															
023															
024															
025															
026															
027															
028	900	0	65.3	6496	-0.82	-9.58	0.769	0.672	12.4	16.8	-1.40	527.1	528.8	903.0	902.0
029	900	2700	64.5	6980	1.91	20.4	0.745	0.655	13.5	17.6	87.9	527.1	529.3	906.9	901.2

loop heat loss tests

TABLE V (contd.)

RESULTS OBTAINED FROM TEST SECTION MEASUREMENTS DURING TWO-PHASE FLOW PUMP TESTS

Test	Nominal System Pressure (psia)	Pump Impeller Speed (rpm)	Flow Rate		Head		Density (lb/ft ³)		Void Fraction [e]		Torque [f]	Temperature (°F)		Pressure (psig)	
			Test Section	Loop	(ft of fluid) [c]	Pump inlet [d]	Pump outlet [d]	Pump inlet [d]	Pump outlet [d]	(in./lb)	Pump inlet [d]	Pump outlet [d]	Pump inlet [d]	Pump outlet [d]	
			(gpm) [a]	(lb/hr)											(psid) [b]
030	900	1606	61.1	6760	0.29	3.02	13.8	12.5	0.739	0.767	76.8	527.1	528.8	900.9	899.1
031	900	1609	50.7	5819	0.80	8.0	14.3	29.5	0.728	0.394	75.8	527.1	528.4	902.9	899.0
032	900	1613	8.4	3184	15.7	47.8	47.2	47.35	0.009	0.020	93.5	524.9	511.7	904.9	914.7
033	900	1603	14.5	3290	1.71	8.68	28.3	46.8	0.421	0.015	87.5	525.3	525.3	898.9	898.0
034	500	0	56.8	6148	-1.45	-15.2	13.5	17.0	0.750	0.680	-1.35	461.9	462.8	493.5	490.2
035	500	1591	60.8	6531	-0.41	-4.45	13.4	18.6	0.752	0.648	61.4	462.4	463.7	501.5	491.3
036	200	0	58.8	5659	-1.71	-20.6	12.0	22.56	0.786	0.496	5.1	382.6	382.6	203.9	196.1
037	200	1597	11.9	5226	16.2	42.5	54.8	54.2	0.000	0.014	78.2	371.6	366.3	194.2	200.0
038	200	1599	12.0	5238	16.3	43.0	54.6	54.3	0.002	0.010	76.7	374.2	368.9	199.2	206.5
039	200	1590	12.0	5242	16.3	43.0	54.5	54.4	0.004	0.008	78.2	374.2	368.9	197.2	206.5
040	500	0	74.0	30209	-1.5	-41.8	50.9	47.1	0.001	0.078	-1.85	460.1	459.3	503.5	488.1
041	500	2693	74.7	28941	38.1	113.3	48.3	53.5	0.053	-0.051	171.7	460.6	460.2	492.5	537.1
042	500	0	70.9	29063	0.02	0.06	51.1	52.95	-0.002	-0.037	0	459.2	459.0	504.5	499.6
043	500	0	85.2	29021	-0.98	-3.31	42.5	42.85	0.170	0.163	0	459.3	461.5	502.5	497.5
044	500	2699	77.0	28277	37.6	118.8	45.8	51.1	0.102	-0.004	169.4	461.9	462.3	511.5	550.7
045	500	1602	84.8	29026	12.5	42.2	42.7	50.8	0.164	0.002	97.7	461.0	462.4	505.0	514.2
046	500	0	121.7	16194	-6.5	-56.4	16.6	11.7	0.687	0.786	-3.25	463.7	463.2	506.5	495.4
047	500	0	113.8	18076	-5.6	-40.7	19.8	16.6	0.623	0.687	-3.25	461.9	461.9	501.5	491.2
048	500	1593	110.5	14175	-3.1	-27.4	16.0	9.78	0.699	0.825	68.5	461.9	462.4	503.5	496.5
049	500	2700	110.1	17654	-1.1	-7.93	20.0	18.25	0.619	0.654	83.5	461.9	462.8	505.5	498.5
050	500	2700	100.7	12359	-0.4	-3.75	15.3	15.31	0.714	0.713	83.5	461.5	462.8	504.5	498.5
051	500	2700	65.0	10417	-1.3	-9.24	19.6	15.2	0.628	0.716	77.5	462.4	463.7	505.5	501.7
052	500	1604	58.2	5465	0.7	8.67	11.7	40.25	0.786	0.213	64.5	463.2	462.8	506.5	504.8
053	500	2700	179.0	24835	-10.4	-86.7	17.3	9.28	0.673	0.834	84.5	463.2	461.9	508.5	493.3
054	500	1605	172.0	29657	-11.8	-78.7	21.5	13.7	0.588	0.746	66.5	462.8	460.2	503.5	487.1
055	500	0	303.1	30626	-27.9	-319.2	12.6	7.39	0.767	0.872	-11.16	466.8	459.3	511.5	478.2
056															
057	200	2710	120.8	18795	-1.07	-7.9	test aborted		0.649	0.873	80.0	380.2	380.4	205.2	199.2

TABLE V (contd.)

RESULTS OBTAINED FROM TEST SECTION MEASUREMENTS DURING TWO-PHASE FLOW PUMP TESTS

Test	Nominal System Pressure (psia)	Pump Impeller Speed (rpm)	Flow Rate		Head		Density (lb/ft ³)		Void Fraction ^[e]		Torque ^[f]	Temperature (°F)		Pressure (psig)	
			Test Section	Loop	(psid) ^[b]	(ft of fluid) ^[c]	Pump inlet[d]	Pump outlet[d]	Pump inlet[d]	Pump outlet[d]	(in./lb)	Pump inlet[d]	Pump outlet[d]	Pump inlet[d]	Pump outlet[d]
			(gpm) ^[a]	(lb/hr)											
058	200	2713	121.8	16212	-2.05	-17.8	16.6	5.2	0.701	0.912	76.8	380.1	380.3	205.2	199.2
059	200	0	122.2	16264	-5.1	-43.8	16.6	3.86	0.700	0.936	-6.97	381.3	380.4	208.2	200.3
060	200	1604	118.4	14433	-2.21	-20.9	15.2	2.27	0.727	0.966	60.9	379.7	380.0	206.2	199.2
061	200	2680	79.3	10680	0.62	5.3	16.8	19.25	0.697	0.652	73.9	378.7	380.0	200.6	197.1
062	200	2690	76.1	6470	-0.36	-4.9	10.6	0.8	0.812	0.993	68.3	379.1	379.6	198.2	196.1
063	200	0	103.1	6450	-0.75	-13.8	7.8	3.38	0.864	0.945	-4.65	379.6	380.9	199.2	198.2
064	200	2690	161.3	25099	-9.6	-71.2	19.4	---	0.649	---	84.6	378.7	376.0	196.2	183.6
065	200	0	63.4	27321	-2.51	-6.7	53.7	36.8	0.015	0.327	---	379.6	380.0	205.2	201.5
066	200	1600	56.6	24528	16.6	44.3	54.0	34.7	0.010	0.366	99.6	378.7	378.2	203.9	218.2
067	200	1600	73.3	24632	14.6	50.3	41.9	34.2	0.234	0.376	99.6	377.8	379.6	190.2	202.3
068	200	0	59.1	24581	-2.3	-6.3	51.9	34.3	0.049	0.374	---	377.1	377.1	190.2	186.7
069	900	1590	213.8	29490	-11.5	-96.6	17.2	11.7	0.665	0.785	86.6	526.7	526.2	903.9	884.5
070	900	0	343.5	30848	-27.0	-346.3	11.24	6.28	0.796	0.903	---	526.7	524.0	---	866.7
071	900	2697	220.0	25046	-10.25	-104	14.2	8.5	0.730	0.855	101.9	525.4	525.4	905.9	890.7
072	900	1603	127.9	19993	-4.5	-33.2	19.5	15.3	0.614	0.706	80.5	524.0	524.4	889.9	881.3
073	900	2698	106.2	16950	0.5	3.66	19.9	21.6	0.605	0.565	95.4	525.8	526.7	898.9	899.1
074	900	0	121.4	15965	-6.0	-52.6	16.4	12.3	0.682	0.771	0	525.4	525.4	890.9	883.4
075	900	0	64.9	24091	-1.94	-6.03	46.3	45.9	0.027	0.039	6.98	524.0	522.3	899.9	895.9
076	900	0	60.8	21762	-1.67	-5.4	44.7	46.1	0.062	0.031	---	526.7	525.4	900.9	899.1
077	900	1608	74.5	22099	0.92	3.58	36.96	37.7	0.299	0.213	83.75	527.1	528.0	907.9	903.2
078	900	2701	70.9	21769	2.89	10.9	38.3	38.6	0.200	0.193	100.04	527.1	528.4	910.9	910.5
079	900	2699	71.5	26647	42.6	131.8	46.5	46.7	0.022	0.019	167.97	524.9	524.4	905.9	948.1
080	900	1599	66.8	25873	14.1	42.1	48.3	46.9	-0.015	-0.050	107.02	523.6	522.7	909.9	919.9
081	900	1604	112.0	29463	-1.14	-5.0	32.8	32.4	0.322	0.329	83.75	526.2	529.3	904.9	902.2
082	900	1599	90.3	9779	-0.18	-1.9	13.5	14.5	0.746	0.725	73.52	526.2	526.1	902.9	906.4
083	900	2701	68.8	10035	1.97	15.6	18.2	16.0	0.642	0.689	88.40	525.4	527.1	899.9	902.2
084	900	1601	35.1	13427	15.3	46.3	47.7	47.9	0.003	0.003	96.78	519.2	517.0	900.9	918.9
085	900	1599	113.6	36178	4.37	15.9	39.7	45.2	0.170	0.049	112.60	526.2	528.0	915.9	916.8
086	900	2696	124.8	39126	7.8	28.6	39.1	44.3	0.183	0.067	144.24	526.2	528.0	---	917.8

TABLE V (contd.)

RESULTS OBTAINED FROM TEST SECTION MEASUREMENTS DURING TWO-PHASE FLOW PUMP TESTS

Test	Nominal System Pressure (psia)	Pump Impeller Speed (rpm)	Flow Rate		Head		Density (lb/ft ³)		Void Fraction ^[e]		Torque ^[f] (in.-lb)	Temperature (°F)		Pressure (psig)	
			Test Section	Loop											
			(gpm) ^[a]	(lb/hr)	(psid) ^[b]	(ft of fluid) ^[c]	Pump inlet ^[d]	Pump outlet ^[d]	Pump inlet ^[d]	Pump outlet ^[d]		Pump inlet ^[d]	Pump outlet ^[d]	Pump inlet ^[d]	Pump outlet ^[d]
087	900	2700	130.3	36253	-2.78	-13.0	30.7	27.5	0.369	0.439	107.48	524.9	525.8	908.9	905.3
088	900	2700	145.2	40995	0.29	1.2	35.2	34.2	0.267	0.290	121.91	527.6	528.9	921.9	921.0
089	900	2700	156.9	46435	3.36	13.1	36.9	39.3	0.233	0.179	139.59	525.4	526.7	905.9	908.5
090	900	1598	162.1	40945	-7.6	-34.8	31.5	26.9	0.352	0.449	87.46	525.3	526.2	910.9	900.1
091	900	2703	233.9	34888	-14.0	-108.6	18.6	11.75	0.634	0.789	107.95	525.3	524.9	909.9	895.9
092	500	2699	272.5	33654	-20.0	-182.5	15.38	7.85	0.711	0.863	89.80	464.5	460.6	517.5	493.3
093	500	1600	257.8	56852	-30.7	-161.0	27.5	15.6	0.468	0.710	84.68	462.8	456.6	510.5	472.5
094	500	1600	235.7	57469	-28.3	-133.9	30.4	18.3	0.411	0.655	79.57	461.5	455.8	502.5	472.5
095	500	1600	197.5	44991	-17.7	-89.7	28.4	17.0	0.452	0.681	75.38	461.5	458.4	508.5	482.9
096	500	2708	191.2	49369	-12.3	-54.9	32.2	22.4	0.375	0.572	111.67	461.5	458.4	507.5	490.2
097	500	2703	188.5	48984	-13.0	-57.8	32.4	22.3	0.371	0.574	110.74	461.5	458.4	507.5	490.2
098	500	2699	162.7	43715	-9.5	-40.9	33.45	22.25	0.349	0.575	106.09	461.5	459.7	507.5	493.3
099	500	2695	154.5	43387	-6.5	-26.6	35.0	25.8	0.319	0.503	107.02	461.9	461.5	508.5	495.4
100	500	2700	159.1	38782	-8.2	-38.8	30.4	20.1	0.410	0.619	95.57	462.4	461.0	512.5	497.5
101	200	2691	96.9	30545	42.1	154.0	39.3	54.6	0.281	-0.002	167.51	378.2	379.6	202.2	239.9
102	200	2703	70.2	30836	49.1	128.9	55.0	54.6	-0.006	-0.002	172.16	379.1	378.7	213.2	259.7
103	200	2703	86.8	31381	48.6	154.9	45.1	54.5	0.175	0.001	173.52	377.4	377.8	200.2	244.1
104	200	2706	135.7	45283	25.0	86.6	41.6	54.6	0.239	-0.002	167.51	378.7	379.6	202.2	223.2
105	200	1600	140.0	48576	-11.9	-39.7	43.25	22.1	0.208	0.600	76.77	380.0	375.6	205.2	188.8
106	200	2700	213.8	37037	-20.1	-134.0	21.6	9.83	0.608	0.826	93.99	381.3	373.8	209.2	186.7
107	200	2703	215.0	36772	-20.0	-135.3	21.3	9.79	0.614	0.827	92.59	380.0	372.5	205.2	180.4
108	200	2686	167.2	54291	3.2	11.6	40.5	50.1	0.259	0.081	134.94	378.6	379.6	200.2	200.3
109	200	2714	167.9	54521	4.2	14.8	40.5	53.7	0.260	0.014	139.59	377.4	379.6	200.2	198.2
110	500	2690	233.5	83883	28.6	92.1	44.8	51.1	0.123	-0.006	234.05	461.0	463.7	504.5	524.6
111	500	2685	202.6	83693	30.4	85.1	51.5	51.5	-0.007	-0.012	234.51	457.5	461.9	489.5	514.2
112	500	2700	218.7	83489	31.4	95.1	47.6	50.9	0.068	0.001	238.2	459.7	460.7	500.5	527.8
113	500	2708	204.2	84499	31.3	87.6	51.6	51.6	-0.001	-0.002	239.6	448.7	448.7	500.5	526.7
114	500	2732	240.9	84023	21.5	71.3	43.5	50.2	0.149	0.013	221.0	460.6	462.8	498.5	520.5
115	500	2700	235.8	82451	17.5	57.9	43.6	49.4	0.145	0.027	207.1	462.4	464.6	494.5	511.1
116	500	2700	265.2	91650	10.0	33.4	43.1	49.0	0.155	0.035	228.0	462.4	464.6	498.5	502.7

TABLE V (contd.)

RESULTS OBTAINED FROM TEST SECTION MEASUREMENTS DURING TWO-PHASE FLOW PUMP TESTS

Test	Nominal System Pressure (psia)	Pump Impeller Speed (rpm)	Flow Rate		Head		Density (lb/ft ³)		Void Fraction ^[e]		Torque ^[f]	Temperature (°F)		Pressure (psig)	
			Test Section	Lcop	(psid) ^[b]	(ft of fluid) ^[c]	Pump inlet ^[d]	Pump outlet ^[d]	Pump inlet ^[d]	Pump outlet ^[d]	(in./lb)	Pump inlet ^[d]	Pump outlet ^[d]	Pump inlet ^[d]	Pump outlet ^[d]
			(gpm) ^[a]	(lb/hr)											
117	500	2795	266.4	90157	6.5	22.2	42.2	46.7	0.175	0.082	214.0	461.9	463.2	498.5	502.7
118	500	2748	269.7	89743	-5.0	-17.3	41.5	36.9	0.189	0.280	195.4	461.9	462.4	499.5	489.2
119	500	2694	304.9	104399	-3.65	-12.3	42.7	39.0	0.165	0.239	223.3	460.6	460.6	496.5	487.1
120	500	2673	302.8	103343	-3.95	-13.3	42.8	39.4	0.163	0.231	221.0	460.6	460.6	496.5	487.1
121	500	2707	298.7	103237	-7.0	-23.4	43.1	34.2	0.157	0.335	221.0	461.0	461.0	500.5	487.1
122	500	2694	125.4	51901	42.0	123.9	48.8	50.1	0.050	0.023	202.87	453.1	453.6	505.5	549.7
123	500	2697	146.3	52201	40.0	129.5	44.5	51.9	0.129	-0.023	197.75	461.5	464.1	498.5	534.0
124	500	2707	153.6	49285	6.0	21.6	40.0	47.6	0.215	0.062	144.24	464.1	466.3	514.5	519.4
125	500	1598	122.1	49943	10.0	28.1	51.0	52.2	0.003	-0.022	115.39	456.6	457.1	502.5	510.0
126	500	1603	139.2	49344	6.0	19.6	44.2	50.8	0.135	0.000	114.93	461.5	463.2	500.5	501.7
127	500	1590	140.8	48764	2.92	9.74	43.2	49.7	0.155	0.022	101.44	461.5	463.2	500.5	498.6
128	500	1601	79.9	32691	13.4	37.8	51.0	52.0	0.006	-0.016	106.55	454.0	454.9	497.5	509.0
129	500	1590	97.4	32584	10.23	35.25	41.8	50.8	0.185	-0.001	107.02	460.6	461.9	495.5	502.7
130	500	1608	94.9	31826	1.75	6.0	41.7	50.9	0.183	0.001	86.08	460.6	462.4	495.5	493.3
131	900	2689	197.6	74970	29.0	88.5	47.25	48.3	0.019	-0.003	236.37	513.9	515.2	903.9	928.2
132	900	2685	220.6	74124	26.6	91.6	41.3	47.4	0.123	-0.002	232.65	524.9	528.4	895.9	918.9
133	900	2700	237.9	72113	11.3	42.9	37.8	42.6	0.213	0.106	200.08	525.4	528.0	899.9	908.5
134	900	2690	138.6	52249	38.0	116.4	47.0	47.7	0.011	-0.002	206.59	523.2	523.2	901.9	936.7
135	900	2699	163.6	53511	34.4	121.7	40.8	47.4	0.147	-0.003	208.92	525.9	529.3	899.9	930.4
136	900	2700	171.8	52752	17.5	65.9	38.3	45.9	0.202	0.030	189.84	525.4	528.9	899.9	917.8
137	900	1602	91.2	34609	12.9	39.1	47.3	48.0	0.014	0.045	115.39	516.6	516.1	899.9	909.5
138	900	1607	117.4	31071	-3.58	-15.6	33.0	31.6	0.318	0.347	89.34	525.4	527.1	902.9	899.1
139	900	1604	85.3	27371	5.12	18.5	40.0	44.9	0.167	0.055	100.50	525.4	527.1	899.9	901.2
140	900	1602	87.7	28937	10.8	37.4	41.4	47.3	0.134	0.003	115.86	524.5	527.1	892.9	899.1
141	900	1605	108.8	34717	8.8	31.7	39.8	46.2	0.170	0.026	111.67	524.5	527.1	892.9	901.2
142	900	1603	108.6	34405	5.0	18.2	39.5	45.2	0.175	0.049	101.44	525.4	527.1	896.9	899.1
143	200	2706	-56.8	-23576	57.5	158.5	52.2	4.34	0.045	0.928	128.39	374.7	354.0	193.0	139.1
144	200	2705	-109.2	-19788	50.2	320.7	22.6	4.01	0.590	0.933	127.96	378.2	354.9	188.8	142.1
145	200	2705	-50.0	-12197	50.4	238.9	30.4	3.25	0.446	0.946	128.42	379.1	354.5	189.8	140.1

TABLE V (contd.)

RESULTS OBTAINED FROM TEST SECTION MEASUREMENTS DURING TWO-PHASE FLOW PUMP TESTS

Test	Nominal System Pressure (psia)	Pump Impeller Speed (rpm)	Flow Rate		Head		Density (lb/ft ³)		Void Fraction ^[e]		Torque ^[f] (in.-lb)	Temperature (°F)		Pressure (psig)	
			Test Section	Loop								Pump	Pump	Pump	Pump
			(gpm) ^[a]	(lb/hr)	(psic) ^[b]	(ft of fluid) ^[c]	Pump inlet ^[d]	Pump outlet ^[d]	Pump inlet ^[d]	Pump outlet ^[d]		inlet ^[d]	outlet ^[d]	inlet ^[d]	outlet ^[d]
146	200	2712	-43.2	-9836	51.8	262.3	28.4	3.27	0.483	0.946	129.35	379.5	354.5	190.9	141.1
147	200	2700	-29.0	-6382	53.1	279.1	27.4	3.12	0.502	0.949	128.89	376.9	353.1	185.7	135.1
148	200	2703	-56.6	-23874	57.1	156.1	52.63	5.12	0.036	0.902	127.03	377.4	351.4	186.7	133.1
149	200	0	-85.9	-17162	7.0	40.2	24.9	9.11	0.548	0.840	1.86	378.1	375.2	185.7	180.2
150	200	-1608	-51.5	-12235	17.3	84.3	29.6	7.62	0.461	0.867	-68.86	378.0	371.6	188.8	173.2
151	200	-1600	-30.3	-7132	16.3	79.6	29.4	12.3	0.464	0.781	-73.05	381.3	373.8	191.9	177.2
152	200	-1607	-17.3	-4066	15.2	74.8	29.3	24.2	0.466	0.558	-74.91	377.8	371.6	184.6	172.2
153	200	-1604	-16.2	-7168	16.4	42.8	55.3	54.4	-0.013	0.008	-72.12	375.6	370.3	184.6	168.2
154	200	-1602	-16.4	-6875	16.9	43.8	55.5	54.5	-0.014	0.007	-72.12	373.0	369.0	187.7	166.2
155	200	-1600	-39.8	-17615	19.9	51.8	52.2	15.1	-0.011	0.730	-64.68	376.0	369.9	182.5	165.2
156	200	-1603	-73.4	-24429	21.6	75.1	41.5	11.9	0.241	0.789	-56.30	379.1	369.0	181.5	161.2
157	500	-1607	-80.0	-28884	23.2	74.3	45.0	15.9	0.116	0.702	-58.63	464.1	458.4	495.7	473.5
158	500	-1603	-73.8	-22842	20.7	77.3	38.6	13.2	0.245	0.756	-55.61	464.1	459.3	498.6	479.5
159	500	-1600	-72.6	-16444	19.1	57.1	48.1	29.6	0.056	0.428	-73.05	462.4	458.8	497.5	478.5
160	500	-1594	-61.4	-12449	15.9	90.5	25.3	16.2	0.512	0.696	-69.80	464.1	459.7	492.5	479.5
161	500	-1597	-36.2	-7001	14.5	86.5	24.1	5.38	0.537	0.912	-79.10	464.1	460.1	502.7	488.5
162	500	-1600	-25.3	-3942	14.5	107.5	19.4	1.57	0.631	0.988	-87.48	464.1	460.1	502.7	488.5
163	500	-1603	-25.5	-6569	15.4	71.8	30.9	13.5	0.401	0.744	-79.10	461.1	452.9	516.3	503.5
164	500	0	-112.9	-16846	10.0	76.4	18.85	9.33	0.647	0.834	0	464.6	461.9	504.8	495.5
165	500	2684	-138.0	-19590	36.3	294.6	17.7	7.85	0.666	0.868	118.19	462.8	454.9	495.4	461.5
166	500	2701	-66.1	-12088	45.1	284.1	22.8	6.94	0.563	0.882	115.86	463.7	453.6	501.7	459.5
167	500	2706	-46.8	-9676	46.3	258.4	25.8	6.87	0.502	0.882	117.26	464.6	454.0	509.0	466.5
168	500	2703	-29.2	-6182	47.6	259.1	26.4	7.34	0.490	0.874	117.72	464.1	453.1	501.7	460.6
169	500	2694	-66.2	-22819	53.1	177.7	43.0	22.8	0.156	0.566	120.05	464.1	452.2	504.8	454.5
170	200	2687	101.3	5201	-0.15	-3.27	6.42	9.47	0.889	0.833	66.07	378.2	379.1	194.2	188.8
171	200	1593	78.2	4702	-0.58	-11.2	7.51	9.47	0.869	0.833	50.72	378.7	378.7	197.2	190.9
172	200	2717	88.3	4816	-0.29	-6.22	6.76	9.63	0.882	0.830	65.14	379.1	379.1	196.2	190.9
173	200	2712	83.0	3796	0.15	3.68	5.73	9.63	0.902	0.830	62.35	376.9	377.4	192.2	189.9
174	200	2707	79.0	3993	0.15	3.35	6.29	9.45	0.891	0.824	63.75	377.8	378.2	185.2	185.7
175	200	1596	78.0	3942	-0.56	-12.75	6.28	10.26	0.892	0.818	50.72	377.8	378.7	194.2	187.7

TABLE V (contd.)

RESULTS OBTAINED FROM TEST SECTION MEASUREMENTS DURING TWO-PHASE FLOW PUMP TESTS

Test	Nominal System Pressure (psia)	Pump Impeller Speed (rpm)	Flow Rate		Head		Density (lb/ft ³)		Void Fraction ^[e]		Torque ^[f]	Temperature (°F)		Pressure (psig)	
			Test Section	Loop											
			(gpm) ^[a]	(lb/hr)	(psid) ^[b]	(ft of fluid) ^[c]	Pump inlet ^[d]	Pump outlet ^[d]	Pump inlet ^[d]	Pump outlet ^[d]	(in./lb)	Pump inlet ^[d]	Pump outlet ^[d]	Pump inlet ^[d]	Pump outlet ^[d]
176	200	2692	78.1	4072	0	0	6.54	9.31	0.888	0.836	69.33	377.5	378.2	192.2	138.8
177	200	2708	75.2	2293	0.39	13.8	3.81	8.68	0.938	0.847	62.35	376.9	377.8	190.2	137.7
178	200	2712	46.4	2193	0.50	12.11	5.91	11.05	0.899	0.804	61.89	377.5	378.7	193.2	186.7
179	200	1595	57.4	2255	0	0	4.9	9.31	0.917	0.836	47.46	376.9	376.5	188.2	184.6
180	200	1597	28.7	2028	0.31	5.0	8.78	22.7	0.845	0.597	61.89	377.8	378.7	193.2	187.8
181	200	1595	22.4	1311	0.31	6.1	7.32	16.8	0.873	0.698	61.86	376.9	377.8	192.2	190.9
182	500	2700	128.6	5670	-0.29	-7.6	5.49	6.66	0.911	0.887	72.12	462.8	463.3	503.5	500.0
183	500	1601	119.8	5570	-1.24	-31.0	5.76	7.12	0.905	0.878	56.30	461.1	461.1	498.5	488.1
184	500	2708	101.0	3401	0.41	13.9	4.24	4.97	0.935	0.921	66.54	460.6	461.9	495.5	489.2
185	500	2707	78.7	3093	0.73	21.37	4.93	7.11	0.921	0.878	65.14	457.1	457.5	473.5	472.5
186	500	1601	83.6	3218	-0.32	-9.7	4.77	4.97	0.925	0.921	54.55	460.6	461.9	493.5	488.1
187	500	2702	122.2	2547	0.53	28.8	2.64	2.26	0.967	0.975	66.07	460.6	461.9	495.5	491.2
188	500	1603	101.7	2366	-0.06	-2.87	2.89	2.55	0.962	0.970	52.37	459.7	462.4	492.5	492.3
189	500	2700	85.1	2320	0.73	30.6	3.44	2.70	0.951	0.967	65.61	461.0	461.5	492.5	492.3
190	500	1605	58.5	1596	0.43	17.9	3.41	2.85	0.952	0.963	53.97	459.3	461.0	489.5	488.1
191	900	1605	121.7	4001	-0.26	-9.3	4.05	2.10	0.951	0.997	74.45	521.8	528.4	903.9	902.2
192	900	2709	118.8	4002	1.08	37.3	4.18	1.95	0.949	0.999	81.43	524.9	527.1	891.9	893.9
193	900	1601	90.6	3559	0	0	4.88	2.85	0.934	0.980	72.59	525.3	528.0	903.9	899.1
194	900	2703	66.7	3289	1.67	39.1	6.15	4.96	0.906	0.934	80.96	524.9	526.7	899.9	898.0
195	900	2704	69.4	2728	1.68	50.0	4.85	3.45	0.935	0.965	80.03	526.2	525.8	899.9	898.0
196	900	1604	39.5	2027	0.82	18.4	6.41	7.26	0.901	0.882	69.33	524.5	525.4	885.9	886.6
197	900	1600	79.3	3052	0.15	4.42	4.81	2.10	0.936	0.996	71.66	525.4	526.7	900.9	898.0
198	900	2697	97.3	3434	1.23	40.7	4.35	1.36	0.946	1.000	82.36	525.8	527.6	901.9	904.3
199	900	2694	66.8	4553	1.39	22.3	8.50	8.66	0.854	0.851	82.36	524.0	525.4	885.9	886.5
200							no data available								
201	900	0	-250.7	-57703	50.0	251.0	28.7	16.1	0.411	0.689	0	527.1	519.2	900.1	850.9
202	900	2672	-257.0	-60794	76.1	373.5	29.5	17.1	0.393	0.668	195.43	527.1	515.7	899.1	825.8
203	900	2704	-172.2	-39900	48.8	242.8	28.9	15.25	0.406	0.706	145.17	527.6	519.6	901.2	852.9
204	900	2711	-121.2	-33632	45.4	189.0	34.6	16.9	0.283	0.672	141.92	526.2	519.2	902.2	855.9

TABLE V (contd.)

RESULTS OBTAINED FROM TEST SECTION MEASUREMENTS DURING TWO-PHASE FLOW PUMP TESTS

Experimental Data Summary																
System Parameters			Flow Rate		Head		Density (lb/ft ³)		Void Fraction ^[e]		Torque ^[f]	Temperature (°F)		Pressure (psig)		
Nominal System		Pump Impeller	Test Section	Loop												
Test	Pressure (psia)	Speed (rpm)	(gpm) ^[a]	(lb/hr)	(psid) ^[b]	(ft of fluid) ^[c]	Pump inlet ^[d]	Pump outlet ^[d]	Pump inlet ^[d]	Pump outlet ^[d]	(in./lb)	Pump inlet ^[d]	Pump outlet ^[d]	Pump inlet ^[d]	Pump outlet ^[d]	
205	500	2694	-278.8	-62611	88.6	455.8	28.0	12.5	0.459	0.771	206.13	462.8	442.6	498.6	411.4	
206	500	2707	-168.0	-44861	53.6	231.5	33.3	14.1	0.352	0.739	135.87	462.8	450.8	498.6	448.5	
207	500	2701	-156.2	-35834	47.1	236.6	28.6	10.9	0.447	0.802	131.63	461.9	450.9	492.3	448.5	
208	200	2705	-129.4	-47631	65.1	-204.2	45.9	8.86	0.158	0.843	149.83	380.9	349.6	199.2	127.1	

[a] Inlet flow based on loop mass flow rate and test section inlet (suction or discharge) fluid density.

[b] Positive ΔP indicates higher pressure at pump discharge.

[c] Based on inlet conditions.

[d] Inlet and outlet refer to the direction of flow.

[e] Calculated using measured density and assumed saturation conditions.

[f] Measured directly.

TABLE VI

RESULTS OBTAINED FROM LOOP MEASUREMENTS DURING TWO-PHASE FLOW PUMP TESTS

Test	Temperature (°F)		Quality (wt fraction)		Void Fraction (volumetric fraction)		Volume Flow (US gpm)		Pressure (psia)		Flow Rate (lb/hr)			Pump ΔP [a]			Specific Volume (ft³/lb)		
	Pump Inlet	Pump Outlet	Pump Inlet	Pump Outlet	Pump Inlet	Pump Outlet	Pump Inlet	Pump Outlet	Pump Inlet	Pump Outlet	Steam	Water	Mass	(psid)	(ft of inlet fluid)	(ft of outlet fluid)	pump inlet	pump outlet	
1							preliminary test, no data recorded												
2	533.1	529.7	0.0013	0.0068	0.03	0.141	169.13	189.4	902.6	880.3	2606.1	59411.1	62017.3	-21.4	-66.6	-75.6	0.0218	0.0245	
3	534.54	530.48	0.00583	0.01186	0.120	0.224	181.26	203.49	908.9	883.92	2106.6	58360.1	60466.7	-24.28	-84.05	-94.35	0.0240	0.0270	
4	534.22	529.64	0.0115	0.0181	0.214	0.310	195.76	220.41	902.0	874.5	2512.4	56410.6	58723.1	-29.61	-113.99	-128.34	0.0267	0.0301	
5	533.46	526.19	0.01733	0.02915	0.293	0.431	277.5	337.7	900.0	850.4	3756.4	71546.0	75302.4	-48.52	-206.52	-251.33	0.0296	0.0359	
6	533.65	525.21	0.01067	0.02187	0.203	0.361	281.49	344.27	897.0	850.44	3661.3	81952.4	85613.7	-53.26	-202.27	-247.37	0.0264	0.0323	
7	535.65	527.69	0.00383	0.0179	0.0801	0.313	279.64	365.06	914.5	856.2	3334.59	93751.5	97086.7	-55.19	-183.58	-239.67	0.0231	0.0302	
8	533.6	527.3	0.01617	0.0264	0.279	0.404	235.43	279.8	900.29	857.4	3106.6	62013.8	65120.5	-38.17	-159.33	-189.44	0.0290	0.0345	
9	533.77	526.41	0.0049	0.0156	0.104	0.284	241.70	297.17	899.72	855.48	2687.6	79469.0	82156.7	-46.45	-157.8	-194.03	0.0240	0.0290	
10	533.77	530.13	0.00731	0.0121	0.148	0.229	185.42	203.19	900.32	880.45	1840.19	58243.6	60083.8	-21.42	-76.33	-83.64	0.0248	0.0271	
11	533.68	530.30	0.00699	0.0116	0.143	0.222	178.5	195.09	897.33	878.3	1751.18	56441.3	58192.5	-19.91	-70.53	-77.10	0.0246	0.0269	
12	468.81	454.42	0.0077	0.0267	0.265	0.596	213.6	376.0	503.1	443.4	3009.4	61183.5	64192.9	-57.93	-222.67	-391.9	0.0267	0.0470	
13	468.1	455.3	0.0043	0.0241	0.168	0.570	191.3	359.0	503.9	441.9	2698.5	62220.6	64899.1	-58.74	-200.0	-375.4	0.0236	0.0444	
14	469.1	459.2	0.00516	0.1096	0.195	0.508	195.8	313.5	502.9	457.1	2422.1	61927.7	64349.9	-53.54	-188.2	-301.3	0.0244	0.0391	
15	467.6	457.3	0.00174	0.0184	0.076	0.498	172.4	309.1	501.3	449.3	2236.4	62614.9	64871.4	-45.72	-140.37	-251.6	0.0213	0.0382	
16 [b]	468.9	450.2	0.00728	0.0362	0.254	0.684	256.1	576.1	506.1	416.0	3833.7	74234.2	78127.9	-89.14	-337.5	-759.1	0.0263	0.0591	
18 [b]	468.9	448.1	0.00643	0.0362	0.236	0.684	252.2	581.4	507.5	415.1	4238.3	74498.2	78736.5	-87.6	-324.1	-746.9	0.0257	0.0592	
19 [c]	241.4	237.5	---	---	---	---	---	---	71.5	70.6	0.0	2191.4	2191.4	-0.20	---	---	---	---	
20	265.2	262.8	---	---	---	---	---	---	58.2	57.7	0.0	4767.4	4767.4	-0.30	---	---	---	---	
21	312.1	297.7	---	---	---	---	---	---	200.8	199.7	0.0	2360.1	2360.1	-0.315	---	---	---	---	
22	344.2	338.7	---	---	---	---	---	---	200.0	199.1	0.0	4683.0	4683.0	-0.49	---	---	---	---	
23	374.9	355.9	---	---	---	---	---	---	501.1	501.9	0.0	2314.2	2314.2	-0.54	---	---	---	---	
24	399.8	387.2	---	---	---	---	---	---	500.0	500.9	0.0	4615.6	4615.6	-0.52	---	---	---	---	
25	435.92	410.16	---	---	---	---	---	---	901.3	904.4	0.0	2202.9	2202.9	-0.56	---	---	---	---	
26	456.2	453.5	---	---	---	---	---	---	897.8	900.3	0.0	3389.2	3389.2	-0.62	---	---	---	---	
27	470.91	453.1	---	---	---	---	---	---	901.6	902.8	0.0	4556.6	4556.6	-0.70	---	---	---	---	
28	532.6	529.7	0.148	0.148	0.803	0.803	74.44	74.44	902.3	902.2	1255.9	5200.5	6496.4	-3.868	-51.18	-51.19	0.0919	0.0919	
29	533.0	530.4	0.162	0.1618	0.8197	0.8197	86.0	85.98	899.77	899.9	1462.5	5517.2	6979.5	-1.355	-19.28	-19.27	0.0988	0.0988	
30	532.7	530.05	0.151	0.151	0.8055	0.8058	78.29	78.38	907.2	906.7	1365.3	5394.9	6760.3	-2.984	-39.92	-39.97	0.0929	0.0929	
31	532.06	529.06	0.0752	0.0752	0.657	0.656	41.59	41.57	900.07	900.27	756.52	5062.84	5819.4	-2.145	-17.70	-17.69	0.0573	0.0573	
32	532.1	512.3	0.0339	0.0299	0.453	0.415	14.88	14.0	898.8	915.8	422.9	2761.5	3184	13.66	73.80	69.57	0.0375	0.0345	
33	532.1	526.2	0.0624	0.0616	0.611	0.606	21.0	20.8	899.2	902.9	556.6	2733.0	3289.7	-1.38	-10.14	-10.03	0.0512	0.0507	
34	468.4	464.0	0.0864	0.0871	0.816	0.818	75.22	76.06	500.4	497.8	695.8	5452.2	6148.0	-3.88	-54.83	-55.43	0.0981	0.0992	
35	468.6	464.3	0.0770	0.0776	0.795	0.797	72.5	73.17	504.4	502.3	747.4	5783.7	6531.0	-3.020	-38.71	-39.07	0.089	0.0898	
36	389.1	382.6	0.0468	0.0483	0.852	0.858	83.8	87.2	211.90	208.7	413.3	5246.0	5659.3	-3.84	-65.66	-68.31	0.1183	0.1236	
37	379.1	366.1	0.0072	0.00029	0.476	---	22.67	11.86	198.26	212.6	175.3	5049.8	5226.1	15.68	78.59	41.09	0.0348	0.0182	
38	381.1	367.6	0.0117	0.0026	0.592	0.226	29.13	15.58	203.2	221.2	223.8	5014.5	5238.3	16.90	108.5	58.02	0.0446	0.0238	
39	381.7	366.6	0.0181	0.0092	0.644	0.513	38.5	24.57	202.2	219.7	262.4	4979.1	5241.5	16.92	143.72	91.60	0.0589	0.0376	
40	466.6	460.2	0.0019	0.00094	---	---	74.20	73.82	505.2	502.0	1080.0	29129.0	30209	-4.65	-13.19	-13.12	0.0197	0.0196	
41	468	462	0.005	-0.0089	0.18	---	86.32	70.70	495.7	540	1170	27770	28941	43.17	148.83	121.8	0.0239	0.0196	
42	467	461	0.0008	0.0015	0.035	0.666	74.10	76.5	503.6	501.2	1151.2	27912	29063	-4.28	-12.6	-13.01	0.0205	0.0211	

TABLE VI (contd.)

RESULTS OBTAINED FROM LOOP MEASUREMENTS DURING TWO-PHASE FLOW PUMP TESTS

Test	Temperature (°F)		Quality (wt fraction)		Void Fraction (volumetric fraction)		Volume Flow (US gpm)		Pressure (psia)		Flow Rate (lb/hr)			Pump ΔP ^[a]			Specific Volume (ft ³ /lb)	
	Pump Inlet	Pump Outlet	Pump Inlet	Pump Outlet	Pump Inlet	Pump Outlet	Pump Inlet	Pump Outlet	Pump Inlet	Pump Outlet	Steam	Water	Mass	(psid)	(ft of)		Pump Inlet	Pump Outlet
															Inlet Fluid	Outlet Fluid		
43	468	463	0.0059	0.0069	0.216	0.247	90.65	94.16	503.4	500	1265.5	27756	29021	-5.40	-19.47	-20.23	0.0251	0.026
44	469.1	464.2	0.0056	-0.0077	0.206	---	87.30	69.10	507.1	550.7	1263.8	27013	28277	42.94	153.1	121.2	0.0248	0.0196
45	469	464.3	0.0067	0.0027	0.241	0.108	93.55	80.13	501.4	514.6	1265.4	27760	29026	11.24	41.8	35.8	0.0258	0.022
46	470	465	0.0746	0.077	0.79	0.797	173.9	181.4	509.9	500.5	1835.3	14359	16194	-9.2	-114.06	-118.98	0.086	0.0899
47	468.8	463.3	0.0516	0.054	0.72	0.73	149.6	155.3	501.9	495.1	1507.7	16568	18076	-9.06	-86.7	-89.9	0.066	0.069
48	469	464	0.077	0.078	0.80	0.80	158.3	160.5	503.3	500.2	1601.8	12573	14175	-6.39	-82.37	-83.5	0.090	0.091
49	468.9	464	0.051	0.052	0.72	0.72	146	148.7	502	499	1539.5	16144	17654	-5.02	-48.04	-48.9	0.066	0.068
50	467.9	463.3	0.075	0.076	0.79	0.79	135.8	137	499.6	497.6	1355.0	11004	12359	-3.33	-42.21	-42.6	0.088	0.089
51	469.0	464.9	0.0451	0.04551	0.688	0.59	78.4	79.0	504.4	503.1	833.1	9584.0	10417.1	-1.772	-15.41	-15.52	0.06038	0.06082
52	469.3	464.3	0.04486	0.04544	0.685	0.6887	40.82	41.28	507.1	505.1	421.5	5042.4	5464.9	-2.682	-23.14	-23.40	0.05992	0.06059
53	470.0	463.4	0.08004	0.08447	0.8001	0.8146	281.8	301.5	509.8	494.3	2905.0	2193.0	24835.0	-15.62	-204.7	-218.9	0.09101	0.09736
54	469.3	462.1	0.05080	0.05569	0.7125	0.7392	241.3	263.7	506.9	490.3	2623.4	27034.0	29657.2	-16.94	-159.1	-173.9	0.06526	0.07132
55	471.3	460.5	0.08424	0.09417	0.8063	0.8357	357.6	414.2	517.3	482.3	3745.8	26880.3	30626.3	-34.08	-459.6	-532.2	0.09365	0.1085
56	----- test incompleted -----																	
57	385.4	378.1	0.017	0.019	0.68	0.71	134.4	147.8	202.5	198.4	1085	17710	18795	-4.67	-38.5	-42.45	-0.057	0.063
58	386	378	0.033	0.036	0.807	0.823	186.6	202	204	199.3	1165	15048	16212	-6.39	-84.9	-92.3	-0.09	0.1
59	387	378	0.032	0.036	0.8	0.82	179	204.8	207	198.6	1164	15100	16264	-7.7	-9.8	-112	-0.088	0.1
60	385.0	378	0.034	0.037	0.81	0.82	170	185	204	198.0	1026	13407	14433	-6.35	-86.9	-94.62	-0.094	0.1
61	385.0	378.8	0.017	0.018	0.683	0.699	75.97	79.8	200.1	197.9	610.5	10069.1	10679.5	-2.39	-19.65	-20.64	-0.057	0.060
62	386	379.5	0.0601	0.0620	0.887	0.892	123.7	128.9	202.4	198.8	646.4	5823.5	6469.9	-3.05	-67.35	-70.25	-0.153	0.160
63	385.3	378.3	0.059	0.0604	0.883	0.888	119.4	124.5	204.7	200.9	641.5	5808.1	6449.7	-4.44	-94.8	-98.9	-0.143	0.155
64	385.2	373.7	0.0326	0.0392	0.808	0.844	289.5	353.4	199.9	187.6	1749.1	23349.5	25098.6	-14.22	-189.4	-231.2	-0.0925	0.1129
65	386.1	378.4	0.00050	0.0022	0.055	0.209	66.5	79.21	211.4	208.1	1122.6	26198.3	27320.9	-3.802	-10.69	-12.73	-0.0195	0.0233
66	384.0	376.0	0.00038	-0.0078	0.043	---	58.8	55.97	207.7	223.9	1032.2	23496.0	24528.3	15.74	43.62	41.48	-0.0193	0.0183
67	383.5	376.9	0.00731	0.00095	0.481	0.102	108.1	62.98	197.1	209.2	1041.2	23590.7	24631.9	12.66	62.98	37.28	0.0352	0.0205
68	383.5	375.5	0.0055	0.0075	0.411	0.493	95.1	110.0	196.9	193.3	992.4	23588.7	24581.1	-3.02	-15.52	-15.64	0.0310	0.0359
69	533	528.7	0.093	0.096	0.708	0.71	242.9	249.2	899.3	888.5	4018	25472	25490	-16.32	-155.24	-159.3	0.066	0.068
70	532.3	525.5	0.147	0.153	0.803	0.81	354.3	376.88	897.8	866.9	5743	25105	30348	-33.02	-438.05	-465.9	0.092	0.098
71	532.6	528.8	0.1373	0.1398	0.790	0.796	272.1	279.1	899.1	886.7	4528.5	20517.1	25346.0	-14.89	-186.9	-191.7	0.06714	0.08939
72	531.6	528.1	0.08966	0.09175	0.7008	0.7089	161.0	164.8	893.1	883.5	2641.1	17352	19993.1	-8.06	-74.99	-76.77	0.06458	0.06611
73	532.9	530.3	0.08677	0.08686	0.692	0.692	133.0	133.1	897.9	897.5	2160.8	14789.0	16950	-2.441	-22.12	-22.14	0.06294	0.06300
74	531.9	528.5	0.14147	0.14286	0.7959	0.7993	177.8	180.3	896.9	890.0	2891.8	13073.1	15965.0	-10.43	-134.10	-135.99	0.089311	0.090570
75	529.3	524.3	0.004	0.005	0.09	0.11	69.5	71.4	899.5	893.9	1264.3	22826.4	24090.6	-3.68	-12.28	-12.6	0.023	0.024
76	531.9	527.1	0.011	0.011	0.202	0.206	71.46	71.7	895.3	894.5	1214.5	20547.4	21762	-3.35	-12.72	-12.77	0.026	0.026
77	532.3	529.6	0.0159	0.0157	0.288	0.288	79.40	79.15	896.3	897.0	1370.3	20678	22098.6	0.193	0.8	0.799	0.029	0.029
78	532.2	530.0	0.0190	0.0181	0.31	0.3	82.4	81.06	900.47	904.5	1394.1	20375	21769.1	1.11	4.86	4.79	0.0304	0.0299
79	530.96	526.8	0.0051	-0.0048	0.108	---	78.7	70.1	896.5	937.7	1362.2	25285	26647.3	40.9	139.7	124.3	0.0237	0.0211
80	530.0	525.4	0.0023	-0.0016	0.05	---	72.1	67.7	900.66	917.0	1318.45	24545	25873.2	12.62	40.63	38.16	0.022	0.0210
81	532.4	529.6	0.0223	0.0230	0.350	0.359	117.4	118.8	898.2	895.1	1960.5	27502.7	29463.2	-4.366	-18.71	-18.94	0.032	0.0323
82	532.9	530.0	0.137	0.1375	0.789	0.789	105.9	106.0	902.9	902.4	1736.3	8042.2	9776.5	-3.47	-43.43	-43.48	0.0869	0.0869
83	532.2	529.7	0.089	0.0886	0.698	0.696	80.07	79.78	897.2	898.8	1303.7	8731.3	10035.0	-0.625	-5.76	-5.74	0.064	0.064

TABLE VI (contd.)

RESULTS OBTAINED FROM LOOP MEASUREMENTS DURING TWO-PHASE FLOW PUMP TESTS

Test	Temperature (°F)		Quality (wt fraction)		Void Fraction (volumetric fraction)		Volume Flow (US gpm)		Pressure (psia)		Flow Rate (lb/hr)			Pump ΔP ^[a]			Specific Volume (ft ³ /lb)	
	Pump Inlet	Pump Outlet	Pump Inlet	Pump Outlet	Pump Inlet	Pump Outlet	Pump Inlet	Pump Outlet	Pump Inlet	Pump Outlet	Steam	Water	Mass	(psid)	(ft of Inlet Fluid)	(ft of Outlet Fluid)	Pump Inlet	Pump Outlet
84	526.1	519.3	0.0032	0.00167	0.071	0.038	38.14	36.93	898.6	904.9	694.3	12732.3	13426.6	14.21	46.62	45.13	0.0227	0.0221
85	533.3	531.4	0.0065	0.0069	0.13	0.14	109.8	110.9	905.7	903.7	2122.1	34056	36178.2	-3.09	-10.83	-10.93	0.024	0.025
85	532.8	531.2	0.0084	0.0079	0.16	0.15	123.4	122.16	900.6	902.8	2357.5	36768	39125.7	5.73	20.86	20.65	0.025	0.025
87	531.6	528.6	0.0165	0.0191	0.28	0.32	131.7	137.8	901.2	890.2	2574.6	33673.6	36253.2	-5.82	-24.42	-25.55	0.029	0.03
88	534.4	532.3	0.0144	0.0171	0.225	0.269	139.0	145.8	919.5	908.0	2451.4	38343.9	40495.3	-2.83	-11.12	-11.67	0.027	0.025
89	532.2	530.05	0.006	0.008	0.12	0.15	139.3	144.3	902.5	895.1	2287.0	44143.1	46435.1	-1.11	-3.86	-3.99	0.024	0.025
90	533.0	528.7	0.015	0.0194	0.27	0.32	145.1	156.6	902.97	884.5	2711.4	38234.8	40945	-11.66	-47.73	-51.52	0.028	0.030
91	532.6	527.4	0.071	0.076	0.65	0.67	244.8	260.7	907	883.15	4943.4	29945.2	34888	-18.9	-153.2	-163.2	0.056	0.055
92	471.2	462.0	0.0486	0.057	0.698	0.746	262.2	306.9	516.3	486.9	3671.2	29982.5	33653.7	-24.85	-223.6	-261.7	0.062	0.073
93	469.9	458.4	0.0062	0.0189	0.227	0.496	180	270.0	503.3	463.1	3022.8	53828.8	56851.5	-36.06	-131.84	-198.1	0.025	0.038
94	468.99	458.0	0.0035	0.0152	0.14	0.44	163.9	247.16	501.3	464.1	2702.9	54766.2	57459.2	-31.44	-103.58	-156.2	0.023	0.034
95	468.9	460.7	0.0095	0.0196	0.309	0.50	159.0	216.2	503.3	471.0	2363.6	42627.2	44990.7	-21.55	-87.96	-119.6	0.028	0.038
96	469.0	461.6	0.00457	0.0109	0.177	0.351	147	184.6	501.3	480.9	2251.7	4711.7	49369.1	-16.28	-55.98	-70.29	0.024	0.030
97	468.3	460.9	0.0033	0.0095	0.134	0.319	138.8	174.8	502.5	482.7	2259.3	46724.6	48983.8	-16.3	-53.27	-67.07	0.0227	0.0285
98	468.3	462.0	0.0043	0.0099	0.168	0.327	128.7	157.9	503.5	485.4	2144.4	41570.0	43714.5	-12.98	-44.16	-54.16	0.0236	0.029
99	468.3	462.6	0.0023	0.0064	0.098	0.236	118.1	138.6	503.2	490.13	2012.3	41375	43387.3	-9.68	-30.45	-35.73	0.0218	0.0256
100	469.3	462.9	0.00937	0.0147	0.304	0.417	136.1	161.2	507.1	489.84	2135.5	36646.96	38782.4	-11.00	-44.59	-52.82	0.0281	0.033
101	385.1	379.3	0.0043	-0.015	0.348	---	107.0	70.07	202.1	240.7	1091.2	29449.4	30544.6	40.7	164.5	107.8	0.0281	0.0184
102	385.6	378.1	-0.0024	-0.026	---	---	70.74	70.74	212	261.5	1146.2	29689.3	30835.5	47.32	125.4	125.4	0.0184	0.0184
103	383.6	377.3	0.0029	-0.0201	0.268	---	98.0	71.99	198.1	243.9	1144.0	30236.6	31380.6	46.50	167.7	123.2	0.0250	0.0184
104	384.8	379.5	0.0030	-0.0086	0.272	---	142.2	103.9	201.4	224.1	1751.5	43531.6	45283.2	21.66	78.53	57.39	0.0252	0.0184
105	386.5	374.5	0.003	0.0126	0.266	0.629	151.5	295.4	206.1	188.0	2016.5	46559.8	48576.3	-16.03	-57.73	-112.56	0.0250	0.0488
106	388.4	372.7	0.0187	0.0333	0.690	0.823	269.9	461.9	212.6	184.6	2096.3	34940.3	37035.6	-24.83	-209.3	-357.7	0.0584	0.100
107	386.8	371.1	0.0185	0.0330	0.692	0.825	269.6	463.2	207.7	180.3	2094.3	34677.8	36772.1	-25.57	-216.56	-372.0	0.0588	0.101
108	384.8	379.5	0.00245	0.0030	0.232	0.270	161.7	170.1	203.1	202.0	2073.2	52217.6	54290.8	±0	±0	±0	0.0239	0.0251
109	384.1	378.8	0.0031	0.0036	0.280	0.311	172.9	180.7	199.4	198.5	2022.2	52498.7	54520.8	-0.137	-0.502	-0.524	0.0254	0.0266
110	468.0	465.19	-0.0277	-0.0093	---	---	206.0	206.0	500.6	521.72	986.7	82896.7	83883.4	48.64	138.0	138.0	0.0197	0.0197
111	464.3	459.6	-0.0049	-0.0120	---	---	205.6	204.5	489.1	511.92	921.68	82771.3	83695.0	25.93	73.6	73.2	0.0197	0.0196
112	465.47	461.43	-0.0044	-0.012	---	---	205.1	204.0	500.37	525.49	1216.6	82272.1	83486.7	26.88	76.5	75.9	0.0197	0.0196
113	454.7	450.0	-0.0237	-0.0311	---	---	205.4	205.4	503.35	526.9	1194.23	83305.1	84495.4	26.69	74.5	74.9	0.0195	0.0195
114	467.6	464.2	-0.0032	-0.0079	---	---	206.4	206.4	501.3	516.6	2054.5	81968.4	84022.9	18.15	51.48	51.48	0.0197	0.0197
115	468.8	465.99	-0.0033	-0.0067	---	---	202.5	202.5	503.4	514.5	2417.5	80033.7	82451.1	22.77	64.59	64.59	0.0197	0.0197
116	468.2	465.3	-0.0044	-0.0050	---	---	225.1	225.1	500.767	502.5	2798.0	88852.2	91649.9	3.67	10.41	10.41	0.0197	0.0197
117	468.17	464.7	-0.0057	-0.0055	---	---	221.4	221.4	500.8	500.2	2876	87280.5	90156.9	-1.76	-4.99	-4.99	0.0197	0.0197
118	468.3	462.9	-0.0065	-0.0011	---	---	220.4	220.4	502.9	485.8	3148.4	86594.8	89743.1	-7.66	-21.73	-21.73	0.0197	0.0197
119	467.3	461.0	-0.0020	0.0025	---	0.11	256.4	287.24	435.4	480.9	1389.5	103009.4	104398.9	-10.55	-29.93	-33.69	0.0197	0.0221
120	467.6	461.6	-0.0018	0.0038	---	0.159	255.3	301.8	497.2	479.4	1386.9	102556.5	103943.4	-11.53	-32.7	-38.45	0.0197	0.0233
121	467.8	461.0	-0.6026	0.0041	---	0.169	253.6	303.3	500.7	479.4	1448.7	101788.5	103237.2	-16.09	-45.6	-54.31	0.0197	0.0236
122	460.3	455.3	-0.0184	-0.0284	---	---	128.13	128.97	514.2	546.3	1003.4	50897.8	51901.3	39.866	115.66	114.41	0.0198	0.01993
123	468.3	465.4	-0.0004	-0.00998	---	---	128.48	129.33	500.2	531.25	1334.7	50866.0	52200.7	36.98	105.12	114.07	0.01974	0.01987
124	470.9	468.2	-0.00034	-0.0012	---	---	121.79	121.79	516.3	519.1	1453.95	47830.9	49284.8	2.43	6.93	6.93	0.01982	0.01982

TABLE VI (contd.)

RESULTS OBTAINED FROM LOOP MEASUREMENTS DURING TWO-PHASE FLOW PUMP TESTS

Test	Temperature (°F)		Quality (wt fraction)		Void Fraction (volumetric fraction)		Volume Flow (US gpm)		Pressure (psia)		Flow Rate (lb/hr)			Pump ΔP ^[a]		Specific Volume (ft ³ /lb)		
	Pump Inlet	Pump Outlet	Pump Inlet	Pump Outlet	Pump Inlet	Pump Outlet	Pump Inlet	Pump Outlet	Pump Inlet	Pump Outlet	Steam	Water	Mass (psia)	(ft of Inlet Fluid)		Pump Inlet	Pump Outlet	
125	463.4	458.2	-0.0128	-0.015	---	---	123.29	123.29	505.6	513.03	1303.6	48638.9	49542.6	7.84	22.35		0.0198	0.01980
126	468.0	464.2	-0.0026	-0.0038	---	---	121.57	121.57	502.4	506.4	1489.4	47854.6	49244.0	4.41	12.54	12.34	0.01976	0.01976
127	468.56	464.56	-0.0020	-0.0012	---	---	120.14	120.02	503.5	500.89	1464.2	47299.8	48764	-0.98	-2.79	-2.79	0.01976	0.01974
128	461.4	455.5	-0.013	-0.016	---	---	80.42	80.62	501.0	509.45	1153.4	31538.4	32691	13.2	37.5	37.59	0.01973	0.01978
129	467.43	463.7	-0.0012	-0.0012	---	---	80.24	80.32	498.3	508.4	1375.0	31208.6	32383.7	7.17	20.39	20.41	0.01975	0.01977
130	467.3	463.2	-0.0027	-0.0056	---	---	78.37	78.33	499.1	498.4	1225.7	30601.1	31326	-1.52	-4.32	-4.31	0.01975	0.01974
131	520.5	516.9	-0.0245	-0.0288	---	---	198.59	199.10	903.1	920.8	1526.8	73444	74970.3	24.74	75.67	75.88	0.02124	0.02130
132	531.7	531.1	0.0011	-0.0028	0.026	---	201.2	196.67	896.8	912.8	2221.0	71903.2	74124.3	21.21	64.75	75.81	0.02120	0.02128
133	532.0	530.7	0.0037	0.0031	0.071	0.069	205.1	204.5	900.5	901.1	2387.0	69725.9	72112.9	5.81	19.08	19.02	0.0228	0.0227
134	529.8	526.4	-0.0094	-0.016	---	---	138.30	138.96	901.9	928.9	1909.5	50339.3	52248.8	35.30	107.92	108.42	0.02123	0.02133
135	531.8	531.8	0.00096	-0.0052	0.022	---	144.8	142.24	898.9	924.4	3081.3	51429.9	53511.1	30.97	94.63	95.08	0.02122	0.02132
136	532.0	531.8	0.0021	-0.0014	0.048	---	139.6	140.03	900.0	914.6	2210.1	50541.8	52752.0	15.50	47.39	47.52	0.02123	0.02129
137	524.2	519.9	-0.0022	-0.024	---	---	91.60	91.65	899.1	904.6	1979.1	32629.5	34608.6	11.25	34.39	34.40	0.02123	0.02124
138	532.3	529.6	0.013	0.0158	0.241	0.277	107.1	111.9	902.9	892.5	2379.1	28691.7	31070.8	-5.13	-20.40	-21.32	0.0216	0.0289
139	531.9	529.9	0.0192	0.0205	0.316	0.332	103.9	106.2	899.1	893.7	2448.4	24922.1	27370.6	-1.176	-5.16	-5.27	0.0304	0.0311
140	531.1	529.6	0.0197	0.0193	0.324	0.319	111.0	110.3	892.2	893.9	2483.9	26452.7	28936.6	8.25	36.5	36.3	0.0308	0.0306
141	531.1	529.4	-0.0017	-0.0020	---	---	91.77	91.81	892.7	893.8	2458.6	32268.2	34716.8	6.90	21.06	21.07	0.02120	0.02121
142	531.9	529.8	-0.0010	-0.00006	---	---	86.65	90.99	897.8	893.3	2461.8	31943.2	34405.0	-1.99	-6.07	-6.08	0.02120	0.02121
143	359.9	375.7	0.0327	0.00093	0.852	0.103	-346.7	-60.22	147.0	202.2	665.1	22910.3	23575.9	55.68	945.6	164.3	0.1179	0.0205
144	361.1	378.9	0.0610	0.0337	0.916	0.814	-496.6	-235.4	149.7	198.5	1125.1	18663.2	19788.1	45.52	1435.3	680.3	0.201	0.0954
145	360.4	378.7	0.0585	0.0299	0.913	0.795	-298.7	-132.4	147.3	197.8	664.6	11532.2	12196.9	51.93	1468.5	651.0	0.196	0.0871
146	360.5	378.8	0.0596	0.0310	0.914	0.800	-243.4	-109.1	148.6	199.6	575.3	9260.7	9836.0	51.72	1477.9	662.5	0.198	0.0889
147	357.8	376.1	0.0590	0.0305	0.916	0.800	-161.2	-71.11	143.5	193.5	346.1	6035.5	6381.6	50.77	1480.9	653.3	0.202	0.893
148	357.1	376.9	0.0367	0.00472	0.871	0.360	-401.4	-85.1	141.1	196.1	645.9	23227.6	23873.6	55.34	1074.7	227.8	0.135	0.0286
149	381.4	377.9	0.0349	0.0328	0.824	0.81	-215.1	-201.3	192.6	196.5	946.9	16215.7	17162.6	5.28	76.48	71.58	0.1005	0.0941
150	378.1	379.4	0.033	0.0303	0.84	0.795	-169.98	-133.3	185.0	199.6	692.6	11542.5	12235.1	13.72	252.3	197.8	0.1114	0.087
151	380.0	380.3	0.030	0.0305	0.79	0.796	-76.3	-77.6	202.0	201.05	410.0	6722.1	7132.12	14.52	179.5	182.7	0.0858	0.0874
152	377.3	377.1	0.0363	0.0292	0.839	0.792	-55.4	-43.4	182.8	196.9	219.5	3846.2	4065.8	14.46	227.7	178.2	0.1093	0.0856
153	376.6	374.9	0.018	0.0106	0.723	0.57	-57.95	-38.44	181.4	196.07	248.1	6919.3	7167.9	16.17	151.01	100.2	0.0648	0.043
154	375.04	372.9	0.0134	0.00738	0.65	0.98	-44.6	-30.02	180.9	192.5	212.66	6661.7	6875	16.6	124.3	83.7	0.052	0.035
155	376.6	375.54	0.0109	0.0093	0.6	0.1046	-100.14	-45.05	181.0	199.26	434.85	17180.07	17614.92	19.28	126.58	56.94	0.0456	0.0205
156	375.4	378.2	0.0149	0.00393	0.679	0.33	-170.81	-83.4	178.2	198.17	653.68	23774.78	24428.5	20.93	169.50	82.75	0.056	0.02737
157	464.86	465.06	0.0095	0.0036	0.319	0.144	-103.09	-82.84	483.44	502.4	555.03	28329.3	28884.3	24.14	99.54	80.00	0.0286	0.023
158	465.7	465.4	0.0132	0.00814	0.39	0.277	-91.2	-77.2	486.7	503.1	498.7	2234.3	22841.6	20.86	96.19	81.39	0.032	0.027
159	462.6	462.23	0.00837	0.00279	0.293	0.153	-56.55	-47.565	480.95	495.53	292.39	16151.4	16443.8	19.94	79.18	66.60	0.0276	0.0232
160	466.2	465.46	0.0664	0.065	0.774	0.76	-126	-119.3	486.8	500.6	918.99	11530.36	12449.3	14.67	172.07	162.38	0.0815	0.0769
161	466.9	465.6	0.081	0.0782	0.807	0.798	-82.22	-78.78	494.23	503.88	620.79	6380.24	7001.03	12.30	166.83	159.86	0.094	0.0902
162	467.1	465.06	0.080	0.0768	0.806	0.795	-45.95	-43.70	493.03	504.28	392.01	3550.4	3942.4	13.24	178.34	169.61	0.0935	0.0889
163	460.2	464.03	0.0189	0.0157	0.47	0.42	-30.1	-27.5	505.62	516.1	212.46	6356.09	6568.54	14.41	76.2	69.74	0.0367	0.0336
164	468.2	466.2	0.0336	0.0828	0.810	0.804	-200.4	-195.00	501.82	508.16	1564.67	15281.35	16846.02	8.551	114.73	111.65	0.0954	0.0928

TABLE VI (contd.)

RESULTS OBTAINED FROM LOOP MEASUREMENTS DURING TWO-PHASE FLOW PUMP TESTS

Test	Temperature (°F)		Quality (wt fraction)		Void Fraction (volumetric fraction)		Volume Flow (US gpm)		Pressure (psia)		Flow Rate (lb/hr)			Pump Δp [a]			Specific Volume (ft ³ /lb)	
	Pump Inlet	Pump Outlet	Pump Inlet	Pump Outlet	Pump Inlet	Pump Outlet	Pump Inlet	Pump Outlet	Pump Inlet	Pump Outlet	Steam	Water	Mass	(psid)	(ft. of Inlet Fluid)	(ft. of Outlet Fluid)	Pump Inlet	Pump Outlet
165	460.7	464.4	0.0877	0.0777	0.83	0.799	-257.6	-220.7	464.97	499.41	1787.4	17802.94	19590.4	34.06	517.26	443.2	0.105	0.0504
166	460.28	465.33	0.0908	0.0794	0.836	0.801	-163.94	-137.75	463.87	503.29	1090.80	10997.06	12087.9	42.58	666.95	560.42	0.1087	0.0514
167	460.28	465.68	0.0902	0.0794	0.833	0.7997	-128.99	-109.60	470.16	507.36	880.90	8796.6	9677.5	44.55	685.9	582.77	0.1069	0.0908
163	459.17	465.33	0.0898	0.0776	0.835	0.797	-83.3	-69.17	461.77	503.58	532.23	5649.48	6161.71	44.03	685.58	568.98	0.1081	0.0897
169	459.54	465.82	0.0221	0.0066	0.54	0.236	-118.77	-73.11	454.78	504.28	520.77	22298.06	22818.83	52.48	315.46	194.18	0.0417	0.0257
170	385.5	378.5	0.105	0.108	0.93	0.94	163	173	204.84	198.04	695.9	4504.8	5200.8	-3.476	-125.98	-133.61	0.252	0.2659
171	385.89	379.43	0.114	0.115	0.94	0.94	159.6	164.6	203.5	199.93	674.3	4027.9	4702.3	-2.38	-93.50	-96.4	0.272	0.2806
172	385.67	379.21	0.1328	0.1344	0.949	0.95	190.65	195.7	201.6	198.3	744.44	4071.54	4815.98	-2.055	-93.99	-96.48	0.3175	0.326
173	384.19	377.5	0.145	0.147	0.955	0.956	164.6	169.63	200.36	196.46	673.00	3122.46	3795.5	-1.701	-85.20	-87.78	0.348	0.358
174	385.67	378.54	0.13	0.13	0.95	0.95	154.89	159.8	201.65	197.7	664.27	3328	3992.6	-2.095	-93.87	-96.84	0.311	0.32
175	385.4	378.67	0.1	0.111	0.94	0.94	130.7	135.7	200.4	196.0	544.83	3396.9	3941.76	-2.424	-92.87	-96.38	0.266	0.276
176	384.0	377.0	0.138	0.139	0.95	0.952	167.2	170.84	201.6	198.8	668.5	3403.9	4072.4	-1.63	-77.5	-79.21	0.329	0.336
177	384.06	377.1	0.250	0.251	0.977	0.977	168.7	170.9	198.56	196.55	639.38	1653.50	2292.87	-1.267	-107.65	-109.04	0.59	0.598
178	383.66	377.64	0.2014	0.203	0.969	0.97	130.2	133.57	199.66	195.96	514.40	1678.20	2192.6	-1.24	-85.10	-87.28	0.476	0.49
179	384.84	378.09	0.2318	0.2326	0.974	0.975	157.3	159.31	194.27	192.39	591.50	1663.4	2254.93	-1.635	-131.74	-133.4	0.560	0.567
180	384.49	377.87	0.126	0.128	0.947	0.948	76.69	78.45	201.15	198.34	331.2	1696.85	2028.01	-1.24	-54.17	-55.42	0.303	0.31
181	383.84	377.06	0.2447	0.2462	0.976	0.976	93.4	95.5	200.9	197.35	340.49	970.65	1311.4	-1.24	-102.0	-104.39	0.5711	0.584
182	469.9	465.06	0.275	0.277	0.946	0.947	187.4	191.2	509.62	502.0	1744.51	3925.25	5670.03	-2.095	-79.97	-81.59	0.265	0.270
183	467.8	462.19	0.2489	0.2503	0.940	0.941	171.57	174.39	497.45	491.58	1541.15	4028.79	5569.94	-2.424	-86.23	-87.65	0.247	0.251
184	467.25	463.13	0.444	0.445	0.974	0.975	180.3	182.8	497.45	491.58	1627.67	1773.08	3400.75	-1.267	-77.571	-78.65	0.425	0.431
185	463.55	459.15	0.383	0.384	0.968	0.969	148.0	149.6	478.99	474.7	1291.80	1801.45	3093.25	-1.043	-57.65	-58.28	0.393	0.388
186	467.34	462.55	0.44	0.44	0.973	0.974	169.85	170.60	494.95	493.07	1520.17	1697.40	3217.57	-2.292	-139.76	-140.38	0.423	0.425
187	467.5	462.5	0.614	0.614	0.987	0.987	183.45	185.79	499.84	494.06	1603.58	943.745	2547.32	-1.24	-103.18	-104.49	0.578	0.585
188	466.16	461.27	0.616	0.616	0.987	0.987	172.91	173.06	493.95	493.56	1479.44	886.36	2365.80	-1.898	-160.21	-160.35	0.586	0.587
189	467.9	462.73	0.586	0.586	0.985	0.985	161.0	162.0	494.15	493.07	1391.04	928.92	2319.96	-0.715	-57.49	-57.62	0.559	0.560
190	466.08	461.57	0.628	0.629	0.988	0.988	120.1	119.57	493.46	491.58	1023.89	572.08	1595.37	-1.214	-104.63	-105.06	0.598	0.601
191	532.84	530.05	0.709	0.709	0.983	0.983	178.8	181.3	906.2	894.90	2866.1	1135.11	4001.22	-2.16	-111.52	-113.09	0.358	0.363
192	531.23	528.53	0.720	0.72	0.984	0.984	185.09	186.1	890.00	885.67	2878.41	1123.65	4002.06	-0.714	-38.16	-38.37	0.371	0.373
193	531.75	528.84	0.684	0.685	0.981	0.981	154.72	157.13	901.48	889.15	2416.89	1141.75	3558.65	-1.898	-95.30	-96.79	0.349	0.354
194	531.88	528.48	0.639	0.639	0.976	0.977	134.13	135.7	900.98	891.63	2089.91	1199.49	3289.40	-0.0744	-3.5	-3.54	0.327	0.331
195	531.80	529.38	0.752	0.752	0.986	0.986	130	130.9	896.79	893.02	2006.7	721.3	2727.96	-0.17	-9.91	-9.95	0.383	0.385
196	531.27	527.95	0.656	0.656	0.979	0.979	86.3	87.0	885.02	878.72	1306.42	720.00	2026.9	-0.714	-35.15	-35.44	0.342	0.344
197	532.06	528.93	0.8047	0.805	0.990	0.990	154.83	157.17	899.95	887.66	2417.46	634.20	3051.65	-5.054	-296.13	-300.61	0.407	0.413
198	532.19	529.60	0.825	0.825	0.991	0.991	177.24	178.29	904.97	900.07	2798.73	635.49	3434.22	-0.846	-50.43	-50.73	0.414	0.416
199	530.97	527.86	0.428	0.428	0.947	0.947	130.6	131.2	886.02	882.69	2088.5	2464.69	4553.17	-0.583	-19.32	-19.407	0.23	0.23
200	Test Incompleted																	
201	525.09	529.38	0.022	0.014	0.366	0.215	-233.17	-192.49	848.51	893.6	3566.2	5437.6	57703	49.85	233.25	192.07	0.0325	0.0268
202	521.25	529.11	0.0283	0.0156	0.436	0.202	-273.74	-199.59	818.18	892.03	4008.99	56785.56	60794	76.75	399.15	291.02	0.0361	0.0263
203	525.26	529.51	0.0235	0.0138	0.3779	0.25	-164.52	-138.92	850.30	890.44	2747.56	37152.66	39900	49.14	234.02	197.60	0.0331	0.0279
204	525.87	529.154	0.0167	0.00715	0.2995	0.15	-124.08	-103.48	854.09	893.71	2168.04	31463.55	33631.6	45.592	194.27	162.01	0.0295	0.0296
205	448.99	465.42	0.0322	0.00395	0.658	0.156	-428.6	-182	415.14	502.9	3178.5	59432.6	62611.0	90.26	713.53	302.98	0.055	0.023

TABLE VI (contd.)

RESULTS OBTAINED FROM LOOP MEASUREMENTS DURING TWO-PHASE FLOW PUMP TESTS

Test	Temperature (°F)		Quality (wt fraction)		Void Fraction (volumetric fraction)		Volume Flow (US gpm)		Pressure (psia)		Flow Rate (lb/hr)			Pump ΔP ^[a]			Specific Volume (ft ³ /lb)	
	Pump Inlet	Pump Outlet	Pump Inlet	Pump Outlet	Pump Inlet	Pump Outlet	Pump Inlet	Pump Outlet	Pump Inlet	Pump Outlet	Steam	Water	Mass	(osid)	(ft of Inlet Fluid)	(ft of Outlet Fluid)	Pump Inlet	Pump Outlet
206	456.84	464.52	0.0189	0.0026	0.507	0.11	-217.0	-123.7	445.87	496.54	2076.65	42784.4	44861.6	52.02	291.12	165.63	0.0389	0.022
207	457.01	463.18	0.027	0.0066	0.528	0.243	-181.0	-115.5	448.26	491.88	1839.36	35994.4	35833.7	45.82	267.68	170.62	0.0457	0.0259
208	355.21	380.55	0.0387	0.0013	0.37	0.14	-84.6	-126.97	139.40	203.6	2269.12	45362.1	47631.2	65.67	1347.23	202.18	0.14	0.0214

[a] Pump ΔP measurement reported as (pump discharge pressure - pump suction pressure) irrespective of the direction of flow.

[b] Large constant frequency pressure oscillations present during data recording.

[c] Tests 19 through 27 were heat loss tests.

Tables V and VI were calculated through use of the homogeneous equation relating void fraction and density^[4]:

$$\rho_m = \alpha \rho_2 + (1 - \alpha) \rho_1 \quad (1)$$

where

$$\begin{aligned} \rho_m &= \text{mean density (lb/ft}^3\text{)} \\ \rho_2 &= \text{saturated vapor density (lb/ft}^3\text{)} \\ \rho_1 &= \text{saturated liquid density (lb/ft}^3\text{)} \\ \alpha &= \text{void fraction} \end{aligned}$$

and

$$\alpha = \frac{\rho_1 - \rho_m}{\rho_1 - \rho_2} \quad (2)$$

The difference in the applications of Equation (2) for computing void fraction is simply that in the case of the void fraction in the loop the calculated mean density was used whereas in the case of the void fraction in the test section the measured mean density at the cross section was used.

2.3 Pump Differential Pressure

The differential pressure measured across the pump for the two-phase tests should be subjected to the same corrections outlined in Section III-1.3 for the single-phase tests because the test section remained unchanged for both the single- and two-phase tests. That is, losses due to piping lengths and due to flow through the turbine flowmeter should be taken into account. In addition, the effect of elevation between taps should be considered for the two-phase tests. Elevation effects have not been included in the data presented in Tables V and VI. For the differential pressure measurements, in the test section elevation effects are for the most part relatively minor. The elevation between taps is 9.75 inches with the tap at the pump inlet the lower of the two. The same taps were used for both forward and reverse flow. The measurements in the test loop used two separate sets of taps for forward or reverse flow. For forward flow, the elevation difference is 39 inches with the tap at the pump inlet the higher of the two. For reverse flow, the elevation difference is 77 inches with the tap at the pump suction the higher of the two. In relating the loop and test section two-phase measurements, an appropriate two-phase multiplier should be used to account for the additional piping losses due to the locations of the loop pressure taps.

2.4 Volumetric Flow Rate

The basis for loop and test section values of volumetric flow rates for each test is the measured total mass flow rate. The loop values are based on the total mass flow rate and the calculated density whereas the test section flow rate is based on the measured total mass flow rate and the measured density at the pump inlet.

2.5 Other Measurements

Impeller speed, shaft torque, fluid temperature, and fluid pressure were measured in the same manner as in the single-phase tests.

2.6 Inconsistent Measurements

Review of the data obtained from measurements at the test section indicated several tests for which the measured pump differential pressure and measured fluid densities are inconsistent. The inconsistency of these measurements makes the use of the data from these tests suspect. Table VII presents a list of the tests in question together with a statement of the probable detector that is in error.

TABLE VII

INCONSISTENT MEASUREMENTS

<u>Test</u>	<u>Suspect Measurement</u>
28	Density measurement at pump outlet
30	Differential pressure measurement - measured ΔP within error range of detector
34	
35	Density measurement at pump outlet
36	
66	
67	Density measurement at pump outlet
76	
80	Density measurement at pump
82	inlet - temperature drift during
83	data recording period.
170 through 199	High void fraction tests - strati- fied flow at pump discharge suspected making the pump outlet fluid density measurement question- able.

IV. DATA REDUCTION PROCEDURES AND ERROR ANALYSIS

The test section measurement characteristics are summarized, the data reduction procedures (volts to engineering units) are described, and the measurement errors are analyzed. The loop measurement characteristics are also summarized and an error analysis is also presented for the loop measurements. A complete discussion of the loop measurements can be obtained from Reference 2.

1. TEST SECTION DATA REDUCTION PROCEDURES

All of the transducers used in the test section convert a physical phenomenon to an electrical signal with the exception of the system pressure transducer which is a direct pneumatic indicator. The electrical signals in turn are converted to engineering units. All the data and equations were processed on either a Monroe 1880 or a Hewlett-Packard 9100B calculator. Data reduction procedures for loop measurements can be obtained from Reference 2.

1.1 Fluid Density

The fluid density measurement was obtained by utilizing the nuclear physics principle of gamma attenuation. The expression of the output of the gamma densitometer as the average pipe density makes use of the assumption of a homogeneous mixture of the fluid.

If a collimated beam from a gamma source of intensity I_0 passes through a material of thickness x , the intensity I_x of the emergent beam is obtained as follows:

$$I_x = I_0 e^{-\mu x} \quad (3)$$

where μ = linear attenuation coefficient of the material.

By use of a sodium iodide, thallium activated NaI(Tl) crystal and photomultiplier tube (PM), the source intensity is converted to a proportional current which in turn can be linearly converted to a voltage by use of a current to voltage amplifier. Equation (3) then becomes

$$V_v = V_o e^{-\mu x} \quad (4)$$

Since the energy range of the gamma source (cesium-137) used in the pump tests is between 0.1 and 10 MeV, the dominant attenuation process is proportional to the mass of the material used as the attenuator (Compton Effect). By dividing the linear attenuation coefficient μ by the density ρ_x , Equation (4) can be expressed as follows:

$$V_x = V_o e^{-\alpha \rho_x x} \quad (5)$$

where α = mass attenuation coefficient.

Solution of Equation (5) for ρ_x provides an expression for the average density in the beam path as a function of the detector voltage output

$$\rho_x = \frac{\log A_2}{A_1} - \frac{\log V_x}{A_1} \quad (6)$$

where

$$A_2 = V_o \text{ (a constant)}$$

$$A_1 = \frac{1}{\alpha x} \text{ (a constant).}$$

In order to calibrate the density measurement system, at least two reference points must be obtained to acquire the constants A_1 and A_2 . Because of operational procedures during the pump tests, two reference fluid conditions could not be established conveniently; therefore, a steel shim 0.250 inch thick was used as a second reference point. This shim was inserted between the crystal-PM detector and the pipe wall. The equivalent water density of the shim was established by a separate test.

The procedure used was to establish a reference point in the single-phase fluid and to record the detector output with and without the shim in the beam path. Solution of Equation (4) for the constants for these two conditions results in:

$$A_1 = \frac{\log \frac{V_{REF}}{V_{SHIM}}}{\rho_{SHIM}}$$

and

$$A_2 = A_1 \text{ REF} - \log V_{REF}$$

where

V_{REF} = voltage out for single-phase fluid reference condition in the pipe

V_{SHIM} = voltage out with shim inserted while a reference condition is maintained in the pipe

ρ_{SHIM} = equivalent water density of the shim.

This procedure was performed at the beginning and ending of each test day.

Because of the long-term detector drift, a drift correction was used. The slope, $1/A_1$, has been verified a constant for a given setup through extensive laboratory and semiscale program testing, so the variable A_2 is the term that changes as a function of time. Therefore, a time-dependent expression of A_2 was derived as follows:

$$\log A_{2c} = \frac{(\log A_2|_{\text{REF 1}} - \log A_2|_{\text{REF 2}})}{t_1 - t_2} t_x + b$$

where

t_1 = time at reference condition 1 (beginning of calibration period)

t_2 = time at reference condition 2 (end of calibration period)

t_x = time of two-phase measurement

b = zero intercept.

The reduction equation becomes

$$\rho_x = \frac{\log A_{2c}}{A_1} - \frac{\log V_x}{A_1}$$

1.2 Differential Pressure

The differential pressure data were obtained from bonded strain gage diaphragm-type transducers. Several differently ranged transducers were used during the two-phase tests. Table VIII gives a complete listing of the transducers used during each test. To obtain units of pounds per square inch differential (psid) the strain gage output was multiplied by the sensitivity factor (psid/volt) which was obtained in the calibration laboratory using a precision dead-weight tester. The normal way of expressing pump head data is in feet and because the transducers are sensitive to system pressure (that is, the zero sensitivity changes as a function of system pressure) the following equation was used:

$$\text{Pump head (ft)} = \frac{(V_x - mx)K (144)}{\rho_x G}$$

where

V_x = transducer output voltage

m = pressure sensitivity (change in zero output as a function of system pressure)

x = actual system pressure

K = calibration factor, psid/volt

TABLE VIII

TEST SECTION DIFFERENTIAL PRESSURE TRANSDUCER RANGE

<u>Test</u>	<u>Transducer Range (+ psid)</u>
1 through 39	100
40 through 55	50
57 through 63	3.6
64 through 74	50
75 through 78	3.6
79 through 80	50
81 through 83	3.6
84	50
85 through 90	10
91 through 98	50
99 through 100	10
101 through 107	50
108 through 109	10
110 through 118	50
119 through 121	10
122 through 126	50
127 through 130	10
131 through 137	50
138 through 140	10
141 through 165	50
170 through 199	10
200 through 209	50

G = gain of amplifier

ρ_x = density of fluid as obtained from the gamma densitometer

144 = conversion factor, in.²/ft².

1.3 Other Measurements

All other transducer data were converted to engineering units through use of a linear calibration factor m:

$$\text{Engineering units} = \text{volts output times } m$$

where

m = engineering units/volts out.

2. ERROR ANALYSIS

Tables IX and X list the complete test section and loop measurement characteristics and a summary of the results of the error analysis, respectively.

The measurement characteristics include the transducer type, transducer vendor, transducer range, transducer response, and data acquisition system response.

To obtain the maximum error limits (95% confidence), the linear error summation method was employed as follows:

$$\epsilon_{\max} = \sum_{i=1}^{k=k} |s_i e_i|$$

where

S_i = sensitivity of the result to the quantity x_i

e_i = the estimated error in the quantity x_i

K = the number of quantities containing the error in determining the result.

The maximum errors are listed separately for the transducers and the data acquisition and processing system.

The 95% confidence error limits were obtained by applying the quadratic error summation technique (room-sum-square) to the individual transducer error estimates and the errors due to data acquisition and data processing as follows:

$$\epsilon_{95\%} = \left[\sum_{i=1}^{k=k} (s_i e_i)^2 \right]^{0.5}$$

TABLE IX

TEST SECTION MEASUREMENT CHARACTERISTICS AND ERROR LIMITS

Measurement	Vendor	Type	Transducer or Measurement Range Full Scale	Transducer Risettime ^[a] (msec)	Data System Response Time ^[b] (sec)	Maximum Error Limits ($\pm\%$ of full scale)		Probable Error at 95% Confidence Level ($\pm\%$ of Full Scale) ^[c]
						Transducer	Data System	
Differential pressure	BLH Electronics, Inc.	Strain gage	100 psid	50 ^[d]	2 ^[d]	0.52	0.4 ^[b]	0.66
			50			0.35		0.472
			10.8			0.8		0.748
			3.6			0.6		0.72
Pressure	Precise Sensors, Inc. Heise Bourdon Tube Company, Inc.	Strain gage	0 to 3000 psig	0.035	2	0.1	0.4	0.412
		Bourdon tube	0 to 1000 psig			0.1		0.117
Temperature	Aerojet Nuclear Company	Chromel-Alumel thermocouple	0 to 600°F ^[e]	10	2	1.0	0.45	1.097
Volumetric flow rate	Flow Technology, Inc.	Turbine	40 to 800 gpm -40 to -800 gpm	5	2	0.6	0.1	0.608
Fluid density	Technical Operations, Inc. and Aerojet Nuclear Company	Gamma attenuation	0.6 to 62.4 lb/ft ³	3.5	2	0.5	0.5	0.707
Momentum flux	Ramapo Instrument Company, Inc.	Drag disc on strain-gaged beam	-100 to 2x10 ⁴ lb/ft-sec ² -100 to -2x10 ⁴ lb/ft-sec ²	23	2	0.5 ^[f]	0.5 ^[f]	0.707 ^[f]
Pump torque	Lebow Associates, Inc.	Strain-gaged slip rings	$\pm$ 500 in./lb ^[e]	1	1	0.5	0.4	0.640
Pump speed	Lebow Associates, Inc.	60-tooth gear and proximity detector	$\pm$ 3600 rpm ^[e]	1	1	0.1	0.1	0.141

[a] Risettime is defined as the time required for the indicated system to go from 10 to 90% of the value of an impressed step input (rated maximum output).

[b] Response time is defined as the time required for the indicated system to go from 0 to 90% of the value of an impressed step input.

[c] Obtained by using the quadratic error summation technique or root sum of the squares error technique.

[d] Values given apply to all measurements within a category unless otherwise indicated.

[e] Range of measurement system.

[f] Expressed as $\pm\%$ of reading.

TABLE X

LOOP MEASUREMENT CHARACTERISTICS AND ERROR LIMITS^[a]

Measurement	Vendor	Type	Range (full scale)	Response Time ^[b]		Maximum Error Limits (% of full scale)
				Transducer (msec)	Data System (sec)	
Differential pressure	Viatran Corp.	Strain gage	50 psid	100	5	0.09
			200 psid			0.02
	Statham Instrument, Inc.	Strain gage	50 psid			0.09
Pressure	Viatran Corp.	Strain gage	0 to 1500 psig	1	5	0.06
	Statham Instrument, Inc.	Strain gage	0 to 1500 psig	1	5	0.06
	Heise Bourdon Tube Company, Inc.	Bourdon tube	0 to 1500 psig	250	5	0.06
Temperature		Chromel-Alumel thermocouple	75 to 600°F	10	5	0.38
Volumetric flow	Westinghouse Canada Limited			100	5	
Small boiler		Venturi and differential pressure transducer	1000 to 6000 lb/hr			1.5
Large boiler		Venturi and differential pressure transducer	6000 to 30,000 lb/hr			1.0
Large recirculator		Orifice and differential pressure transducer	50,000 to 120,000 lb/hr			0.6
Small recirculator		Orifice and differential pressure transducer	10,000 to 60,000 lb/hr			1.0
Medium steam		Orifice and differential pressure transducer	3000 to 9000 lb/hr			1.5
Small steam		Orifice and differential pressure transducer	800 to 4000 lb/hr			1.5

[a] Data reproduced from Reference 2.

[b] Values given apply to all measurements within a category unless otherwise indicated.

V. REFERENCES

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