# PULSED HEAT TRANSFER

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SCOPE AND CONTENTS:

The "Water-Blow" Pulsation generator has been used to produce pulsing fluid flow in an off-the-shelf industrial single pass heat exchanger containing 5/8 in. O. D. tubes, 37 inches long. Experimental results showed that heat transfer from steam to flowing water could be enhanced by as much as 100%, although a more practical enhancement would likely be about 40%. From the experimental results it was estimated that pulsing air requirement (standard cu. ft. air per cu. ft. water) increased linearly from about 0 to 4.0 over a range of heat transfer enhancement from 0 to 40%. Two factors which influenced pulsing air requirement were the air surge volume sizes and the pressure fluctuations which occurred therein.

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# INTRODUCTION

There has been considerable research activity in pulsed heat exchange since the first paper on this subject was published by Martinelli(1) in 1943. An extensive review of the work carried out up to 1961 is available in a paper by Lemlich(2). Most of the experimental results reviewed in Lemlich's paper were done in small scale single tube exchangers using conventional pulse generators such as reciprocating pumps or flow interrupters. The reported results of these are in considerable disagreement. However, from this review and later work by Lemlich and Armour(3) and Baird(4), it would appear then an improvement of as much as 50% should be possible.

There are no known industrial applications of a pulsed heat exchanger, perhaps because the heat exchanger equipment would not justify the cost of a conventional pulse generator, or because most of the pulsed heat transfer research has been done on such a small scale that it cannot be meaningfully related to industrial operations.

In order to overcome the electrical and mechanical weaknesses of conventional pulse generators, Baird(5, 6) has devised the so-called "Water Blow" Pulsation technique which is self-triggered and involves no mechanical moving parts or electrical components. The original work(5) on "Water Blow" pulsation was essentially concerned with lightly damped systems and comparatively low liquid throughputs, as are typical in solvent extraction. Recently a "Water Blow" Pulsation Generator, capable of handling high overall throughputs and resistances in 3/4" and 2" diameter pipes was constructed and is described in an M. ENG. thesis by Mr. C. R. Milburn(7).

The work described in this report was done using Milburn's Pulsation generator. An OC2 - 6" Oil Cooler was purchased from the S. A. Armstrong Limited and fitted into Milburn's apparatus, which required only minor modifications.

The main objective of the present work was to determine the effect of fluid flow pulsations on the overall heat transfer coefficient in an industrially made heat exchanger.

Tests were carried out under both steady state and pulsed flow conditions. A tube bundle containing twelve tubes was used for most of the work but as it will be shown some tests were necessary on a tube bundle containing four tubes.

The experimental results were compared to the predictions of a quasi-steady state theory (see p. 4.)
It was found that the theory often underestimated the improvement in heat transfer at high fluid velocities and overestimated the improvement at low fluid velocities.

A record was kept of the air additions for the pulsed flow tests and an attempt was made to determine some of the factors affecting air requirements.

# I THEORY

## A) STEADY STATE OPERATION

The steady state overall heat transfer coefficient, $U_{ST}$, for a condensing vapor transferring heat to a flowing fluid can be calculated from the following equation:

$$q = U_{ST} \times AR \times (\Delta T_{ln}) = M \times Cp \times \Delta T \qquad (1)$$

where q - heat transferred per unit time

AR - heat transfer area

$\Delta T_{ln}$ - natural log mean temperature difference

$$\Delta T_{ln} = \frac{T_o - T_1}{\ln \frac{T_1 - T_{SM}}{T_o - T_{SM}}}$$

where $T_1$ = entering water temperature

$T_o$ = exit water temperature

$T_{SM}$ = steam temperature

M - mass flow rate

$C_p$ - fluid heat capacity

$\Delta T$ - temperature gain or loss of the flowing fluid.

$U_{ST}$ can be further broken down into a film heat transfer coefficient, $h_f$, and a tube and shell side heat transfer coefficient, $h_s$, by means of a Wilson plot as described in Perry's Handbook(8).

The film heat transfer coefficient $h_f$ can also be predicted using the Dittus-Boelter equation(9).

$$\frac{h_f D}{k} = 0.023 \; \frac{DG}{\mu}^{0.8} \; \frac{\mu C_p}{k}^{0.4} \tag{2}$$

which applies to fluids of low viscosity being heated.

### B) PULSED FLOW OPERATION

It has been proposed(1, 2, 4) that probably the simplest theoretical treatment for predicting improvements in heat transfer for a pulsed fluid system is by using the "quasi-steady" state theory.

In this theory, it is assumed that the frequency of pulsation is low enough that usual steady-state correlations hold at every instant. Integration is then carried out with respect to time over a complete cycle to find the average coefficient.

It is assumed that a sinusoidal curve describes the fluid velocity or:

$$V = \bar{V}_{ST}(1 + \alpha \sin wt)$$

where $V$ - is the instantaneous fluid velocity

$\bar{V}_{ST}$ - is the mean fluid velocity

$\alpha$ - DPV or dimensionless pulsation velocity, which is the ratio of maximum fluctuation to the mean fluid velocity

$w$ - angular frequency

At steady state the Wilson plot may be used to determine A and B in the equation:

$$\frac{1}{U_{ST}} = A + \frac{B}{\overline{V}_{ST}^{\,0.8}} \qquad (4)$$

Assuming quasi-steady behaviour of the pulsating system this equation (4) would be written as:

$$\frac{1}{U_{PU}} = A + B \;/\; \overline{V}_{ST}^{\,0.8}(1 + \alpha \sin wt)^{0.8} \qquad (5)$$

where $U_{PU}$ is the overall heat transfer coefficient in pulsating flow, thus combining equations (4) and (5) gives

$$\frac{U_{PU}}{U_{ST}} = 1.0/\; 1. + \frac{(1. + \alpha \sin wt)^{-0.8} - 1.}{1. + A \times \overline{V}_{ST}^{\,0.8}/B} \qquad (6)$$

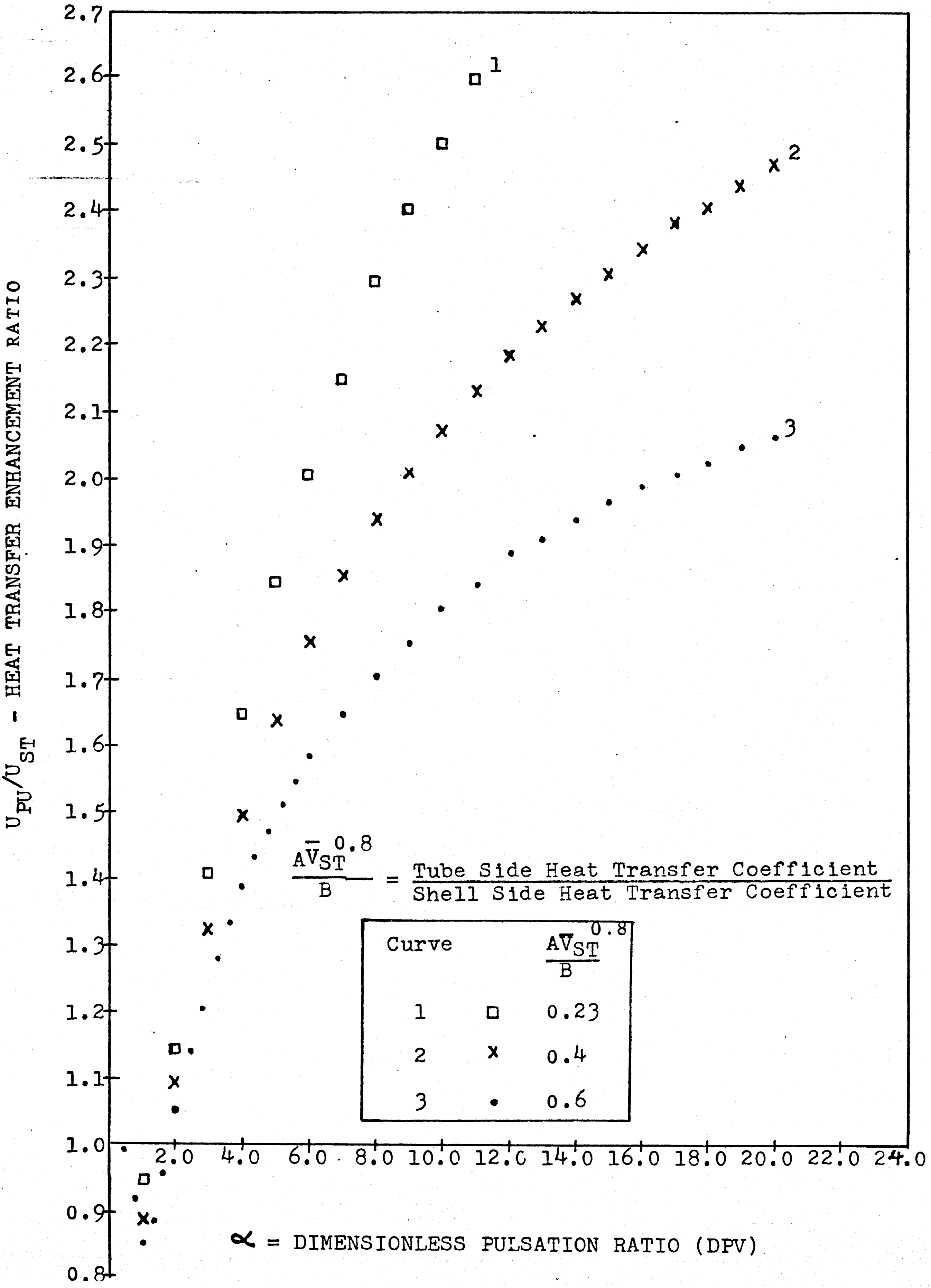
The time average value of $U_{PU}/U_{ST}$ can be got by the numerical integration with respect to time of the right hand side of equation (6). This was done for value of $A.\overline{V}_{ST}^{\,0.8}/B$ equal to 0.23, 0.4 and 0.6 over a range of $\alpha$ (DPV) from 0 to 20, using a third order Runger-Kutta integration computer program which is given in Appendix I. The actual range of DPV in the experimental runs varied between 0 and 10.0. A description of how DPV is measured is given on P. 21. The results are plotted in Figure 1 and indicate the following:

1) The heat transfer enhancement ratio ($U_{PU}/U_{ST}$) should decrease below the steady state value for DPV's in a range from 0 to approximately 2.0.

2) The enhancement ratio is dependent upon the ratio of $A \times \overline{V}_{ST}^{\,0.8}/B$. For example at a given value of DPV, $U_{PU}/U_{ST}$

FIGURE 1

THEORETICAL ENHANCEMENT OF THE OVERALL HEAT TRANSFER COEFFICIENT



$$\frac{A\bar{V}_{ST}^{0.8}}{B} = \frac{\text{Tube Side Heat Transfer Coefficient}}{\text{Shell Side Heat Transfer Coefficient}}$$

should increase with decreasing mean fluid velocities.

3) $U_{PU}/U_{ST}$ for any $A_x\overline{V}_{ST}^{0.8}/B$ should approach a limiting value. For example with $A_x\overline{V}_{ST}^{0.8}/B = 0.6$. the limit of $U_{PU}/U_{ST}$ should be 2.67.

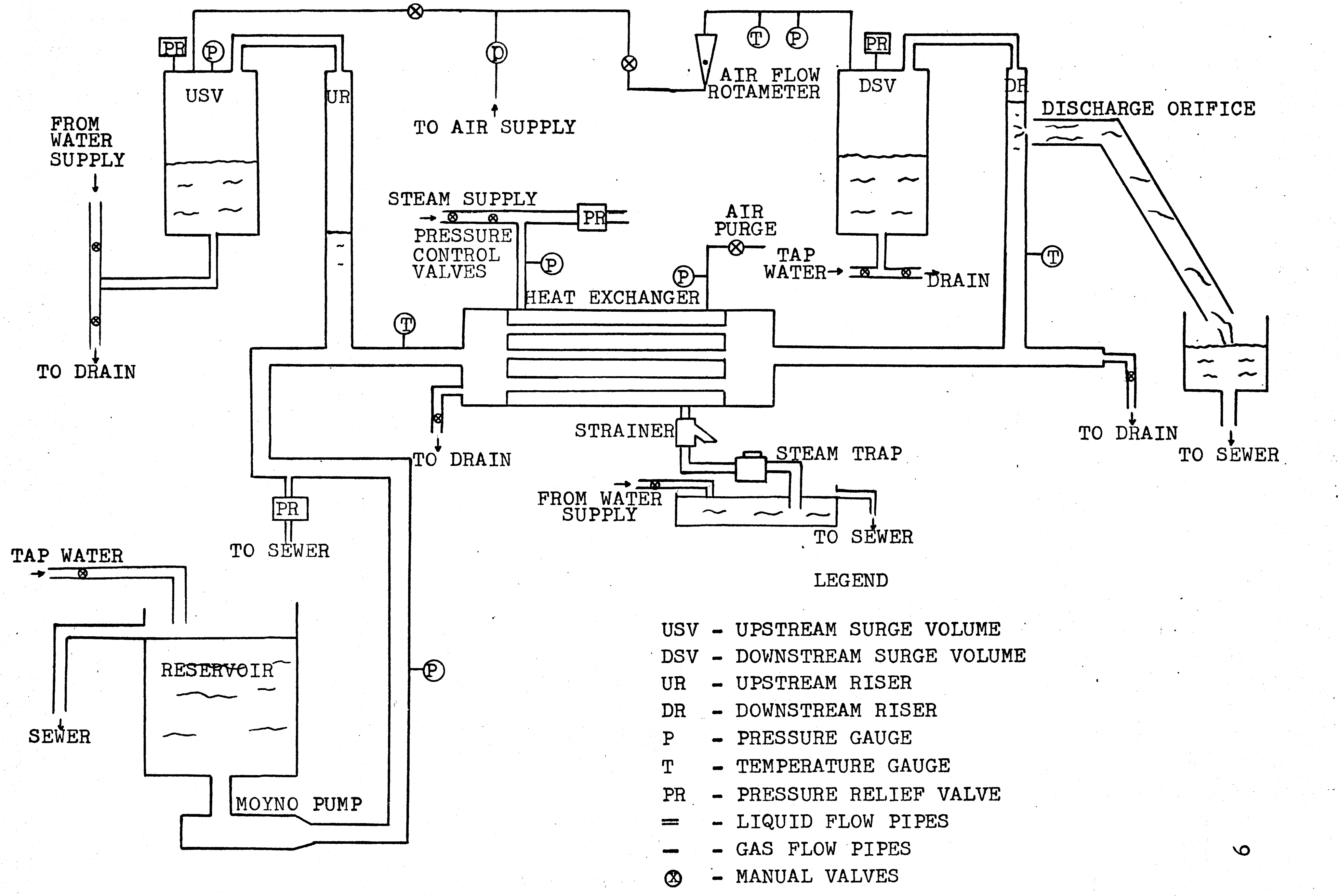
## II DESCRIPTION OF THE APPARATUS

The "Water Blow" pulsation generator that was used to produce pulsed flow was built by Mr. C. R. Milburn and is described in his M. Eng. Thesis(7).

Figure 2 shows a detailed schematic diagram of the apparatus used for the present work. The additions made to Milburn's "Water Blow" Pulsation generator were:

i) HEAT EXCHANGER - this was inserted into the apparatus as the process equipment. The exchanger is a single pass OC2 - 6" Oil Cooler, manufactured by S. A. Armstrong Limited, Toronto, Canada. The main design specifications are given in Table 1. Inside and outside tube diameters were found in Ref. (8) using the specifications supplied by the manufacturer. Outside tube diameters were also checked with calipers and found to be 0.625 ± 0.001 in. Tube length was measured from tubesheet to tubesheet with a steel rule and found to be 37.0 ±0.10 in. The shell surface of the exchanger, between the flanges, which enclosed the tubes was covered with 1" thick Fiberglas insulation.

ii) STEAM TRAP - a 3/4 in. diameter Sarco Thermodynamic Type trap was installed after a strainer that was fitted to the heat exchanger. The condensate from the steam trap was discharged into a bucket that was continuously fed with cold tap water. In this way flashing condensate did not



LEGEND

USV - UPSTREAM SURGE VOLUME
DSV - DOWNSTREAM SURGE VOLUME
UR - UPSTREAM RISER
DR - DOWNSTREAM RISER
P - PRESSURE GAUGE
T - TEMPERATURE GAUGE
PR - PRESSURE RELIEF VALVE
═ - LIQUID FLOW PIPES
— - GAS FLOW PIPES
⊗ - MANUAL VALVES

FIGURE 2. FLOWCHART FOR WATER BLOW PULSATION WITH A HEAT EXCHANGER

discharge into the room. According to the manufacturer's literature the trap could handle 1000 lbs./hr. of condensate at saturated steam temperature using 10 psig. steam. This was satisfactory for our requirements.

iii) THERMOMETERS - two Premium Instrument (range 20 to 240 °F) thermometers were fitted into the apparatus, one was installed 3.5 feet from the heat exchanger in the water feed line. The other was installed 4.5 feet from the discharge of the heat exchanger, in the 2" discharge line.

iv) STEAM LINE - a 3/4 in. diameter, 100 psig. steam line was connected to an opening on top of the heat exchanger. Two valves were set in this line, one was used as coarse control and the other as a fine control for the steam pressure in the heat exchanger shell. The line was covered with 1 inch thick Fiberglass insulation.

v) AIR PURGE - this was a 1/2 in. diameter line leading from the heat exchanger through which steam or air could be bled at any time through a valve.

vi) PRESSURE GAUGE - a Weksler pressure gauge reading from 30 inches vacuum to 30 psig. pressure was placed on the air purge line before the valve.

vii) PRESSURE RELIEF - a 3/4 in. Lunkenheimer-Morrison valve set to discharge at 50 psig. was installed on the steam line after the control valves.

Modifications made to Milburn's "Water Blow" Pulsation Generator were:

i) The glass downstream riser was replaced with 6 feet of 2 in. D. galvanized pipe. A discharge, 1 1/64 in. in diameter was drilled 4 feet above the bottom of the pipe. Copper strips with desired discharge orifice diameters were available that could be clamped over the drilled opening.

ii) The reservoir was used as a holding tank for tap water. The "Moyno" brand screw pump forced water through the apparatus directly to a sewer rather than recirculating it to the reservoir.

iii) All instrumentation wires for level and pressure measurements were removed from the apparatus.

iv) For most of the tests, compressed air was available at only 70 psig. rather than the normal 118 psig. The range of the air inflow measured by the rotameter at 70 psig. was taken to be 0.010 to 0.134 scfs.

v) In order to facilitate insertion and removal of the heat exchanger the piping layout in the process section between the upstream and downstream risers was made as simple as possible. There were no valves or bypass lines for control of water flow in this section of the apparatus. All piping, unions and elbows used were 2" diameter galvanized pipe.

## TABLE 1

## DESIGN SPECIFICATIONS OF THE OC2 - 6" OIL COOLER

1) Catalog No. OC2-63 S.A. Armstrong Ltd, Toronto, Ontario.
2) Serial No. 34654
3) Maximum Temperature - 375 °F
   (Shell and Tubes)
4) Maximum Pressure - 150 P.S.I.
   (Shell and Tubes)
5) Hydrostatic Test Pressure - 225 P.S.I.
6) Overall Length - 44.5 in.
7) Overall Outside Diameter - 10.5 in.
8) Shell Outside Diameter - 6.625 in.

## TUBE BUNDLE

### A) ORIGINAL TUBE BUNDLE SUPPLIED WITH THE EXCHANGER

1) Number of Tubes - 36
2) Tube Outside Diameter - 0.625 in.
3) Tube Inside Diameter - 0.527 in.
4) Tube Length - 37 in.
5) Tubes on a Triangular Pitch, Center-to-center Distance of 0.75 in.
6) Material of Construction - ASTM-B111-52T Copper

## TABLE 1 CONT.

### B) REPLACEMENT TUBE BUNDLE

1) Number of Tubes - 12
2) Tube Outside Diameter - 0.625 in.
3) Tube Inside Diameter - 0.527 in.
4) Tube Length - 37 in.
5) Tubes on a Triangular Pitch, Center-to-center Distance of 1.5 in.
6) Material of Construction - #18 BWG Admiralty Brass

# III EXPERIMENTAL PROCEDURE

## A) OPERATING VARIABLES

The modifications to the "Water Blow" pulsation generator did not appreciably change the range of operating variables that are described in Milburn's Thesis(7). They are reproduced in this report together with additional new work and any relevant comments.

### 1) Surge Volumes

The downstream glass riser was replaced with galvanized pipe of equivalent diameter. Thus there should be little or no change in the surge volumes that were calculated by Milburn(7). The values used in the present report are given in Table 2.

TABLE 2

AIR SURGE VOLUMES AS A FUNCTION OF WATER HEIGHT

| Downstream Steel Tape Reading (in.) | Surge Volume (cu. ft.) | Upstream Steel Tape Reading (in.) |
|---|---|---|
| 52.1 | 0.2 | 52.9 |
| 71.1 | 0.5 | 70.1 |
| 90.9 | 0.8 | 89.3 |

## 2) Liquid Throughput

The throughput of water can be determined by the "Moyno" pump speed. The flowrate through the system was determined by two methods. The first was simply to weigh a quantity of water discharging from the heat exchanger over a period of time. The second method was to determine the decrease in the height of water in the reservoir over a period of time. Measurements of the reservoir diameter and height of water were accurate to within ± 1/8 in. The results of the tests are given in Table 3.

### TABLE 3

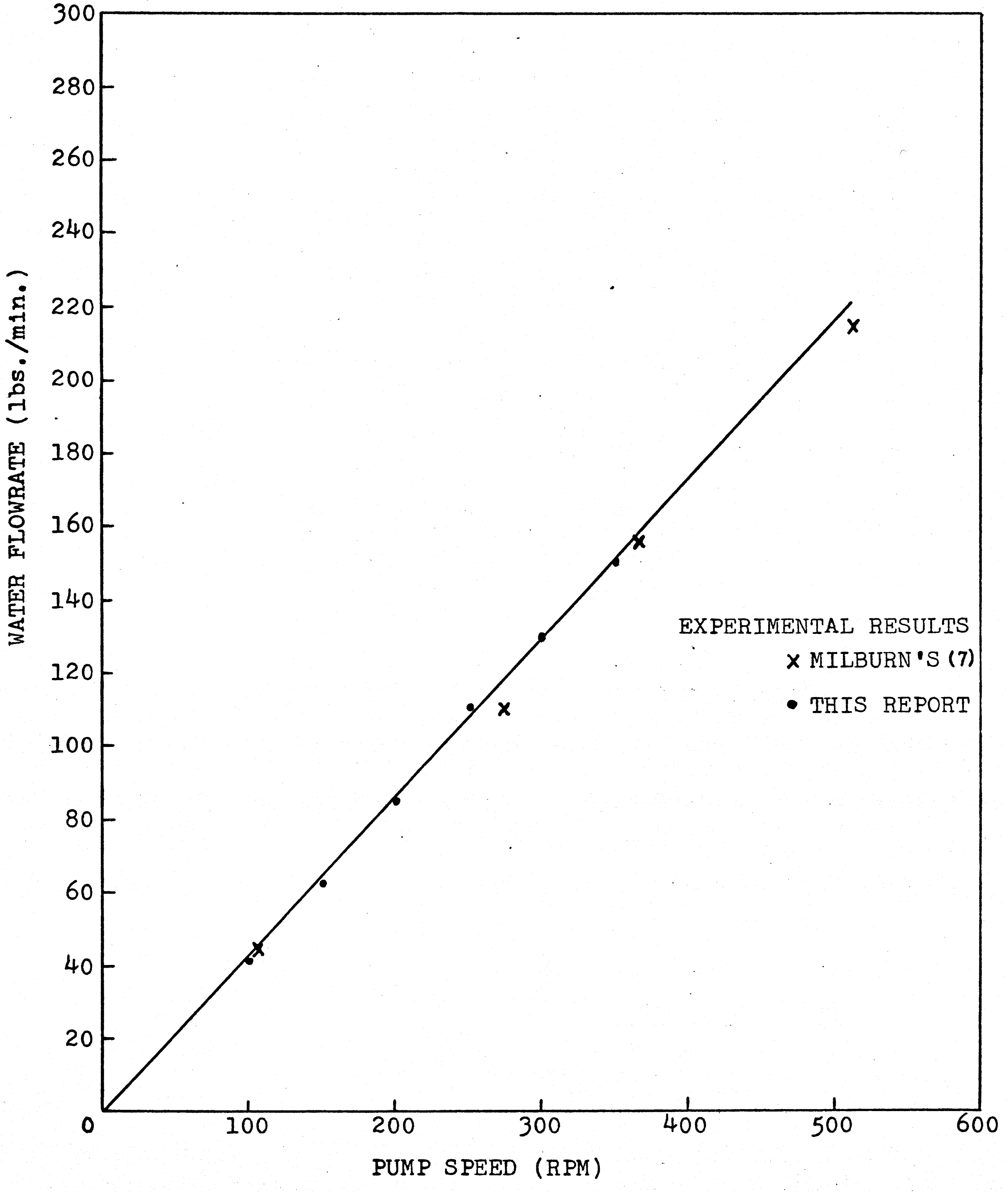
### CALIBRATION OF THE MOYNO PUMP

| | Calibration Method | |
|---|---|---|
| Pump Speed (RPM) | Weighing (lb./min.) | Height of Reservoir (lb./min.) |
| 100 | 41.4 | 42.2 |
| 150 | 63.5 | 65.0 |
| 200 | 85.1 | 85.8 |
| 250 | 108.5 | 111.1 |
| 300 | not done | 130.5 |
| 350 | not done | 151.2 |

The results in Table 3 are compared with those of Milburn(7) in Figure 3. It is seen that there is good

## FIGURE 3

## CALIBRATION OF MOYNO PUMP



agreement of the results. In subsequent work a value of 0.425 lb./revolution was used.

### 3) Air Flowrates

The calibration curve for airflow through the rotameter at 118 psig. is shown in Figure 4. Also shown is a curve for airflow at 70 psig., which is the pressure used for most of the tests that are to be described in this report. The relation used to calculate this curve was taken from reference (9).

$$\text{AIRFLOW (70 PSIG)} = \text{AIRFLOW (118 PSIG)} \times \sqrt{\frac{70 + 14.7}{118 + 14.7}} \qquad (7)$$

## B) DESCRIPTION OF EXPERIMENTAL METHODS AND TECHNIQUES

The experimental work was divided into two sections. These were: 1) Steady State tests and 2) Pulsed Flow tests.

### 1) Steady State Tests

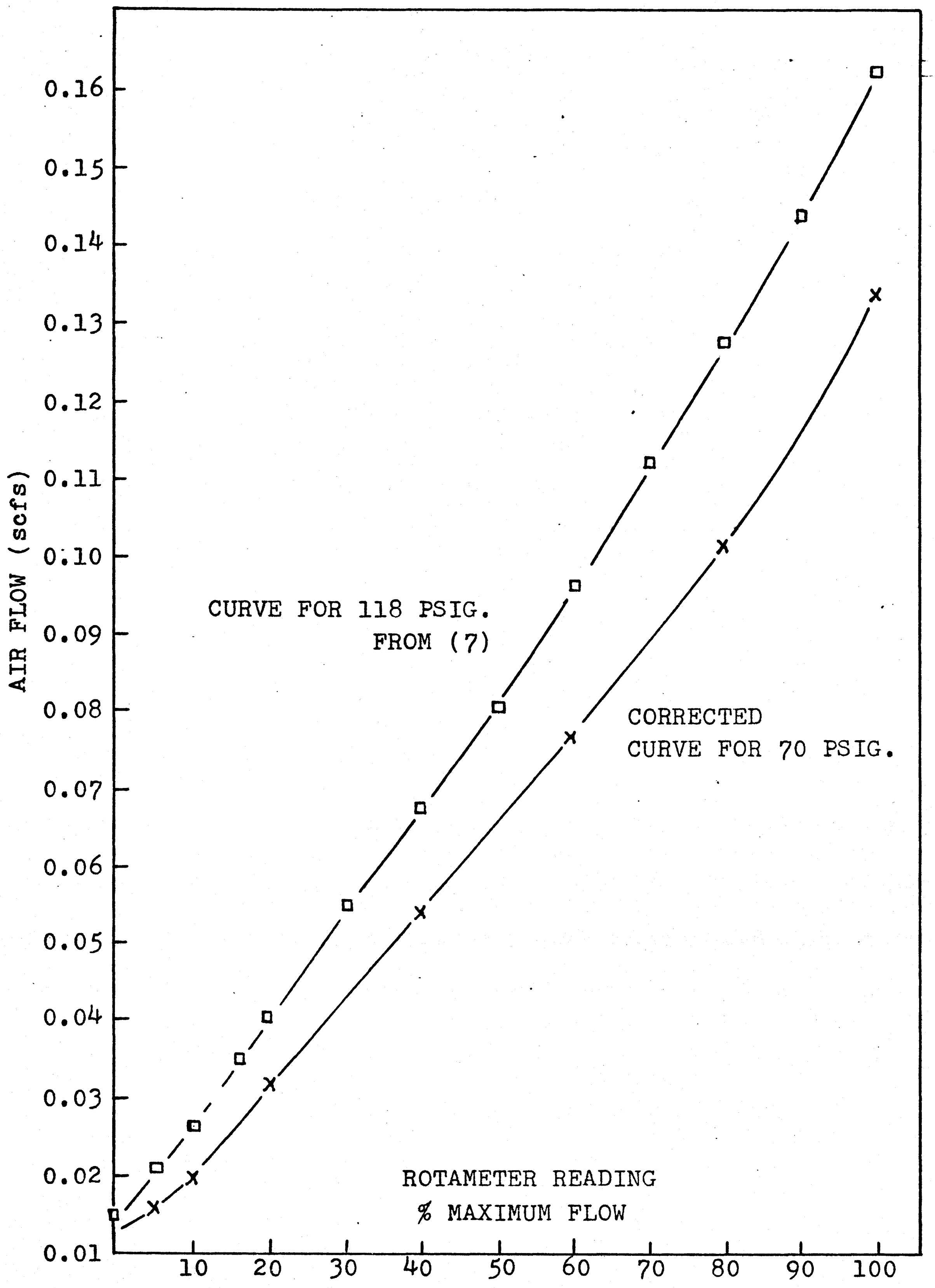
These tests were carried out for the following reasons:

a) To make heat balances that would aid in determining if there were any defects in the apparatus such as leaks through the tubes or the graphite packing material.

b) To determine values for the constants A and B which were required for equation (4). Tests using various flowrates were done over short periods of time in order to

FIGURE 4

CALIBRATION CURVE FOR AIR ROTAMETER



minimize the effects of uncontrollable variables such as scaling of the heat exchanger tubes and variations in the air content of the steam.

c) To find and eliminate any defective thermometers or pressure gauges.

The experimental technique used in the steady state tests was as follows:

Initially, all the drain valves on the apparatus were closed and the tap water valve to the reservoir and the air purge line on the heat exchanger were opened. The Moyno pump was started and set to a desired flow with a strobe-lite for over 110 RPM and by counting revolutions when flows under 110 RPM were required. Tap water flow to the reservoir was adjusted until a constant level was obtained. These conditions were maintained until both temperature gauges, before and after the heat exchanger were reading the same constant temperature as the water in the reservoir. When this was achieved the 100 psig. steam line was opened into the heat exchanger and controlled manually to a shell pressure not greater than 2 psig. When live steam was blowing through the air purge line, the valve on that line was closed and the steam pressure was allowed to build up to a desired level by hand manipulation of the steam control valves. A steady state temperature on the downstream side of the heat exchanger was usually obtained within 1 - 2 minutes.

For a different water flow rate the Moyno pump was set to the desired value. If water in the risers overflowed into the surge volumes, air was added to increase the pressure in the upstream surge volume. The range of flowrates, using this method was limited by a self imposed limit of about 10 psig. in the surge volumes. Higher flowrates were got by increasing the diameter of the discharge.

## 2) Pulsed Flow Tests

The procedure followed in these tests was identical to that outlined in the steady state tests except as follows:

For fluid pulsation, air was passed through the rotameter into the downstream surge volume. For each mean water flowrate the temperature in the downstream riser was recorded at rotameter readings of 10, 20, 40, 60, 80 and 100% of maximum calibrated air flow. In a few cases all levels of air flow could not be tested because multiple pulsations occurred or upstream surge volume pressure became too high. Attempts were made within each flowrate to perform runs at three levels of surge volumes (0.2, 0.5 and 0.8 cu. ft.)

For each level of air flow the following operating procedure was used. The valves on the steam supply line were manually controlled so that the pressure gauge that was mounted on the air purge line was as close as possible to the desired value. It should be noted that the shell side steam pressure often fluctuated as much as ± 3 psig. under pulsed flow conditions. When the average desired steam pressure was obtained the frequency of fluid pulsations was counted over a period of one minute to within ± 0.5 pulsations per minute. Then the maximum and minimum heights of water in the upstream riser were recorded, usually to within ± 0.25 inches. Also the maximum and minimum pressures in the upstream surge volume were noted. During this time any necessary corrections to maintain desired steam pressure and air flow were made. Finally the temperature of the water in the downstream riser was read and recorded. The total time required for one such test was usually not more than 3 minutes.

The dimensionless pulsation velocity DPV, also referred to as $\alpha$ in equations (5 - 6), was calculated thus:

$$\text{DPV} = \pi \times (\text{Stroke}) \times (\text{Frequency}) / \bar{V}_{ST}$$

In this way, for a sinusoidal wave form, flow reversal would occur when the DPV exceeds 1.0.

# IV RESULTS AND DISCUSSION

## A) HEAT BALANCES FOR STEADY STATE OPERATION

Two series of tests were made in order to attempt to make heat balances across the heat exchanger.

### Series I

The first set of tests was done with a tube bundle containing 36 tubes as received from the Armstrong Company, and fitted with the new steam trap. The experimental method used has already been described. For each test, condensate was collected in a graduated beaker over a period of 15 seconds. Condensate flow from the steam trap appeared to be steady during these tests. The data and results are shown in Table 4. The total heat in, was calculated assuming the condensate was formed from dry saturated steam. Total heat out, was calculated from the water flowrate and its temperature rise. There is good agreement between total heat in and out of the exchanger. The % error was calculated from 100 x (total heat in - total heat out)/total heat out. The largest error found in this manner was 4.5%. These tests showed that experimental errors were small and that heat losses due to radiation and convection to the ambient air could be neglected. The tests confirmed, approximately, the assumption of a dry saturated steam supply. It also showed that we were limited to a maximum flowrate of

## TABLE 4

## HEAT BALANCES FOR STEADY STATE OPERATION

Series I - 36/36 Bundle* Steam Pressure - 10 psig.

| Test No. | Water Flow (RPM) | Water Flow (lb./min.) | Water Temp. (°F) In | Water Temp. (°F) Out | Measured Condensate Flow (cc/15 sec.) | Total Heat In (BTU/min.) | Total Heat Out (BTU/min.) | % Error |
|---|---|---|---|---|---|---|---|---|
| 1 | 110 | 46.8 | 50 | 193 | 835 | 6700 | 7000 | 4.5 |
| 2 | 150 | 63.8 | 50 | 156 | 840 | 6760 | 7040 | 4.2 |
| 3 | 200 | 85.0 | 50 | 137 | 870 | 7390 | 7300 | - 1.2 |
| 4 | 250 | 106.3 | 50 | 121 | 870 | 7550 | 7300 | - 3.3 |

Series II - 12/4 Bundle* Steam Pressure (10 psig. - Tests 1 - 4)

Steam Pressure (2 psig. - Tests 5 - 8)

| Test No. | Water Flow (RPM) | Water Flow (lb./min.) | Water Temp. (°F) In | Water Temp. (°F) Out | Measured Condensate Flow (lb./min.) | Heat In (BTU/min.) | Heat Out In Water (BTU/min.) | Heat Out Live Steam In Condensate (BTU/min.) | Heat Out Total | % Error |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 200 | 85.0 | 55 | 96 | 4.69 | 4460 | 3480 | 860 | 4340 | - 2.8 |
| 2 | 250 | 106.3 | 54 | 91 | 5.15 | 4910 | 3930 | 816 | 4746 | - 3.5 |
| 3 | 300 | 127.5 | 54 | 88 | 5.24 | 5000 | 4340 | 733 | 5073 | 1.4 |
| 4 | 400 | 170.0 | 54 | 82.5 | 5.93 | 5650 | 4850 | 697 | 5547 | - 1.9 |
| 5 | 200 | 85.0 | 55 | 92 | 3.75 | 3620 | 3140 | 327 | 3467 | - 4.4 |
| 6 | 250 | 106.3 | 55 | 88 | 4.13 | 3990 | 3500 | 345 | 3845 | - 3.8 |
| 7 | 300 | 127.5 | 54 | 84 | 4.32 | 4160 | 3820 | 247 | 4067 | - 2.3 |
| 8 | 400 | 170.0 | 54 | 79 | 4.74 | 4590 | 4250 | 257 | 4507 | - 1.8 |

* See description of bundle nomenclature on page 83

about 106 lb./min., when using 10 psig. steam in the shell. Since we wished to operate at higher flowrates and lower steam pressures the only alternative was to obtain a tube bundle containing fewer tubes. A new tube bundle containing 12 tubes was therefore ordered from the S. A. Armstrong Co. Ltd.

## Series II

At the conclusion of the experimentation with pulsed fluid flow a second series of steady state tests was done in order to determine whether any changes had taken place in the equipment. At this time the new tube bundle contained only four active tubes carrying water. The other eight tubes had been blocked with 1/2 in. diameter steel rods bolted tightly into the tubes.

For these tests condensate was collected over a period of one minute in a bucket containing a weighed amount of tap water. Heat balances were made as in the first series of tests. Very poor agreement was found between heat in and heat out. The steam trap was suspected of leaking steam and the tests were rerun. In the rerun tests the initial and final temperatures of the tap water and tap water-condensate mixture were measured.

An unexpected temperature rise of the water-condensate mixture could be explained by steam escaping through the steam trap and condensing in the tap water.

The results of this series of tests are also shown in Table 4. The error between the heat in and heat out is again no larger than about 4% if the heat balance is corrected for live steam leakage through the steam traps. In operation the steam leakage could actually be heard collapsing in the bucket of tap water. No attempt was made to repair the steam trap because heat balances were not made on any other tests carried out in this work and the leakage caused no problems.

## B) STEADY STATE TESTS

The experimental technique and the reasons for running tests under steady state conditions have been explained earlier in the report.

In previous steady state heat transfer work several investigators(10) have shown that non-uniform distribution of water in a tube bundle occurs if water velocities are less than 3 ft./sec. It is also stated that the most suitable velocities are between 7 - 7.5 ft./sec.

With the new 12-tube bundle, the maximum average velocity obtainable was only about 3.0 ft./sec. To run tests at higher velocities some of the tubes were blocked. The original tube bundle was reduced to a 4-tube bundle by blocking each end with 1/4 in., thick aluminum plates and one thickness of 1/8 in. "Klingerit" as a gasket. One-half inch diameter holes were drilled through the plates and gaskets at desired positions. The sets of plates and gaskets were bolted together and to the heat exchanger by four 1/2 in. diameter rods which passed through the entire length of the tube bundle. The new tube bundle of 12 tubes was reduced to a bundle of four effective tubes by having eight 1/2 in. diameter steel rods bolted into the tube bundle to block undesired tubes. For both tube bundles active tubes were situated as close to the centre of the tube bundle as possible. This was done in an effort to overcome the possibility of poor fluid distribution to the tubes.

In the remainder of this report the number of active tubes in a tube bundle will be referred to as follows:

The 36/36 bundle = 36 tubes with 36 active
The 36/4 bundle = 36 tubes with only 4 active
The 12/12 bundle = 12 tubes with 12 active
The 12/4 bundle = 12 tubes with only 4 active

## 1) Wilson Plots

In order to determine a theoretical enhancement of the overall heat transfer coefficient by equation (6), the values of A and B must be determined for each heat exchanger under consideration. From the Wilson plot, a straight line should be obtained by plotting $\frac{1.0}{U_{ST}}$ versus the corresponding $1.0/\bar{V}_{ST}^{0.8}$ on rectangular coordinates. The value of A is the intercept, and is the combined thermal resistance of the heat exchanger tube (including any scale) and condensate film. The slope of the line is B, and for any mean fluid velocity the value of $B/V_{ST}^{0.8}$ can be calculated. This is the thermal resistance of the tube side of the bundle. The ratio $A \cdot \overline{V}_{ST}^{0.8}/B$ is then the ratio $h_f/h_s$.

The value of B was also predicted from equation (2). The calculations are shown in Appendix II and indicate B should be between 0.00247 and 0.00313. The experimental work gave an average value of 0.00232, (see page 35.)

## 2) Results from the 12/12 Tube Bundle

The data and results of three tests (nos. 1, 2, 3) with the 12/12 bundle are given in Table 5. The calculations were performed by a computer program which is given in Appendix I. Tests were conducted with 0.5 in., 0.75 and 1 1/64 in. diameter discharges. Within each test, flowrates were varied as widely as possible with the maximum being at about 230 lb./min. (a mean velocity of 3.5 ft./sec. in the tubes). The effect of shell side temperature was studied by using two different steam pressures within each test.

The results are shown on a Wilson plot in Figure 5. It is obvious that the expected straight lines were not obtained and that any attempt at drawing straight lines through the data do not give slopes predicted by the Dittus-Boelter equation. It was suspected that the reason for this was poor distribution of the water in the tubes which has already been mentioned. This would cause boiling effects in tubes containing relatively low fluid velocities and high

## TABLE 5

## DATA AND RESULTS OF STEADY STATE TESTS 1, 2 AND 3

| | TEST 1 | TEST 1A |
|---|---|---|
| Tube Bundle | 12/12 | 12/12 |
| Discharge Diameter (in.) | 0.5 | 0.5 |
| Steam Pressure (psig.) | 5 | 10 |

| Run No. | Flow $\frac{\text{lb.}}{\text{min.}}$ | $\bar{V}_{ST}$ $\frac{\text{ft.}}{\text{sec.}}$ | $\left(\frac{1}{\bar{V}_{ST}}\right)^{0.8}$ | Water Temp. In (°F) | Water Temp. Out (°F) | $\frac{1}{U_{ST}}$ | Water Temp. Out (°F) | $\frac{1}{U_{ST}}$ |
|---|---|---|---|---|---|---|---|---|
| 1 | 42.5 | 0.624 | 1.457 | 60 | 154 | 0.00264 | 170 | 0.00232 |
| 2 | 63.8 | 0.937 | 1.053 | 60 | 139 | 0.00230 | 150 | 0.00212 |
| 3 | 85.0 | 1.249 | 0.837 | 60 | 124 | 0.00229 | 134 | 0.00209 |
| 4 | 106.3 | 1.562 | 0.700 | 60 | 116 | 0.00214 | 124 | 0.00199 |
| 5 | 127.5 | 1.878 | 0.604 | 60 | 110 | 0.00204 | 116 | 0.00195 |

| | TEST 2 | TEST 2A |
|---|---|---|
| Tube Bundle | 12/12 | 12/12 |
| Discharge Diameter (in.) | 0.75 | 0.75 |
| Steam Pressure (psig.) | 5 | 10 |

| Run No. | Flow $\frac{\text{lb.}}{\text{min.}}$ | $\bar{V}_{ST}$ $\frac{\text{ft.}}{\text{sec.}}$ | $\left(\frac{1}{\bar{V}_{ST}}\right)^{0.8}$ | Water Temp. In (°F) | Water Temp. Out (°F) | $\frac{1}{U_{ST}}$ | Water Temp. Out (°F) | $\frac{1}{U_{ST}}$ |
|---|---|---|---|---|---|---|---|---|
| 1 | 42.5 | 0.624 | 1.457 | 60 | 160 | 0.00240 | 174 | 0.00218 |
| 2 | 63.8 | 0.937 | 1.053 | 60 | 143 | 0.00212 | 155 | 0.00194 |
| 3 | 85.0 | 1.249 | 0.837 | 60 | 130 | 0.00204 | 139 | 0.00191 |
| 4 | 106.3 | 1.561 | 0.700 | 60 | 120 | 0.00197 | 129 | 0.00181 |
| 5 | 127.5 | 1.878 | 0.604 | 60 | 115 | 0.00182 | 122 | 0.00171 |
| 6 | 148.8 | 2.186 | 0.535 | 60 | 110 | 0.00176 | 116 | 0.00168 |
| 7 | 191.3 | 2.811 | 0.437 | 60 | 104 | 0.00159 | 110 | 0.00149 |

## TABLE 5 CONT.

| | TEST 1 | TEST 1A |
|---|---|---|
| Tube Bundle | 12/12 | 12/12 |
| Discharge Diameter (in.) | 1 1/64 | 1 1/64 |
| Steam Pressure (psig.) | 2 | 10 |

| Run No. | Flow $\frac{\text{lb.}}{\text{min.}}$ | $\bar{V}_{ST}$ $\frac{\text{ft.}}{\text{sec.}}$ | $\left(\frac{1}{\bar{V}_{ST}}\right)^{0.8}$ | Water Temp. In ($^\circ$F) | Water Temp. Out ($^\circ$F) | $\frac{1}{U_{ST}}$ | Water Temp. Out ($^\circ$F) | $\frac{1}{U_{ST}}$ |
|---|---|---|---|---|---|---|---|---|
| 1 | 53.2 | 0.782 | 1.218 | 65 | 142 | 0.00250 | 166 | 0.00203 |
| 2 | 63.8 | 0.937 | 1.053 | 65 | 135 | 0.00238 | 156 | 0.00199 |
| 3 | 85.0 | 1.249 | 0.837 | 67 | 128 | 0.00211 | 142 | 0.00192 |
| 4 | 106.3 | 1.561 | 0.700 | 66 | 120 | 0.00199 | 134 | 0.00177 |
| 5 | 127.8 | 1.878 | 0.604 | 66 | 114 | 0.00192 | 126 | 0.00172 |
| 6 | 148.8 | 2.186 | 0.534 | 66 | 110 | 0.00183 | 122 | 0.00161 |
| 7 | 170.0 | 2.498 | 0.481 | 66 | 107 | 0.00174 | 118 | 0.00154 |
| 8 | 191.3 | 2.811 | 0.437 | 65 | 104 | 0.00165 | 115 | 0.00144 |
| 9 | 212.6 | 3.124 | 0.402 | 65 | 102 | 0.00158 | 112 | 0.00140 |
| 10 | 234.1 | 3.440 | 0.372 | 65 | 98 | 0.00164 | 109 | 0.00137 |

heat transfer rates in the tubes containing higher than average fluid velocities. No attempt was made to predict the results of such a phenomenon. However some of the effects can be seen in the data in Table 5 or from Figure 5. Highest heat transfer coefficients at any mean fluid velocity were obtained by operating with the largest possible discharge orifice (this means low water pressure in the tubes) and the highest steam pressure. Both these factors point to a boiling effect in the tubes. It should be noted here that all of the tests were performed either in the transition or turbulent regions of flow. This would be expected to further cause difficulties in analyzing results from these tests.

### 3) Results from the 36/4 and 12/4 Tube Bundles

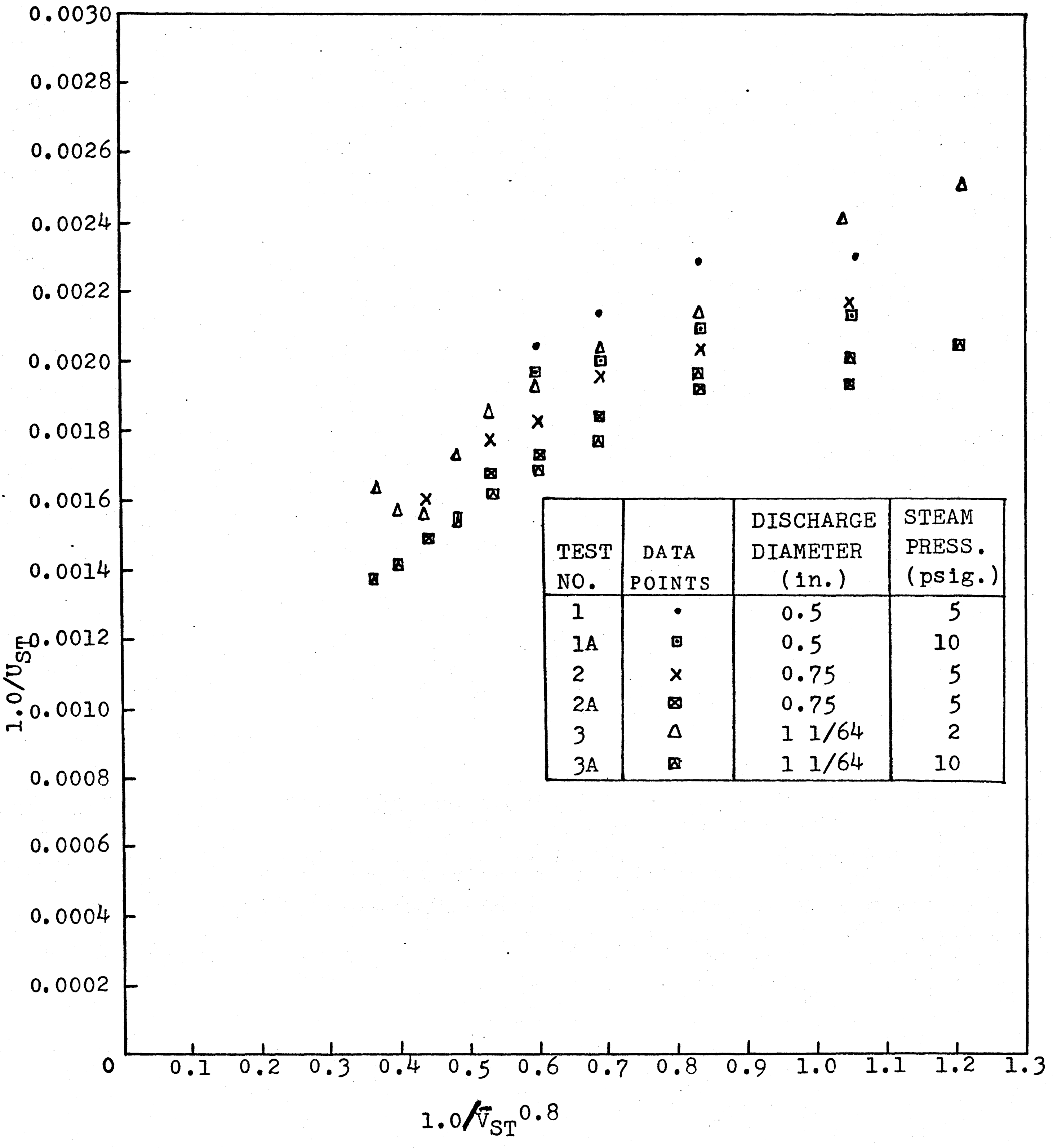
The results from the 12/12 Tube Bundle were not encouraging. It was suspected that the reason for the poor results was poor distribution of water in the tubes. It was therefore decided to increase velocities in the tubes by reducing the number of active tubes in the bundle. In order not to damage the new 12-tube bundle, the 36/36 bundle was modified first, with blocking plates that have already been described. When this approach appeared successful, some tests were conducted on the 12/12 bundle by blocking undesired tubes with steel rods.

The data and results of four tests are given in Table 6 and on a Wilson plot in Figure 6. Three tests (steady state tests 4, 5 and 6 which correspond to discharge diameters

FIGURE 5

WILSON PLOT FOR STEADY STATE TESTS

12/12 TUBE BUNDLE

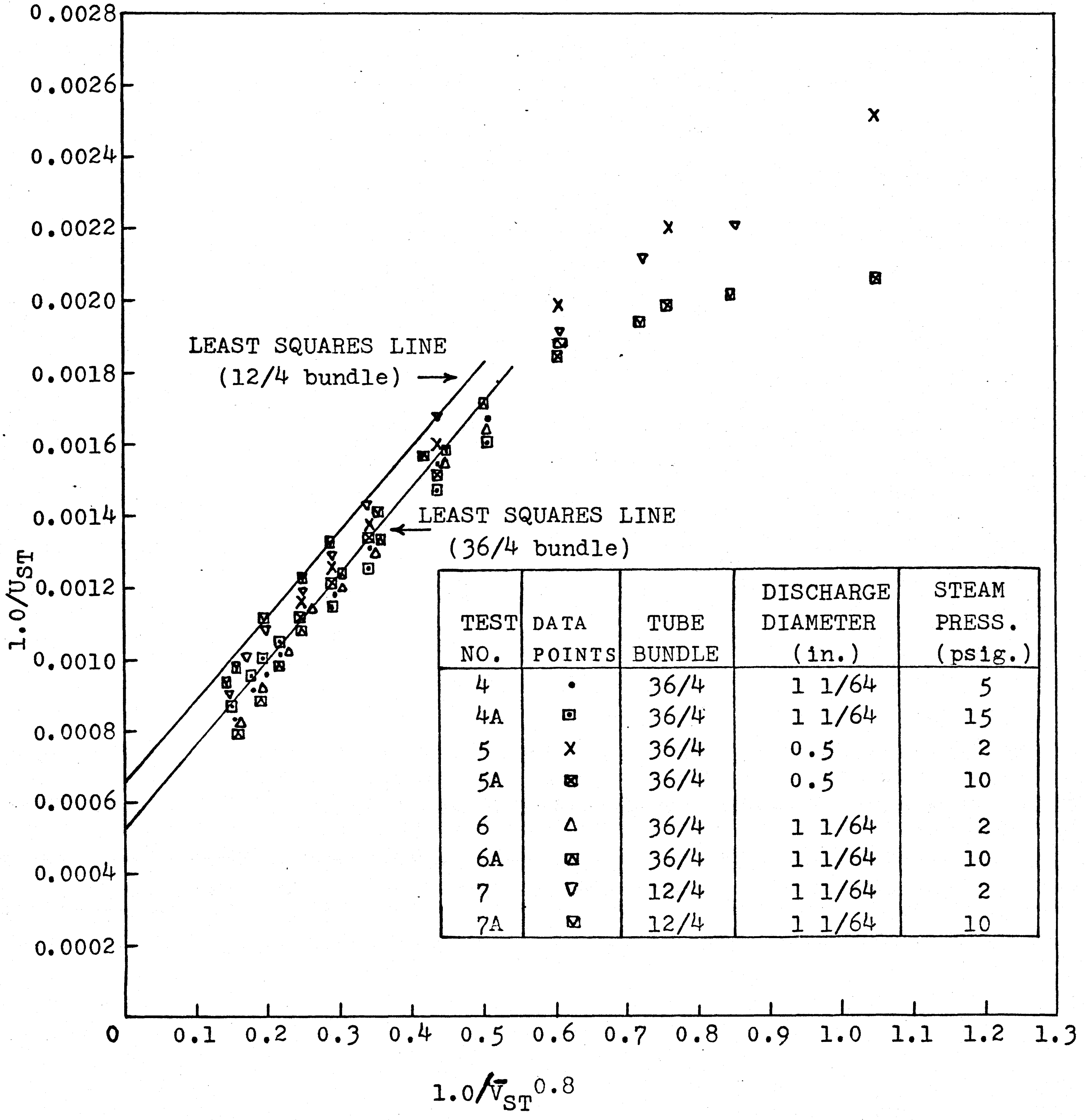


| TEST NO. | DATA POINTS | DISCHARGE DIAMETER (in.) | STEAM PRESS. (psig.) |
|---|---|---|---|
| 1 | • | 0.5 | 5 |
| 1A | ⊡ | 0.5 | 10 |
| 2 | × | 0.75 | 5 |
| 2A | ⊠ | 0.75 | 5 |
| 3 | Δ | 1 1/64 | 2 |
| 3A | ⧅ | 1 1/64 | 10 |

## FIGURE 6

## WILSON PLOT FOR STEADY STATE TESTS

## - 36/4, 12/4 TUBE BUNDLES



| TEST NO. | DATA POINTS | TUBE BUNDLE | DISCHARGE DIAMETER (in.) | STEAM PRESS. (psig.) |
|---|---|---|---|---|
| 4 | • | 36/4 | 1 1/64 | 5 |
| 4A | ⊡ | 36/4 | 1 1/64 | 15 |
| 5 | × | 36/4 | 0.5 | 2 |
| 5A | ⊠ | 36/4 | 0.5 | 10 |
| 6 | △ | 36/4 | 1 1/64 | 2 |
| 6A | ⍍ | 36/4 | 1 1/64 | 10 |
| 7 | ▽ | 12/4 | 1 1/64 | 2 |
| 7A | ⍔ | 12/4 | 1 1/64 | 10 |

## TABLE 6

## DATA AND RESULTS OF STEADY STATE TESTS 4, 5, 6 AND 7

| | TEST 4 | TEST 4A |
|---|---|---|
| Tube Bundle | 36/4 | 36/4 |
| Discharge Diameter (in.) | 1 1/64 | 1 1/64 |
| Steam Pressure (psig.) | 5 | 15 |

| Run No. | Flow $\frac{\text{lb.}}{\text{min.}}$ | $\bar{V}_{ST}$ $\frac{\text{ft.}}{\text{sec.}}$ | $\frac{1}{\bar{V}_{ST}}^{0.8}$ | Water Temp. In (°F) | Water Temp. Out (°F) | $\frac{1}{U_{ST}}$ | Water Temp. Out (°F) | $\frac{1}{U_{ST}}$ |
|---|---|---|---|---|---|---|---|---|
| 1 | 53.2 | 2.345 | 0.506 | 70 | 116 | 0.00168 | 125 | 0.00160 |
| 2 | 63.8 | 2.812 | 0.437 | 70 | 112 | 0.00156 | 120 | 0.00149 |
| 3 | 85.0 | 3.747 | 0.348 | 70 | 108 | 0.00132 | 115 | 0.00127 |
| 4 | 106.3 | 4.686 | 0.291 | 70 | 104 | 0.00119 | 110 | 0.00116 |
| 5 | 148.8 | 6.556 | 0.222 | 70 | 99 | 0.00102 | 103 | 0.00103 |
| 6 | 170.0 | 7.494 | 0.200 | 70 | 97 | 0.00097 | 100 | 0.00100 |
| 7 | 191.3 | 8.433 | 0.182 | 70 | 95 | 0.00093 | 98 | 0.00096 |
| 8 | 234.1 | 10.319 | 0.155 | 70 | 92 | 0.00088 | 96 | 0.00085 |

| | TEST 5 | TEST 5A |
|---|---|---|
| Tube Bundle | 36/4 | 36/4 |
| Discharge Diameter (in.) | 0.5 | 0.5 |
| Steam Pressure (psig.) | 2 | 10 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 1 | 21.3 | 0.939 | 1.052 | 70 | 135 | 0.00252 | 156 | 0.00206 |
| 2 | 31.8 | 1.402 | 0.763 | 70 | 123 | 0.00220 | 136 | 0.00198 |
| 3 | 42.5 | 1.873 | 0.605 | 69 | 115 | 0.00198 | 125 | 0.00184 |
| 4 | 63.8 | 2.812 | 0.437 | 69 | 108 | 0.00160 | 115 | 0.00155 |
| 5 | 85.0 | 3.747 | 0.347 | 69 | 104 | 0.00136 | 110 | 0.00133 |
| 6 | 106.3 | 4.686 | 0.291 | 69 | 100 | 0.00125 | 106 | 0.00120 |
| 7 | 127.8 | 5.633 | 0.251 | 69 | 97 | 0.00117 | 102 | 0.00113 |

## TABLE 6 CONT.

| | TEST 6 | TEST 6A |
|---|---|---|
| Tube Bundle | 36/4 | 36/4 |
| Discharge Diameter (in.) | 1 1/64 | 1 1/64 |
| Steam Pressure (psig.) | 2 | 10 |

| Run No. | Flow $\frac{\text{lb.}}{\text{min.}}$ | $\bar{V}_{ST}$ $\frac{\text{ft.}}{\text{sec.}}$ | $\frac{1}{\bar{V}_{ST}}^{0.8}$ | Water Temp. In (°F) | Water Temp. Out (°F) | $\frac{1}{U_{ST}}$ | Water Temp. Out (°F) | $\frac{1}{U_{ST}}$ |
|---|---|---|---|---|---|---|---|---|
| 1 | 53.2 | 2.345 | 0.506 | 70 | 114 | 0.00165 | 119 | 0.00171 |
| 2 | 63.8 | 2.812 | 0.437 | 70 | 110 | 0.00154 | 116 | 0.00154 |
| 3 | 85.0 | 3.747 | 0.348 | 70 | 106 | 0.00131 | 111 | 0.00132 |
| 4 | 106.3 | 4.686 | 0.291 | 70 | 102 | 0.00120 | 106 | 0.00123 |
| 5 | 127.8 | 5.633 | 0.251 | 70 | 100 | 0.00107 | 104 | 0.00109 |
| 6 | 148.8 | 6.559 | 0.222 | 70 | 97 | 0.00103 | 102 | 0.00100 |
| 7 | 191.3 | 8.433 | 0.182 | 70 | 94 | 0.00092 | 98 | 0.00090 |

| | TEST 7 | TEST 7A |
|---|---|---|
| Tube Bundle | 12/4 | 12/4 |
| Discharge Diameter (in.) | 1 1/64 | 1 1/64 |
| Steam Pressure (psig.) | 2 | 10 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 1 | 27.6 | 1.217 | 0.855 | 55 | 120 | 0.00221 | 134 | 0.00202 |
| 2 | 34.0 | 1.499 | 0.724 | 55 | 112 | 0.00212 | 124 | 0.00195 |
| 3 | 42.5 | 1.874 | 0.605 | 55 | 108 | 0.00185 | 117 | 0.00179 |
| 4 | 63.8 | 2.812 | 0.437 | 55 | 96 | 0.00168 | 104 | 0.00158 |
| 5 | 85.0 | 3.747 | 0.348 | 55 | 92 | 0.00142 | 97 | 0.00142 |
| 6 | 106.3 | 4.686 | 0.291 | 55 | 88 | 0.00129 | 92 | 0.00131 |
| 7 | 127.8 | 5.634 | 0.251 | 55 | 85 | 0.00119 | 89 | 0.00119 |
| 8 | 170.0 | 7.494 | 0.200 | 55 | 80 | 0.00110 | 83.5 | 0.00109 |
| 9 | 212.6 | 9.372 | 0.167 | 55 | 77 | 0.00101 | 80 | 0.00100 |
| 10 | 255.0 | 11.241 | 0.144 | 55 | 74 | 0.00098 | 77 | 0.00096 |

of 1 1/64 in., 0.5 in. and 1 1/64 in.) were done on the 36/4 bundle with flowrates ranging from approximately 20 to 250 lbs./min. (mean linear velocities from 1.0 to 11.0 ft./sec.) Within each test, data were gathered for two different steam pressures. For the 12/4 bundle a test (No. 7) was done with a 1 1/64 in. discharge diameter and steam pressures of 2 and 10 psig.

As predicted by equation (2) a straight line relationship exists between $\frac{1}{U_{ST}}$ and $\frac{1}{\bar{V}_{ST}^{0.8}}$ but only for fluid velocities above approximately 2.5 ft./sec. ($1.0/\bar{V}_{ST}^{0.8} = 0.5$). Therefore only values of $1.0/\bar{V}_{ST}^{0.8} = 0.5$ or less and the corresponding $1.0/U_{ST}$ were used to determine the shell side thermal resistance. A least squares calculation was used to calculate A and B (see the computer program in Appendix I). The results are given in Table 7, and show that the average experimentally determined values of B were 0.002319 for the 36/4 bundle and 0.002269 for the 12/4 bundle. This could be compared to the predicted values of B calculated from equation (2), (see Appendix II) of between 0.00247 and 0.00313. The difference between the predicted and experimental values is not considered to be significant and in future work the value of B was chosen to be 0.00232.

The shell side heat transfer resistance A, was found to average 0.000520 for the 36 tube bundle and 0.000634 for the new 12 tube bundle. The difference between the two values of

A is large and appears to be real. No definite reasons can be stated for the difference other than that, since the 12 tube bundle was in service for a longer period of time a larger amount of scale had accumulated on the tubes. For the required calculations in later work the two different values of A were used.

## TABLE 7

## MEASURED CONSTANTS A AND B FOR - 4-TUBE BUNDLE HEAT EXCHANGER

(A and B as defined in equation (4))

| Test No. | Tube Bundle | | Non-varying Factors B | 1.0/B | Shell Side Coefficient A | 1.0/A |
|---|---|---|---|---|---|---|
| 4 | 36/4 | | 0.002356 | 424.5 | 0.000504 | 1982.4 |
| 4A | 36/4 | | 0.002070 | 483.0 | 0.000564 | 1772.5 |
| 5 | 36/4 | | 0.002312 | 432.5 | 0.000578 | 1728.7 |
| 5A | 36/4 | | 0.002287 | 437.3 | 0.000544 | 1837.0 |
| 6 | 36/4 | | 0.002357 | 424.2 | 0.000488 | 2050.6 |
| 6A | 36/4 | | 0.002357 | 394.2 | 0.000440 | 2271.9 |
| | | Average | 0.002319 | 432.6 | 0.000520 | 1940.5 |
| 7 | 12/4 | | 0.002367 | 422.5 | 0.000617 | 1620.7 |
| 7 | 12/4 | | 0.002171 | 460.7 | 0.000651 | 1535.0 |
| | | Average | 0.002269 | 441.6 | 0.000634 | 1577.8 |

### 4) Discussion of Errors

The main sources of errors in the calculation of the steady state overall heat transfer coefficient ($U_{ST}$) are the following:

| Source of Error | Units | Estimate of Error |
|---|---|---|
| Reading Thermometers | (°F) | ± 1.0 |
| Reading Steam Pressure Gauge | (Psig.) | ± 0.5 |
| Tube Diameter | (in.) | ± 0.001 |
| Tube Length | (in.) | ± 0.1 |
| Setting Flowrate in RPM | % | ± 1.0 |

Assuming maximum possible errors it was calculated that values of $U_{ST}$ at low flowrates (about 25 lb./min.) could be in error by as much as ± 7%, while at higher flowrates (about 250 lb./min.) it was found that any value of $U_{ST}$ could be in error by as much as ± 14%. At high flowrates water temperature rises were small, thus calculations become very sensitive to errors in temperature measurement.

The results shown in Tables 5 and 6 indicate that any two comparable values of $U_{ST}$ are well within the limits of expected deviations when mean fluid velocities were greater than 2.5 ft./sec. For mean velocities less than 2.5 ft./sec. the deviations in comparable values of $U_{ST}$ were often greater than expected from experimental errors. This has been attributed to boiling effects in some tubes caused by a non-uniform distribution of the water flow.

The error in the calculation of mean velocities greater than 2.5 ft./sec. is estimated to be within ± 1.0%, which is not significant compared to deviations that could result from incorrect temperature measurements.

## C) PULSED FLOW TESTS

A total of 574 experimental runs were carried out under pulsed flow conditions, which have been combined for convenience into 36 tests. The operating variables for each test are outlined in Table 8 and include the following:

a) Tube Bundle that was used

b) Mean Flowrate and Velocity

c) Discharge Diameter

d) Shell Steam Pressure

e) The Run Numbers for each Surge Volume (0.2, 0.5 or 0.8 cu. ft.)

f) Steady State Temperatures and the Overall Heat Transfer Coefficient - $U_{ST}$

At any fixed surge volume within a test, upstream displacement and pulsation frequency were changed by varying the air flow to the downstream surge volume. This has been described on p. 20.

The complete data and results of the 574 experimental runs are given in Table 9. The calculations were performed by a computer program (see Appendix I).

The operation of the apparatus was most effective with the 12/12 bundle and a 5/8 in. discharge diameter in the downstream riser. Under these conditions it was possible to test with water flowrates between 85.0 and 191.3 lb./min. (mean velocities of 1.25 to 2.81 ft./sec.). Above and below

## TABLE 8

## PULSED FLOW TESTS - OPERATING VARIABLES

| Test No. | Tube Bundle | Mean Flow | | Discharge Diameter (in.) | Steam Pressure (psig.) | Run Numbers For Surge Volumes (cu. ft.) | | | Steady State Results Water Temp. (°F) | | $U_{ST}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | (lb./min.) | (ft./sec.) | | | 0.2 | 0.5 | 0.8 | In | Out | $\frac{BTU}{ft.^2\ hr.\ ^\circ F}$ |
| 1 | 36/4 | 106.3 | 4.69 | 0.5 | 2 | 1-6 | 7-11 | - | 68 | 98 | 820.6 |
| 2 | 36/4 | 106.3 | 4.69 | 0.5 | 10 | 12-17 | 18-22 | - | 68 | 104 | 803.1 |
| 3 | 36/4 | 85.0 | 3.75 | 0.5 | 2 | 23-28 | 29-34 | - | 65 | 100 | 712.3 |
| 4 | 36/4 | 85.0 | 3.75 | 0.5 | 10 | 35-40 | 41-46 | - | 65 | 102 | 651.4 |
| 5 | 36/4 | 63.8 | 2.81 | 0.5 | 2 | 47-52 | 53-58 | 59-64 | 65 | 104 | 607.5 |
| 6 | 36/4 | 63.8 | 2.81 | 0.5 | 10 | 65-70 | 71-76 | 77-82 | 65 | 110 | 613.7 |
| 7 | 36/4 | 42.5 | 1.87 | 0.5 | 2 | 83-88 | 89-94 | 95-100 | 62 | 107 | 472.1 |
| 8 | 36/4 | 42.5 | 1.87 | 0.5 | 10 | 101-106 | 107-112 | 113-118 | 62 | 118 | 524.0 |
| 9 | 36/4 | 31.8 | 1.40 | 0.5 | 2 | - | 119-124 | 125-130 | 61 | 115 | 435.1 |
| 10 | 36/4 | 31.8 | 1.40 | 0.5 | 10 | - | 131-136 | 137-142 | 61 | 130 | 502.7 |
| 11 | 12/12 | 85.0 | 1.25 | 0.625 | 2 | 143-148 | 149-154 | 155-160 | 56 | 116 | 422.9 |
| 12 | 12/12 | 85.0 | 1.25 | 0.625 | 10 | 161-166 | 167-172 | 173-178 | 56 | 135 | 512.8 |
| 13 | 12/12 | 106.3 | 1.56 | 0.625 | 2 | 179-184 | 185-190 | 191-196 | 57 | 112 | 476.4 |
| 14 | 12/12 | 106.3 | 1.56 | 0.625 | 10 | 197-202 | 203-208 | 209-214 | 57 | 122 | 500.2 |
| 15 | 12/12 | 127.5 | 1.88 | 0.625 | 2 | 215-220 | 221-226 | 227-231 | 59 | 108 | 503.2 |
| 16 | 12/12 | 127.5 | 1.88 | 0.625 | 10 | 232-237 | 238-243 | 244-248 | 59 | 117 | 527.6 |
| 17 | 12/12 | 148.8 | 2.19 | 0.625 | 2 | 249-254 | 255-260 | 261-265 | 61 | 102 | 481.7 |
| 18 | 12/12 | 148.8 | 2.19 | 0.625 | 10 | 266-271 | 272-277 | 278-282 | 59 | 112 | 551.4 |
| 19 | 12/12 | 170.0 | 2.50 | 0.625 | 2 | 283-287 | 288-293 | 294-299 | 59 | 98 | 514.5 |
| 20 | 12/12 | 170.0 | 2.50 | 0.625 | 10 | 300-304 | 305-310 | 311-316 | 61 | 107 | 543.0 |
| 21 | 12/12 | 191.3 | 2.81 | 0.625 | 2 | 317-320 | 321-326 | 327-332 | 54 | 88 | 542.2 |
| 22 | 12/12 | 191.3 | 2.81 | 0.625 | 10 | 333-336 | 337-342 | 343-348 | 54 | 100 | 584.5 |
| 23 | 12/12 | 106.3 | 1.56 | 0.5 | 2 | 349-354 | 355-360 | 361-365 | 56 | 108 | 442.5 |
| 24 | 12/12 | 106.3 | 1.56 | 0.5 | 10 | 366-371 | 372-377 | 378-382 | 56 | 118 | 469.7 |
| 25 | 12/12 | 42.5 | 0.62 | 0.5 | 2 | 383-388 | 389-394 | 395-400 | 64 | 144 | 335.0 |
| 26 | 12/12 | 42.5 | 0.62 | 0.5 | 10 | 401-406 | 407-412 | 413-418 | 64 | 165 | 389.8 |
| 27 | 12/12 | 42.5 | 0.62 | 0.5 | 2 | 419-421 | 422-424 | 425-427 | 67 | 137 | 284.7 |
| 28 | 12/12 | 42.5 | 0.62 | 0.5 | 10 | 428-430 | 431-433 | 434-436 | 67 | 160 | 352.5 |
| 29 | 12/12 | 127.5 | 1.87 | 0.75 | 2 | 437-439 | 440-445 | 446-451 | 66 | 113 | 507.2 |
| 30 | 12/12 | 127.5 | 1.87 | 0.75 | 10 | 452-454 | 455-460 | 461-466 | 66 | 123 | 544.2 |
| 31 | 12/12 | 170.0 | 2.50 | 0.75 | 2 | 467-472 | 473-478 | 479-484 | 67 | 107 | 562.6 |
| 32 | 12/12 | 170.0 | 2.50 | 0.75 | 10 | 485-490 | 491-496 | 497-502 | 67 | 115 | 594.1 |
| 33 | 12/4 | 85.0 | 3.75 | 0.5 | 2 | 503-508 | 509-514 | 515-520 | 64 | 99 | 707.0 |
| 34 | 12/4 | 85.0 | 3.75 | 0.5 | 10 | 521-526 | 527-532 | 533-538 | 64 | 104 | 707.0 |
| 35 | 12/4 | 63.8 | 2.81 | 0.5 | 2 | 539-544 | 545-550 | 551-556 | 64 | 104 | 619.0 |
| 36 | 12/4 | 63.8 | 2.81 | 0.5 | 10 | 557-562 | 563-568 | 569-574 | 64 | 110 | 619.0 |

LINE AIR PRESSURE - TESTS 1 AND 2 - 105 PSIG., ALL OTHERS - 70 PSIG.

## TABLE 9 (continues to p. 57)

## PULSED FLOW RUNS* DATA AND RESULTS

| RUN NO. | STEAM PRESS. PSIG. MAX | MIN | UPSTREAM SURGE PRESS. MAX | MIN | WATER TEMP. OUT DEG.F. | GAS FLOW SCFM | UPSTREAM DISPL. INS. | FREQ. C/MIN. | OVERALL UPU | URATIO UPU / UST | DPV |
|---|---|---|---|---|---|---|---|---|---|---|---|
| TEST NO. 1 | | | | | | | | | | | |
| 1 | 2.00 | 2.00 | 8.1 | 7.9 | 98.0 | 1.39 | 1.75 | 56.0 | 820.6 | 1.000 | 0.330 |
| 2 | 2.00 | 2.00 | 8.2 | 7.8 | 98.0 | 2.23 | 3.00 | 56.0 | 820.6 | 1.000 | 0.565 |
| 3 | 2.25 | 1.75 | 9.3 | 8.7 | 98.0 | 3.79 | 7.00 | 55.0 | 820.6 | 1.000 | 1.295 |
| 4 | 2.25 | 1.75 | 10.5 | 9.5 | 99.0 | 5.35 | 9.50 | 55.0 | 849.7 | 1.036 | 1.757 |
| 5 | 2.25 | 1.75 | 11.1 | 9.9 | 102.0 | 7.07 | 11.50 | 56.0 | 938.5 | 1.144 | 2.165 |
| 6 | 2.25 | 1.75 | 12.9 | 11.1 | 103.0 | 9.05 | 12.00 | 58.0 | 968.6 | 1.180 | 2.340 |
| 7 | 2.00 | 2.00 | 7.6 | 7.4 | 98.0 | 1.39 | 1.75 | 45.0 | 820.6 | 1.000 | 0.265 |
| 8 | 2.25 | 1.75 | 8.2 | 7.8 | 98.0 | 2.23 | 4.75 | 42.0 | 820.6 | 1.000 | 0.671 |
| 9 | 2.25 | 1.75 | 8.8 | 8.2 | 98.0 | 3.79 | 8.00 | 40.0 | 820.6 | 1.000 | 1.076 |
| 10 | 2.25 | 1.75 | 10.1 | 8.9 | 98.0 | 5.35 | 12.50 | 38.0 | 820.6 | 1.000 | 1.597 |
| 11 | 2.25 | 1.75 | 11.9 | 10.1 | 100.0 | 7.07 | 14.00 | 40.0 | 879.0 | 1.071 | 1.883 |
| TEST NO. 2 | | | | | | | | | | | |
| 12 | 10.00 | 10.00 | 8.1 | 7.9 | 104.0 | 1.39 | 2.75 | 56.0 | 803.1 | 1.000 | 0.518 |
| 13 | 10.00 | 10.00 | 8.2 | 7.8 | 104.0 | 2.23 | 3.50 | 56.0 | 803.1 | 1.000 | 0.659 |
| 14 | 10.50 | 9.50 | 9.3 | 8.7 | 104.0 | 3.79 | 7.00 | 55.0 | 803.1 | 1.000 | 1.294 |
| 15 | 10.50 | 9.50 | 10.5 | 9.5 | 106.0 | 5.35 | 9.50 | 55.0 | 853.7 | 1.063 | 1.757 |
| 16 | 10.50 | 9.50 | 11.1 | 9.9 | 108.0 | 7.07 | 11.50 | 56.0 | 905.2 | 1.127 | 2.165 |
| 17 | 10.50 | 9.50 | 12.9 | 11.1 | 110.0 | 9.05 | 12.00 | 58.0 | 957.4 | 1.192 | 2.340 |
| 18 | 10.00 | 10.00 | 7.6 | 7.4 | 104.0 | 1.39 | 1.75 | 45.0 | 803.1 | 1.000 | 0.265 |
| 19 | 10.50 | 9.50 | 8.2 | 7.8 | 104.0 | 2.23 | 4.75 | 42.0 | 803.1 | 1.000 | 0.671 |
| 20 | 10.50 | 9.50 | 8.8 | 8.2 | 104.0 | 3.79 | 8.00 | 40.0 | 803.1 | 1.000 | 1.076 |
| 21 | 10.50 | 9.50 | 10.0 | 9.0 | 104.0 | 5.35 | 12.50 | 38.0 | 803.1 | 1.000 | 1.597 |
| 22 | 10.50 | 9.50 | 11.1 | 9.9 | 107.0 | 7.07 | 14.00 | 40.0 | 879.4 | 1.095 | 1.883 |

*NOTE: TEST NOS. 1 - 36, RUN NOS. 1 - 574

Conditions in each test are given in Table 8

| RUN NO. | STEAM PRESS. PSIG. |  | UPSTREAM SURGE PRESS. |  | WATER TEMP. OUT DEG.F. | GAS FLOW SCFM | UPSTREAM DISPL. INS. | FREQ. C/MIN. | OVERALL UPU | URATIO UPU / UST | DPV |
|---|---|---|---|---|---|---|---|---|---|---|---|
|  | MAX | MIN | MAX | MIN |  |  |  |  |  |  |  |
| TEST NO. 3 |  |  |  |  |  |  |  |  |  |  |  |
| 23 | 2.25 | 1.75 | 5.0 | 5.0 | 100.0 | 1.20 | 2.50 | 50.0 | 712.3 | 1.000 | 0.524 |
| 24 | 2.25 | 1.75 | 5.5 | 5.0 | 100.0 | 1.92 | 4.50 | 50.0 | 712.3 | 1.000 | 0.943 |
| 25 | 2.25 | 1.75 | 6.5 | 5.5 | 102.0 | 3.24 | 7.50 | 50.0 | 759.2 | 1.066 | 1.572 |
| 26 | 2.25 | 1.75 | 7.0 | 6.0 | 104.0 | 4.82 | 10.00 | 51.0 | 806.9 | 1.133 | 2.138 |
| 27 | 2.25 | 1.75 | 8.0 | 6.0 | 106.0 | 6.12 | 10.50 | 55.0 | 855.4 | 1.200 | 2.422 |
| 28 | 2.25 | 1.75 | 8.5 | 6.5 | 108.0 | 8.04 | 10.50 | 58.0 | 904.8 | 1.270 | 2.554 |
| 29 | 2.00 | 2.00 | 5.0 | 5.0 | 100.0 | 1.20 | 2.00 | 38.0 | 712.3 | 1.000 | 0.319 |
| 30 | 2.25 | 1.75 | 5.5 | 5.0 | 100.0 | 1.92 | 3.50 | 38.0 | 712.3 | 1.000 | 0.717 |
| 31 | 2.25 | 1.75 | 6.0 | 5.0 | 101.0 | 3.24 | 8.00 | 36.0 | 735.6 | 1.033 | 1.208 |
| 32 | 2.25 | 1.75 | 6.5 | 5.5 | 102.0 | 4.82 | 12.00 | 36.0 | 759.2 | 1.066 | 1.811 |
| 33 | 2.25 | 1.75 | 7.5 | 5.5 | 104.0 | 6.12 | 14.00 | 36.0 | 806.9 | 1.133 | 2.113 |
| 34 | 2.25 | 1.75 | 8.0 | 6.0 | 106.0 | 8.04 | 14.50 | 38.0 | 855.4 | 1.200 | 2.470 |
| TEST NO. 4 |  |  |  |  |  |  |  |  |  |  |  |
| 35 | 10.50 | 9.50 | 5.0 | 5.0 | 102.0 | 1.20 | 2.50 | 50.0 | 651.4 | 1.000 | 0.524 |
| 36 | 10.50 | 9.50 | 5.5 | 5.0 | 102.0 | 1.92 | 4.00 | 50.0 | 651.4 | 1.000 | 0.839 |
| 37 | 10.50 | 9.50 | 6.5 | 5.5 | 104.0 | 3.24 | 8.00 | 50.0 | 691.4 | 1.062 | 1.677 |
| 38 | 10.50 | 9.50 | 7.0 | 6.0 | 108.0 | 4.82 | 10.00 | 51.0 | 773.3 | 1.187 | 2.139 |
| 39 | 10.50 | 9.50 | 8.0 | 6.0 | 110.0 | 6.12 | 10.50 | 54.0 | 815.1 | 1.251 | 2.380 |
| 40 | 10.50 | 9.50 | 8.5 | 6.5 | 111.0 | 8.04 | 10.50 | 58.0 | 836.3 | 1.284 | 2.554 |
| 41 | 10.00 | 10.00 | 5.0 | 5.0 | 102.0 | 1.20 | 2.00 | 38.0 | 651.4 | 1.000 | 0.319 |
| 42 | 10.25 | 9.75 | 5.5 | 5.0 | 102.0 | 1.92 | 3.75 | 38.0 | 651.4 | 1.000 | 0.598 |
| 43 | 10.50 | 9.50 | 6.0 | 5.0 | 103.0 | 3.24 | 8.50 | 36.0 | 671.3 | 1.031 | 1.283 |
| 44 | 10.50 | 9.50 | 6.5 | 5.5 | 106.0 | 4.82 | 12.00 | 36.0 | 732.0 | 1.124 | 1.811 |
| 45 | 10.50 | 9.50 | 7.5 | 5.5 | 107.0 | 6.12 | 14.50 | 36.0 | 752.6 | 1.155 | 2.189 |
| 46 | 10.50 | 9.50 | 8.0 | 6.0 | 110.0 | 8.04 | 15.50 | 37.0 | 815.1 | 1.251 | 2.405 |

| RUN NO. | STEAM PRESS. PSIG. MAX | STEAM PRESS. PSIG. MIN | UPSTREAM SURGE PRESS. MAX | UPSTREAM SURGE PRESS. MIN | WATER TEMP. OUT DEG.F. | GAS FLOW SCFM | UPSTREAM DISPL. INS. | FREQ. C/MIN. | OVERALL UPU | URATIO UPU / UST | DPV |
|---|---|---|---|---|---|---|---|---|---|---|---|
| TEST NO. 5 | | | | | | | | | | | |
| 47 | 2.10 | 1.90 | 2.5 | 1.5 | 104.0 | 1.20 | 4.25 | 48.0 | 607.5 | 1.000 | 1.000 |
| 48 | 2.10 | 1.90 | 4.5 | 2.5 | 106.0 | 1.92 | 5.00 | 48.0 | 644.1 | 1.060 | 1.337 |
| 49 | 2.10 | 1.90 | 5.0 | 3.0 | 110.0 | 3.24 | 7.75 | 50.0 | 719.2 | 1.184 | 2.158 |
| 50 | 2.10 | 1.90 | 5.0 | 3.0 | 115.0 | 4.82 | 7.75 | 56.0 | 817.0 | 1.345 | 2.629 |
| 51 | 2.10 | 1.90 | 5.5 | 3.5 | 115.0 | 6.12 | 8.00 | 59.0 | 817.0 | 1.345 | 2.629 |
| 52 | 2.10 | 1.90 | 6.0 | 4.0 | 118.0 | 8.04 | 8.75 | 61.0 | 878.1 | 1.445 | 2.972 |
| 53 | 2.10 | 1.90 | 3.2 | 2.8 | 104.0 | 1.20 | 3.50 | 34.0 | 607.5 | 1.000 | 0.663 |
| 54 | 2.10 | 1.90 | 3.2 | 2.8 | 104.0 | 1.92 | 5.75 | 33.0 | 607.5 | 1.000 | 1.057 |
| 55 | 2.10 | 1.90 | 4.0 | 3.0 | 108.0 | 3.24 | 10.50 | 32.0 | 681.3 | 1.121 | 1.871 |
| 56 | 2.10 | 1.90 | 4.0 | 3.0 | 111.0 | 4.82 | 12.50 | 34.0 | 738.4 | 1.215 | 2.367 |
| 57 | 2.10 | 1.90 | 4.5 | 3.5 | 113.0 | 6.12 | 13.50 | 35.0 | 777.3 | 1.280 | 2.631 |
| 58 | 2.20 | 1.80 | 5.0 | 4.0 | 114.0 | 8.04 | 14.50 | 37.0 | 797.1 | 1.312 | 2.988 |
| 59 | 2.10 | 1.90 | 3.1 | 2.9 | 104.0 | 1.20 | 2.50 | 30.0 | 607.5 | 1.000 | 0.418 |
| 60 | 2.10 | 1.90 | 3.1 | 2.9 | 104.0 | 1.92 | 4.50 | 30.0 | 607.5 | 1.000 | 0.752 |
| 61 | 2.20 | 1.80 | 3.1 | 2.9 | 106.0 | 3.24 | 9.75 | 28.0 | 644.1 | 1.060 | 1.520 |
| 62 | 2.20 | 1.80 | 3.7 | 3.3 | 108.0 | 4.82 | 12.50 | 28.0 | 681.3 | 1.121 | 1.949 |
| 63 | 2.20 | 1.80 | 3.8 | 3.2 | 110.0 | 6.12 | 15.00 | 29.0 | 719.2 | 1.184 | 2.422 |
| 64 | 2.20 | 1.80 | 4.3 | 3.7 | 111.0 | 8.04 | 14.00 | 31.0 | 738.4 | 1.215 | 2.417 |
| TEST NO. 6 | | | | | | | | | | | |
| 65 | 10.10 | 9.90 | 3.0 | 2.0 | 110.0 | 1.20 | 3.75 | 48.0 | 613.7 | 1.000 | 1.002 |
| 66 | 10.10 | 9.90 | 4.5 | 2.5 | 112.0 | 1.92 | 5.50 | 48.0 | 645.7 | 1.052 | 1.470 |
| 67 | 10.10 | 9.90 | 5.0 | 3.0 | 117.0 | 3.24 | 7.50 | 50.0 | 728.0 | 1.186 | 2.088 |
| 68 | 10.10 | 9.90 | 5.5 | 3.5 | 120.0 | 4.82 | 7.50 | 56.0 | 779.0 | 1.269 | 2.339 |
| 69 | 10.10 | 9.90 | 6.0 | 4.0 | 122.0 | 6.12 | 8.00 | 60.0 | 813.7 | 1.326 | 2.673 |
| 70 | 10.10 | 9.90 | 6.0 | 4.0 | 123.0 | 8.04 | 8.50 | 62.0 | 831.3 | 1.354 | 2.935 |
| 71 | 10.10 | 9.90 | 3.1 | 2.9 | 110.0 | 1.20 | 3.25 | 34.0 | 613.7 | 1.000 | 0.615 |
| 72 | 10.10 | 9.90 | 3.2 | 2.8 | 112.0 | 1.92 | 6.00 | 34.0 | 645.7 | 1.052 | 1.136 |
| 73 | 10.20 | 9.80 | 4.0 | 3.0 | 114.0 | 3.24 | 10.00 | 33.0 | 678.3 | 1.105 | 1.838 |
| 74 | 10.20 | 9.80 | 4.5 | 3.5 | 117.0 | 4.82 | 12.50 | 34.0 | 728.0 | 1.186 | 2.367 |
| 75 | 10.20 | 9.80 | 4.5 | 3.5 | 119.0 | 6.12 | 14.00 | 36.0 | 761.9 | 1.241 | 2.807 |
| 76 | 10.20 | 9.80 | 5.0 | 4.0 | 120.0 | 8.04 | 14.00 | 37.0 | 779.0 | 1.269 | 2.885 |
| 77 | 10.10 | 9.90 | 2.9 | 2.8 | 110.0 | 1.20 | 2.50 | 30.0 | 613.7 | 1.000 | 0.418 |
| 78 | 10.10 | 9.90 | 2.9 | 2.8 | 110.0 | 1.92 | 4.50 | 29.0 | 613.7 | 1.000 | 0.727 |
| 79 | 10.30 | 9.70 | 3.2 | 2.8 | 112.0 | 3.24 | 9.00 | 28.0 | 645.7 | 1.052 | 1.403 |
| 80 | 10.30 | 9.70 | 3.7 | 3.3 | 115.0 | 4.82 | 12.00 | 28.0 | 694.7 | 1.132 | 1.871 |
| 81 | 10.30 | 9.70 | 3.7 | 3.3 | 116.0 | 6.12 | 14.50 | 29.0 | 711.3 | 1.159 | 2.342 |
| 82 | 10.50 | 9.70 | 4.8 | 4.2 | 118.0 | 8.04 | 15.00 | 31.0 | 744.9 | 1.214 | 2.590 |

| RUN NO. | STEAM PRESS. PSIG. | | UPSTREAM SURGE PRESS. | | WATER TEMP. OUT DEG.F. | GAS FLOW SCFM | UPSTREAM DISPL. INS. | FREQ. C/MIN. | OVERALL UPU | URATIO UPU --- UST | DPV |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | MAX | MIN | MAX | MIN | | | | | | | |
| TEST NO. 7 | | | | | | | | | | | |
| 83 | 2.10 | 1.90 | 2.1 | 1.9 | 110.0 | 1.20 | 3.75 | 4.7 | 510.1 | 1.080 | 1.461 |
| 84 | 2.10 | 1.90 | 2.5 | 1.9 | 113.0 | 1.92 | 4.50 | 50.0 | 549.2 | 1.163 | 1.865 |
| 85 | 2.10 | 1.90 | 2.9 | 2.1 | 116.0 | 3.24 | 4.75 | 58.0 | 589.4 | 1.249 | 2.284 |
| 86 | 2.10 | 1.90 | 3.0 | 2.2 | 117.0 | 4.82 | 4.75 | 62.0 | 603.1 | 1.277 | 2.441 |
| 87 | 2.10 | 1.90 | 3.4 | 2.4 | 118.0 | 6.12 | 5.75 | 63.0 | 616.9 | 1.307 | 3.003 |
| 88 | 2.10 | 1.90 | 4.0 | 2.8 | 121.0 | 8.04 | 6.50 | 64.0 | 659.1 | 1.396 | 3.448 |
| 89 | 2.10 | 1.90 | 2.1 | 1.9 | 108.0 | 1.20 | 4.75 | 32.0 | 484.7 | 1.027 | 1.260 |
| 90 | 2.20 | 1.80 | 2.4 | 2.0 | 112.0 | 1.92 | 7.25 | 32.0 | 536.0 | 1.135 | 1.923 |
| 91 | 2.20 | 1.80 | 2.6 | 2.2 | 117.0 | 3.24 | 9.00 | 35.0 | 603.1 | 1.277 | 2.611 |
| 92 | 2.20 | 1.80 | 2.8 | 2.2 | 121.0 | 4.82 | 10.25 | 37.0 | 659.1 | 1.396 | 3.143 |
| 93 | 2.20 | 1.80 | 3.0 | 2.4 | 122.0 | 6.12 | 10.50 | 39.0 | 673.5 | 1.427 | 3.394 |
| 94 | 2.20 | 1.80 | 3.3 | 2.7 | 124.0 | 8.04 | 11.00 | 41.0 | 702.7 | 1.489 | 3.738 |
| 95 | 2.10 | 1.90 | 2.1 | 1.9 | 107.0 | 1.20 | 3.75 | 28.0 | 472.1 | 1.000 | 0.871 |
| 96 | 2.20 | 1.80 | 2.2 | 2.0 | 109.0 | 1.92 | 7.00 | 27.0 | 497.3 | 1.053 | 1.567 |
| 97 | 2.20 | 1.80 | 2.6 | 2.2 | 115.0 | 3.24 | 10.25 | 29.0 | 575.9 | 1.220 | 2.464 |
| 98 | 2.20 | 1.80 | 2.7 | 2.3 | 117.0 | 4.82 | 11.50 | 30.0 | 603.1 | 1.277 | 2.860 |
| 99 | 2.20 | 1.80 | 2.9 | 2.3 | 118.0 | 6.12 | 12.00 | 31.0 | 616.9 | 1.307 | 3.083 |
| 100 | 2.20 | 1.80 | 3.1 | 2.5 | 119.0 | 8.04 | 12.50 | 32.0 | 630.8 | 1.336 | 3.315 |
| TEST NO. 8 | | | | | | | | | | | |
| 101 | 10.10 | 9.90 | 2.3 | 1.9 | 121.0 | 1.20 | 3.50 | 47.0 | 558.6 | 1.066 | 1.461 |
| 102 | 10.10 | 9.90 | 2.6 | 2.0 | 123.0 | 1.92 | 6.25 | 50.0 | 582.1 | 1.111 | 1.761 |
| 103 | 10.10 | 9.90 | 2.9 | 2.1 | 127.0 | 3.24 | 9.75 | 58.0 | 630.3 | 1.203 | 2.163 |
| 104 | 10.10 | 9.90 | 3.1 | 2.3 | 128.0 | 4.82 | 11.50 | 62.0 | 642.7 | 1.226 | 2.313 |
| 105 | 10.10 | 9.90 | 3.4 | 2.6 | 129.0 | 6.12 | 12.00 | 63.0 | 655.1 | 1.250 | 2.872 |
| 106 | 10.10 | 9.90 | 4.0 | 2.8 | 133.0 | 8.04 | 13.00 | 65.0 | 706.0 | 1.347 | 3.233 |
| 107 | 10.10 | 9.90 | 2.2 | 2.0 | 120.0 | 1.20 | 4.50 | 32.0 | 547.0 | 1.044 | 1.194 |
| 108 | 10.10 | 9.90 | 2.4 | 2.0 | 122.0 | 1.92 | 6.75 | 32.0 | 570.3 | 1.088 | 1.790 |
| 109 | 10.20 | 9.80 | 2.8 | 2.2 | 127.0 | 3.24 | 8.75 | 34.0 | 630.3 | 1.203 | 2.466 |
| 110 | 10.20 | 9.80 | 3.0 | 2.4 | 129.0 | 4.82 | 10.00 | 37.0 | 655.1 | 1.250 | 3.067 |
| 111 | 10.20 | 9.80 | 3.1 | 2.5 | 131.0 | 6.12 | 10.25 | 39.0 | 680.3 | 1.298 | 3.313 |
| 112 | 10.20 | 9.80 | 3.3 | 2.7 | 132.0 | 8.04 | 11.00 | 41.0 | 693.1 | 1.323 | 3.738 |
| 113 | 10.10 | 9.90 | 2.1 | 1.9 | 119.0 | 1.20 | 3.75 | 28.0 | 535.5 | 1.066 | 0.812 |
| 114 | 10.20 | 9.80 | 2.1 | 1.9 | 120.0 | 1.92 | 4.25 | 28.0 | 547.0 | 1.111 | 1.450 |
| 115 | 10.20 | 9.80 | 2.4 | 2.0 | 124.0 | 3.24 | 4.50 | 29.0 | 594.0 | 1.203 | 2.344 |
| 116 | 10.20 | 9.80 | 2.8 | 2.2 | 126.0 | 4.82 | 4.50 | 30.0 | 618.1 | 1.226 | 2.660 |
| 117 | 10.20 | 9.80 | 2.9 | 2.3 | 129.0 | 6.12 | 5.50 | 32.0 | 642.7 | 1.250 | 3.183 |
| 118 | 10.20 | 9.80 | 3.1 | 2.5 | 131.0 | 8.04 | 6.00 | 33.0 | 680.3 | 1.348 | 3.556 |

| RUN NO. | STEAM PRESS. PSIG. | | UPSTREAM SURGE PRESS. | | WATER TEMP. OUT DEG.F. | GAS FLOW SCFM | UPSTREAM DISPL. INS. | FREQ. C/MIN. | OVERALL UPU | URATIO UPU / UST | DPV |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | MAX | MIN | MAX | MIN | | | | | | | |
| TEST NO. 9 | | | | | | | | | | | |
| 119 | 2.10 | 1.90 | 1.4 | 1.0 | 117.0 | 1.20 | 4.25 | 33.0 | 455.4 | 1.047 | 1.562 |
| 120 | 2.10 | 1.90 | 1.6 | 1.2 | 118.0 | 1.92 | 4.75 | 36.0 | 465.7 | 1.070 | 1.905 |
| 121 | 2.10 | 1.90 | 1.7 | 1.3 | 123.0 | 3.24 | 5.50 | 40.0 | 518.6 | 1.192 | 2.450 |
| 122 | 2.10 | 1.90 | 1.8 | 1.4 | 128.0 | 4.82 | 6.00 | 43.0 | 574.4 | 1.320 | 2.874 |
| 123 | 2.10 | 1.90 | 1.9 | 1.5 | 129.0 | 6.12 | 7.00 | 43.0 | 586.0 | 1.347 | 3.352 |
| 124 | 2.10 | 1.90 | 2.1 | 1.7 | 131.0 | 8.04 | 8.00 | 43.0 | 609.4 | 1.400 | 3.831 |
| 125 | 2.10 | 1.90 | 1.2 | 1.0 | 117.0 | 1.20 | 4.75 | 28.0 | 455.4 | 1.047 | 1.481 |
| 126 | 2.10 | 1.90 | 1.5 | 1.1 | 121.0 | 1.92 | 6.25 | 29.0 | 497.1 | 1.142 | 2.019 |
| 127 | 2.10 | 1.90 | 1.6 | 1.2 | 124.0 | 3.24 | 7.25 | 32.0 | 529.5 | 1.217 | 2.584 |
| 128 | 2.10 | 1.90 | 1.7 | 1.3 | 128.0 | 4.82 | 8.25 | 33.0 | 574.4 | 1.320 | 3.032 |
| 129 | 2.10 | 1.90 | 1.8 | 1.4 | 130.0 | 6.12 | 9.00 | 34.0 | 597.6 | 1.373 | 3.408 |
| 130 | 2.10 | 1.90 | 2.0 | 1.6 | 132.0 | 8.04 | 9.25 | 36.0 | 621.4 | 1.428 | 3.709 |
| TEST NO. 10 | | | | | | | | | | | |
| 131 | 10.10 | 1.90 | 2.4 | 2.0 | 133.0 | 1.20 | 4.00 | 34.0 | 531.2 | 1.057 | 1.515 |
| 132 | 10.10 | 1.90 | 2.7 | 2.3 | 136.0 | 1.92 | 4.50 | 37.0 | 560.6 | 1.115 | 1.854 |
| 133 | 10.10 | 1.90 | 2.9 | 2.5 | 139.0 | 3.24 | 5.50 | 38.0 | 590.8 | 1.175 | 2.328 |
| 134 | 10.10 | 1.90 | 3.0 | 2.6 | 141.0 | 4.82 | 5.25 | 42.0 | 611.4 | 1.216 | 2.456 |
| 135 | 10.10 | 1.90 | 3.1 | 2.7 | 143.0 | 6.12 | 6.25 | 44.0 | 632.5 | 1.258 | 3.063 |
| 136 | 10.10 | 1.90 | 3.2 | 2.8 | 145.0 | 8.04 | 7.25 | 44.0 | 654.0 | 1.301 | 3.553 |
| 137 | 10.10 | 1.90 | 2.2 | 2.0 | 133.0 | 1.20 | 4.00 | 28.0 | 531.2 | 1.057 | 1.247 |
| 138 | 10.10 | 1.90 | 2.5 | 2.1 | 136.0 | 1.92 | 5.00 | 29.0 | 560.6 | 1.115 | 1.620 |
| 139 | 10.10 | 1.90 | 2.7 | 2.3 | 140.0 | 3.24 | 6.25 | 32.0 | 601.0 | 1.196 | 2.228 |
| 140 | 10.10 | 1.90 | 2.8 | 2.4 | 143.0 | 4.82 | 7.50 | 33.0 | 632.5 | 1.258 | 2.757 |
| 141 | 10.10 | 1.90 | 2.8 | 2.4 | 144.0 | 6.12 | 8.00 | 34.0 | 643.2 | 1.280 | 3.029 |
| 142 | 10.10 | 1.90 | 3.0 | 2.6 | 147.0 | 8.04 | 8.00 | 36.0 | 676.0 | 1.345 | 3.208 |

TEST NO. 11

| RUN NO. | STEAM PRESS. PSIG. MAX | MIN | UPSTREAM SURGE PRESS. MAX | MIN | WATER TEMP. OUT DEG.F. | GAS FLOW SCFM | UPSTREAM DISPL. INS. | FREQ. C/MIN. | OVERALL UPU | URATIO UPU --- UST | DPV |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 143 | 2.50 | 1.50 | 3.0 | 2.0 | 120.0 | 1.20 | 6.25 | 56.0 | 459.4 | 1.087 | 1.468 |
| 144 | 2.60 | 1.40 | 3.4 | 2.0 | 122.0 | 1.92 | 8.00 | 58.0 | 478.3 | 1.131 | 1.946 |
| 145 | 2.60 | 1.40 | 3.8 | 2.2 | 124.0 | 3.24 | 9.50 | 62.0 | 497.5 | 1.177 | 2.470 |
| 146 | 2.60 | 1.40 | 4.3 | 2.5 | 127.0 | 4.82 | 10.25 | 65.0 | 527.2 | 1.247 | 2.794 |
| 147 | 2.60 | 1.40 | 4.9 | 2.1 | 130.0 | 6.12 | 13.50 | 65.0 | 557.8 | 1.319 | 3.407 |
| 148 | 2.60 | 1.40 | 5.2 | 2.4 | 133.0 | 8.04 | 14.25 | 66.0 | 589.5 | 1.394 | 3.944 |
| 149 | 2.70 | 1.30 | 2.7 | 2.1 | 119.0 | 1.20 | 8.75 | 38.0 | 450.2 | 1.065 | 1.394 |
| 150 | 3.00 | 1.00 | 2.9 | 2.1 | 121.0 | 1.92 | 13.25 | 38.0 | 468.8 | 1.109 | 2.111 |
| 151 | 3.00 | 1.00 | 3.2 | 2.0 | 126.0 | 3.24 | 17.50 | 39.0 | 517.2 | 1.223 | 2.862 |
| 152 | 3.00 | 1.00 | 3.5 | 2.1 | 130.0 | 4.82 | 20.25 | 41.0 | 557.8 | 1.319 | 3.481 |
| 153 | 3.00 | 1.00 | 3.8 | 2.2 | 132.0 | 6.12 | 22.00 | 42.0 | 578.8 | 1.369 | 3.874 |
| 154 | 3.00 | 1.00 | 4.2 | 2.2 | 134.0 | 8.04 | 24.50 | 43.0 | 600.3 | 1.420 | 4.417 |
| 155 | 2.70 | 1.30 | 2.2 | 2.0 | 119.0 | 1.20 | 7.75 | 32.0 | 450.2 | 1.064 | 1.040 |
| 156 | 3.10 | 0.90 | 2.4 | 2.0 | 121.0 | 1.92 | 14.50 | 32.0 | 468.8 | 1.109 | 1.946 |
| 157 | 3.40 | 0.60 | 2.8 | 1.8 | 125.0 | 3.24 | 19.00 | 32.0 | 507.3 | 1.200 | 2.549 |
| 158 | 3.40 | 0.60 | 3.0 | 2.0 | 130.0 | 4.82 | 24.00 | 33.0 | 557.8 | 1.319 | 3.321 |
| 159 | 3.40 | 0.60 | 3.1 | 2.1 | 132.0 | 6.12 | 26.50 | 33.0 | 578.8 | 1.369 | 3.667 |
| 160 | 3.40 | 0.60 | 3.3 | 2.1 | 133.0 | 8.04 | 28.75 | 34.0 | 589.5 | 1.394 | 4.099 |

TEST NO. 12

| RUN NO. | STEAM PRESS. PSIG. MAX | MIN | UPSTREAM SURGE PRESS. MAX | MIN | WATER TEMP. OUT DEG.F. | GAS FLOW SCFM | UPSTREAM DISPL. INS. | FREQ. C/MIN. | OVERALL UPU | URATIO UPU --- UST | DPV |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 161 | 10.20 | 9.80 | 3.0 | 2.0 | 137.0 | 1.20 | 6.00 | 55.0 | 530.3 | 1.034 | 1.384 |
| 162 | 10.50 | 9.50 | 3.2 | 2.2 | 139.0 | 1.92 | 8.00 | 58.0 | 548.3 | 1.069 | 1.946 |
| 163 | 10.50 | 9.50 | 3.7 | 2.3 | 142.0 | 3.24 | 8.00 | 62.0 | 575.8 | 1.123 | 2.080 |
| 164 | 10.50 | 9.50 | 4.1 | 2.5 | 146.0 | 4.82 | 10.50 | 65.0 | 613.9 | 1.197 | 2.862 |
| 165 | 10.50 | 9.50 | 4.8 | 2.4 | 148.0 | 6.12 | 12.50 | 65.0 | 633.6 | 1.236 | 3.407 |
| 166 | 10.50 | 9.50 | 5.0 | 2.2 | 150.0 | 8.04 | 14.00 | 67.0 | 653.7 | 1.275 | 3.933 |
| 167 | 10.50 | 9.50 | 2.4 | 2.0 | 138.0 | 1.20 | 7.00 | 37.0 | 539.3 | 1.052 | 1.086 |
| 168 | 11.00 | 9.00 | 2.8 | 2.2 | 139.0 | 1.92 | 12.00 | 37.0 | 548.3 | 1.069 | 1.862 |
| 169 | 11.00 | 9.00 | 3.2 | 2.0 | 144.0 | 3.24 | 17.00 | 39.0 | 594.7 | 1.160 | 2.780 |
| 170 | 11.20 | 8.80 | 3.5 | 2.1 | 149.0 | 4.82 | 20.00 | 40.0 | 633.6 | 1.236 | 3.354 |
| 171 | 11.20 | 8.80 | 3.8 | 2.2 | 150.0 | 6.12 | 22.00 | 41.0 | 653.7 | 1.275 | 3.782 |
| 172 | 11.20 | 8.80 | 4.0 | 2.2 | 153.0 | 8.04 | 23.75 | 42.0 | 684.7 | 1.335 | 4.183 |
| 173 | 10.50 | 9.50 | 2.4 | 2.0 | 137.0 | 1.20 | 7.25 | 33.0 | 530.3 | 1.034 | 1.003 |
| 174 | 11.00 | 9.00 | 2.5 | 2.1 | 138.0 | 1.92 | 12.00 | 33.0 | 539.3 | 1.052 | 1.660 |
| 175 | 11.50 | 8.50 | 2.8 | 2.0 | 141.0 | 3.24 | 19.75 | 33.0 | 566.6 | 1.105 | 2.733 |
| 176 | 11.60 | 8.40 | 3.1 | 2.1 | 144.0 | 4.82 | 24.00 | 33.0 | 594.7 | 1.160 | 3.321 |
| 177 | 11.70 | 8.30 | 3.3 | 2.3 | 148.0 | 6.12 | 26.50 | 34.0 | 633.6 | 1.236 | 3.778 |
| 178 | 11.70 | 8.30 | 3.6 | 2.4 | 150.0 | 8.04 | 28.75 | 35.0 | 653.7 | 1.275 | 4.219 |

| RUN NO. | STEAM PRESS. PSIG. MAX | STEAM PRESS. PSIG. MIN | UPSTREAM SURGE PRESS. MAX | UPSTREAM SURGE PRESS. MIN | WATER TEMP. OUT DEG.F. | GAS FLOW SCFM | UPSTREAM DISPL. INS. | FREQ. C/MIN. | OVERALL UPU | URATIO UPU / UST | DPV |
|---|---|---|---|---|---|---|---|---|---|---|---|
| TEST NO. 13 | | | | | | | | | | | |
| 179 | 2.60 | 1.40 | 4.0 | 3.0 | 114.0 | 1.20 | 7.00 | 55.5 | 498.1 | 1.046 | 1.306 |
| 180 | 2.90 | 1.10 | 4.8 | 2.8 | 116.0 | 1.92 | 10.50 | 56.5 | 520.3 | 1.092 | 1.995 |
| 181 | 2.90 | 1.10 | 5.6 | 2.8 | 120.0 | 3.24 | 13.50 | 59.5 | 565.9 | 1.188 | 2.701 |
| 182 | 3.00 | 1.00 | 5.9 | 3.0 | 124.0 | 4.82 | 15.00 | 62.0 | 613.4 | 1.288 | 3.127 |
| 183 | 3.00 | 1.00 | 6.8 | 3.2 | 126.0 | 6.12 | 16.00 | 64.0 | 637.9 | 1.339 | 3.443 |
| 184 | 3.00 | 1.00 | 7.6 | 3.2 | 128.0 | 8.04 | 17.00 | 66.0 | 662.9 | 1.392 | 3.773 |
| 185 | 3.00 | 1.00 | 3.5 | 2.9 | 112.0 | 1.20 | 8.00 | 38.5 | 476.4 | 1.000 | 1.036 |
| 186 | 3.20 | 1.80 | 3.8 | 2.8 | 114.0 | 1.92 | 13.25 | 38.5 | 498.1 | 1.046 | 1.715 |
| 187 | 3.30 | 0.70 | 4.2 | 2.8 | 119.0 | 3.24 | 19.75 | 38.0 | 554.3 | 1.164 | 2.523 |
| 188 | 3.40 | 0.60 | 4.8 | 2.8 | 124.0 | 4.82 | 24.75 | 38.5 | 613.4 | 1.288 | 3.204 |
| 189 | 3.40 | 0.60 | 5.2 | 3.0 | 126.0 | 6.12 | 27.50 | 39.5 | 637.9 | 1.339 | 3.652 |
| 190 | 3.40 | 0.60 | 5.5 | 3.1 | 128.0 | 8.04 | 29.75 | 40.5 | 663.0 | 1.392 | 4.051 |
| 191 | 2.80 | 1.20 | 3.2 | 2.8 | 112.0 | 1.20 | 6.50 | 33.0 | 476.4 | 1.000 | 0.832 |
| 192 | 3.10 | 0.90 | 3.3 | 2.9 | 113.0 | 1.92 | 11.25 | 32.5 | 484.2 | 1.023 | 1.229 |
| 193 | 3.50 | 0.50 | 3.6 | 2.8 | 117.0 | 3.24 | 18.75 | 33.0 | 531.5 | 1.116 | 2.080 |
| 194 | 3.70 | 0.30 | 4.2 | 2.8 | 122.0 | 4.82 | 26.25 | 32.0 | 589.4 | 1.237 | 2.824 |
| 195 | 3.70 | 0.30 | 4.4 | 3.0 | 124.0 | 6.12 | 29.50 | 32.5 | 613.4 | 1.288 | 3.224 |
| 196 | 3.70 | 0.30 | 4.8 | 3.2 | 126.0 | 8.04 | 32.50 | 33.5 | 637.5 | 1.339 | 3.604 |
| TEST NO. 14 | | | | | | | | | | | |
| 197 | 10.50 | 9.50 | 3.9 | 2.9 | 125.0 | 1.20 | 6.50 | 56.0 | 529.5 | 1.059 | 1.224 |
| 198 | 10.50 | 9.50 | 4.4 | 2.6 | 127.0 | 1.92 | 10.25 | 57.0 | 549.5 | 1.099 | 1.964 |
| 199 | 11.00 | 9.00 | 5.1 | 2.9 | 132.0 | 3.24 | 13.25 | 59.5 | 601.1 | 1.202 | 2.651 |
| 200 | 11.00 | 9.00 | 5.9 | 3.5 | 135.0 | 4.82 | 14.00 | 63.0 | 633.2 | 1.266 | 2.966 |
| 201 | 11.00 | 9.00 | 6.6 | 3.0 | 138.0 | 6.12 | 15.00 | 64.5 | 666.3 | 1.332 | 3.362 |
| 202 | 11.00 | 9.00 | 7.2 | 3.0 | 143.0 | 8.04 | 17.00 | 65.0 | 723.6 | 1.447 | 3.715 |
| 203 | 11.00 | 9.00 | 3.4 | 3.0 | 124.0 | 1.20 | 7.50 | 39.0 | 519.7 | 1.039 | 0.984 |
| 204 | 11.50 | 8.50 | 4.0 | 2.8 | 125.0 | 1.92 | 12.25 | 38.5 | 529.5 | 1.059 | 1.586 |
| 205 | 12.00 | 8.00 | 4.7 | 2.8 | 130.0 | 3.24 | 19.25 | 38.5 | 580.2 | 1.160 | 2.492 |
| 206 | 12.00 | 8.00 | 4.7 | 2.7 | 134.0 | 4.82 | 24.75 | 39.0 | 622.4 | 1.244 | 3.246 |
| 207 | 12.00 | 8.00 | 5.1 | 2.9 | 138.0 | 6.12 | 26.75 | 40.0 | 666.3 | 1.332 | 3.598 |
| 208 | 12.00 | 8.00 | 5.2 | 3.0 | 141.0 | 8.04 | 29.00 | 41.0 | 700.3 | 1.400 | 3.998 |
| 209 | 11.00 | 9.00 | 2.7 | 2.5 | 122.0 | 1.20 | 7.50 | 32.0 | 500.2 | 1.000 | 0.807 |
| 210 | 11.20 | 8.80 | 3.0 | 2.6 | 124.0 | 1.92 | 13.00 | 32.0 | 519.7 | 1.039 | 1.399 |
| 211 | 12.00 | 8.00 | 3.3 | 2.7 | 127.0 | 3.24 | 19.75 | 32.0 | 549.5 | 1.099 | 2.125 |
| 212 | 12.50 | 7.50 | 3.6 | 2.8 | 132.0 | 4.82 | 27.00 | 31.5 | 601.1 | 1.202 | 2.860 |
| 213 | 12.50 | 7.50 | 4.4 | 3.0 | 134.0 | 6.12 | 30.00 | 32.5 | 622.4 | 1.244 | 3.278 |
| 214 | 12.50 | 7.50 | 5.0 | 3.6 | 137.0 | 8.04 | 32.00 | 34.0 | 655.2 | 1.310 | 3.658 |

| RUN NO. | STEAM PRESS. PSIG. | | UPSTREAM SURGE PRESS. | | WATER TEMP. OUT DEG.F. | GAS FLOW SCFM | UPSTREAM DISPL. INS. | FREQ. C/MIN. | OVERALL UPU | URATIO UPU/UST | DPV |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | MAX | MIN | MAX | MIN | | | | | | | |
| TEST NO. 15 | | | | | | | | | | | |
| 215 | 2.60 | 1.40 | 5.1 | 3.9 | 109.0 | 1.20 | 7.00 | 57.0 | 515.6 | 1.025 | 1.120 |
| 216 | 2.90 | 1.10 | 5.8 | 3.8 | 112.0 | 1.92 | 10.25 | 57.0 | 553.8 | 1.101 | 1.640 |
| 217 | 3.00 | 1.00 | 7.2 | 3.8 | 116.0 | 3.24 | 15.50 | 58.0 | 660.3 | 1.205 | 2.523 |
| 218 | 3.00 | 1.00 | 8.0 | 3.7 | 119.0 | 4.82 | 17.75 | 60.5 | 647.1 | 1.286 | 3.014 |
| 219 | 2.90 | 1.10 | 8.6 | 4.0 | 120.0 | 6.12 | 17.50 | 62.5 | 660.9 | 1.314 | 3.070 |
| 220 | 2.90 | 1.10 | 9.4 | 4.0 | 121.0 | 8.04 | 19.00 | 64.0 | 674.9 | 1.341 | 3.413 |
| 221 | 2.90 | 1.10 | 4.8 | 4.4 | 108.0 | 1.20 | 6.50 | 40.0 | 503.2 | 1.000 | 0.730 |
| 222 | 3.10 | 0.90 | 5.2 | 4.4 | 110.0 | 1.92 | 11.00 | 39.5 | 528.2 | 1.050 | 1.219 |
| 223 | 3.60 | 0.40 | 5.8 | 4.2 | 113.0 | 3.24 | 19.00 | 39.0 | 566.7 | 1.126 | 2.080 |
| 224 | 3.70 | 0.30 | 6.4 | 4.2 | 117.0 | 4.82 | 24.50 | 39.5 | 619.7 | 1.232 | 2.716 |
| 225 | 3.80 | 0.20 | 6.8 | 4.4 | 122.0 | 6.12 | 28.00 | 40.0 | 689.1 | 1.370 | 3.143 |
| 226 | 3.80 | 0.20 | 7.5 | 4.5 | 123.0 | 8.04 | 31.50 | 40.0 | 703.4 | 1.398 | 3.536 |
| 227 | 2.90 | 1.10 | 4.8 | 4.4 | 108.0 | 1.20 | 6.00 | 34.5 | 503.2 | 1.000 | 0.581 |
| 228 | 3.10 | 0.90 | 4.9 | 4.5 | 108.0 | 1.92 | 9.50 | 34.5 | 503.2 | 1.000 | 0.919 |
| 229 | 3.90 | 0.10 | 5.2 | 4.6 | 110.0 | 3.24 | 17.75 | 33.5 | 528.2 | 1.050 | 1.669 |
| 230 | 3.90 | 0.10 | 5.6 | 4.4 | 113.0 | 4.82 | 24.50 | 33.0 | 566.7 | 1.126 | 2.290 |
| 231 | 3.90 | 0.10 | 6.0 | 4.4 | 116.0 | 6.12 | 29.00 | 33.0 | 606.3 | 1.205 | 2.686 |
| TEST NO. 16 | | | | | | | | | | | |
| 232 | 10.80 | 9.20 | 5.2 | 4.0 | 118.0 | 1.20 | 7.50 | 57.5 | 538.7 | 1.021 | 1.049 |
| 233 | 11.10 | 8.90 | 5.9 | 4.8 | 121.0 | 1.92 | 11.25 | 58.0 | 572.7 | 1.086 | 1.831 |
| 234 | 11.30 | 8.70 | 7.1 | 3.9 | 126.0 | 3.24 | 15.00 | 58.5 | 631.4 | 1.197 | 2.463 |
| 235 | 11.30 | 8.70 | 8.0 | 4.0 | 131.0 | 4.82 | 17.75 | 59.5 | 692.7 | 1.313 | 2.964 |
| 236 | 11.30 | 8.70 | 8.8 | 4.8 | 133.0 | 6.12 | 18.25 | 64.0 | 717.9 | 1.361 | 3.279 |
| 237 | 11.30 | 8.70 | 9.5 | 4.5 | 136.0 | 8.04 | 20.00 | 65.0 | 756.8 | 1.434 | 3.648 |
| 238 | 11.10 | 8.90 | 4.8 | 4.2 | 117.0 | 1.20 | 6.75 | 40.0 | 527.6 | 1.000 | 0.758 |
| 239 | 11.50 | 8.50 | 5.0 | 4.2 | 118.0 | 1.92 | 12.25 | 39.5 | 538.7 | 1.021 | 1.358 |
| 240 | 12.10 | 7.90 | 5.8 | 4.2 | 122.0 | 3.24 | 18.75 | 39.5 | 584.3 | 1.108 | 2.078 |
| 241 | 12.20 | 7.80 | 6.2 | 4.1 | 127.0 | 4.82 | 25.00 | 39.0 | 643.4 | 1.220 | 2.736 |
| 242 | 12.20 | 7.80 | 6.9 | 4.3 | 131.0 | 6.12 | 28.25 | 39.5 | 692.6 | 1.313 | 3.132 |
| 243 | 12.20 | 7.80 | 7.2 | 4.4 | 133.0 | 8.04 | 32.00 | 40.0 | 717.9 | 1.361 | 3.592 |
| 244 | 11.00 | 9.00 | 4.6 | 4.4 | 117.0 | 1.20 | 5.75 | 34.5 | 527.6 | 1.000 | 0.557 |
| 245 | 11.50 | 8.50 | 4.8 | 4.4 | 118.0 | 1.92 | 10.00 | 34.0 | 538.7 | 1.021 | 0.954 |
| 246 | 12.10 | 7.90 | 5.1 | 4.3 | 120.0 | 3.24 | 17.50 | 33.0 | 561.3 | 1.064 | 1.621 |
| 247 | 12.30 | 7.70 | 5.4 | 4.4 | 123.0 | 4.82 | 24.00 | 32.5 | 595.9 | 1.130 | 2.189 |
| 248 | 12.50 | 7.50 | 6.0 | 4.6 | 127.0 | 6.12 | 28.75 | 33.0 | 643.4 | 1.220 | 2.663 |

TEST NO. 17

| RUN NO. | STEAM PRESS. PSIG. MAX | MIN | UPSTREAM SURGE PRESS. MAX | MIN | WATER TEMP. OUT DEG.F. | GAS FLOW SCFM | UPSTREAM DISPL. INS. | FREQ. C/MIN. | OVERALL UPU | URATIO UPU --- UST | DPV |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 249 | 2.70 | 1.30 | 6.8 | 5.8 | 102.0 | 1.20 | 5.50 | 59.0 | 481.7 | 1.000 | 0.781 |
| 250 | 2.90 | 1.10 | 7.4 | 5.6 | 104.0 | 1.92 | 9.00 | 59.0 | 509.4 | 1.058 | 1.279 |
| 251 | 3.10 | 0.90 | 8.8 | 5.2 | 108.0 | 3.24 | 14.25 | 59.0 | 566.2 | 1.176 | 2.025 |
| 252 | 3.20 | 0.80 | 9.9 | 5.1 | 112.0 | 4.82 | 18.00 | 60.0 | 625.2 | 1.298 | 2.601 |
| 253 | 3.20 | 0.80 | 10.8 | 5.2 | 114.0 | 6.12 | 20.50 | 61.5 | 655.5 | 1.361 | 3.036 |
| 254 | 3.20 | 0.80 | 11.9 | 5.5 | 115.0 | 8.04 | 21.00 | 63.5 | 670.9 | 1.393 | 3.211 |
| 255 | 2.70 | 1.30 | 6.3 | 5.9 | 102.0 | 1.20 | 5.75 | 42.0 | 481.7 | 1.000 | 0.582 |
| 256 | 3.10 | 0.90 | 6.9 | 5.9 | 102.0 | 1.92 | 9.50 | 41.5 | 481.7 | 1.000 | 0.949 |
| 257 | 3.50 | 0.50 | 7.5 | 5.9 | 105.0 | 3.24 | 17.00 | 40.5 | 523.4 | 1.087 | 1.658 |
| 258 | 3.80 | 0.20 | 8.0 | 6.0 | 108.0 | 4.82 | 23.25 | 40.0 | 566.2 | 1.176 | 2.240 |
| 259 | 3.90 | 0.10 | 8.8 | 6.0 | 111.0 | 6.12 | 28.00 | 40.0 | 610.2 | 1.267 | 2.697 |
| 260 | 3.90 | 0.10 | 9.0 | 6.0 | 111.0 | 8.04 | 29.50 | 40.5 | 610.2 | 1.267 | 2.877 |
| 261 | 2.70 | 1.30 | 6.2 | 5.8 | 102.0 | 1.20 | 4.75 | 35.5 | 481.7 | 1.000 | 0.406 |
| 262 | 3.10 | 0.90 | 6.2 | 5.8 | 102.0 | 1.92 | 9.00 | 35.5 | 481.7 | 1.000 | 0.769 |
| 263 | 3.80 | 0.20 | 6.8 | 5.8 | 103.0 | 3.24 | 15.75 | 34.5 | 495.5 | 1.029 | 1.310 |
| 264 | 4.00 | 0.00 | 7.1 | 5.9 | 105.0 | 4.82 | 23.00 | 34.0 | 523.4 | 1.087 | 1.883 |
| 265 | 4.00 | 0.00 | 7.6 | 5.8 | 106.0 | 6.12 | 28.00 | 33.5 | 537.5 | 1.116 | 2.259 |

TEST NO. 18

| RUN NO. | STEAM PRESS. PSIG. MAX | MIN | UPSTREAM SURGE PRESS. MAX | MIN | WATER TEMP. OUT DEG.F. | GAS FLOW SCFM | UPSTREAM DISPL. INS. | FREQ. C/MIN. | OVERALL UPU | URATIO UPU --- UST | DPV |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 266 | 10.80 | 9.20 | 6.8 | 5.8 | 112.0 | 1.20 | 5.50 | 59.0 | 551.4 | 1.000 | 0.781 |
| 267 | 11.20 | 8.80 | 7.3 | 5.7 | 114.0 | 1.92 | 8.75 | 59.0 | 576.5 | 1.046 | 1.243 |
| 268 | 11.70 | 8.30 | 8.8 | 5.2 | 117.0 | 3.24 | 14.50 | 59.0 | 614.8 | 1.115 | 2.060 |
| 269 | 11.70 | 8.30 | 8.8 | 5.4 | 122.0 | 4.82 | 18.25 | 60.0 | 680.9 | 1.235 | 2.637 |
| 270 | 11.70 | 8.30 | 10.9 | 5.5 | 125.0 | 6.12 | 20.50 | 61.0 | 721.9 | 1.309 | 3.011 |
| 271 | 11.70 | 8.30 | 11.8 | 5.8 | 128.0 | 8.04 | 22.00 | 63.0 | 763.9 | 1.385 | 3.334 |
| 272 | 11.00 | 9.00 | 6.2 | 6.0 | 112.0 | 1.20 | 5.00 | 42.0 | 551.4 | 1.000 | 0.506 |
| 273 | 11.50 | 8.50 | 6.6 | 5.8 | 112.0 | 1.92 | 8.75 | 41.0 | 551.4 | 1.000 | 0.864 |
| 274 | 12.00 | 8.00 | 7.2 | 5.8 | 113.0 | 3.24 | 16.00 | 40.5 | 563.9 | 1.023 | 1.561 |
| 275 | 12.50 | 7.50 | 7.9 | 5.9 | 115.0 | 4.82 | 22.25 | 40.0 | 589.2 | 1.069 | 2.143 |
| 276 | 12.80 | 7.20 | 8.9 | 5.9 | 120.0 | 6.12 | 27.75 | 40.5 | 654.1 | 1.186 | 2.706 |
| 277 | 12.50 | 7.50 | 9.2 | 6.0 | 122.0 | 8.04 | 30.00 | 40.5 | 680.9 | 1.235 | 2.926 |
| 278 | 11.00 | 9.00 | 6.1 | 5.9 | 112.0 | 1.20 | 4.50 | 36.0 | 551.4 | 1.000 | 0.390 |
| 279 | 11.50 | 8.50 | 6.2 | 5.8 | 112.0 | 1.92 | 7.75 | 35.5 | 551.4 | 1.000 | 0.663 |
| 280 | 12.00 | 8.00 | 6.8 | 6.0 | 113.0 | 3.24 | 14.75 | 34.5 | 563.9 | 1.023 | 1.225 |
| 281 | 12.50 | 7.50 | 7.1 | 5.9 | 114.0 | 4.82 | 21.00 | 34.5 | 576.5 | 1.046 | 1.745 |
| 282 | 13.00 | 7.00 | 7.6 | 6.0 | 117.0 | 6.12 | 27.50 | 35.5 | 614.8 | 1.115 | 2.219 |

| RUN NO. | STEAM PRESS. PSIG. MAX | MIN | UPSTREAM SURGE PRESS. MAX | MIN | WATER TEMP. OUT DEG.F. | GAS FLOW SCFM | UPSTREAM DISPL. INS. | FREQ. C/MIN. | OVERALL UPU | URATIO UPU --- UST | DPV |
|---|---|---|---|---|---|---|---|---|---|---|---|
| TEST NO. 19 | | | | | | | | | | | |
| 283 | 2.50 | 1.50 | 8.2 | 7.4 | 98.0 | 1.20 | 4.50 | 62.0 | 514.5 | 1.000 | 0.585 |
| 284 | 3.00 | 1.00 | 9.0 | 7.2 | 99.0 | 1.92 | 7.50 | 61.0 | 529.8 | 1.030 | 0.959 |
| 285 | 3.20 | 0.80 | 10.2 | 7.2 | 100.0 | 3.24 | 13.00 | 61.0 | 545.2 | 1.060 | 1.663 |
| 286 | 3.20 | 0.80 | 11.4 | 7.0 | 102.0 | 4.82 | 17.25 | 61.5 | 576.4 | 1.121 | 2.224 |
| 287 | 3.20 | 0.80 | 12.6 | 7.0 | 104.0 | 6.12 | 20.75 | 62.0 | 608.2 | 1.182 | 2.697 |
| 288 | 2.80 | 1.20 | 7.7 | 7.5 | 98.0 | 1.20 | 4.50 | 42.5 | 514.5 | 1.000 | 0.401 |
| 289 | 2.80 | 1.20 | 8.1 | 7.5 | 98.0 | 1.92 | 7.50 | 42.0 | 514.5 | 1.000 | 0.660 |
| 290 | 3.40 | 0.60 | 8.7 | 7.3 | 99.0 | 3.24 | 14.25 | 41.5 | 529.8 | 1.030 | 1.240 |
| 291 | 4.00 | 0.00 | 9.5 | 7.4 | 100.0 | 4.82 | 20.50 | 41.0 | 545.2 | 1.060 | 1.762 |
| 292 | 4.00 | 0.00 | 10.0 | 7.4 | 102.0 | 6.12 | 25.50 | 41.0 | 576.4 | 1.121 | 2.192 |
| 293 | 3.60 | 0.40 | 10.8 | 7.6 | 105.0 | 8.04 | 27.00 | 42.0 | 624.3 | 1.214 | 2.554 |
| 294 | 2.50 | 1.50 | 7.9 | 7.7 | 98.0 | 1.20 | 3.25 | 37.5 | 514.5 | 1.000 | 0.256 |
| 295 | 2.90 | 1.10 | 7.9 | 7.7 | 98.0 | 1.92 | 5.50 | 37.0 | 514.5 | 1.000 | 0.427 |
| 296 | 3.20 | 0.80 | 8.2 | 7.8 | 97.0 | 3.24 | 12.00 | 36.5 | 499.3 | .971 | 0.918 |
| 297 | 3.80 | 0.20 | 8.8 | 7.8 | 98.0 | 4.82 | 18.00 | 35.5 | 514.5 | 1.000 | 1.340 |
| 298 | 4.10 | -.10 | 9.2 | 7.8 | 100.0 | 6.12 | 24.00 | 35.0 | 545.2 | 1.060 | 1.761 |
| 299 | 4.10 | -.10 | 9.8 | 8.0 | 102.0 | 8.04 | 28.00 | 35.0 | 576.4 | 1.121 | 2.055 |
| TEST NO. 20 | | | | | | | | | | | |
| 300 | 10.80 | 9.20 | 8.4 | 7.6 | 107.0 | 1.20 | 4.00 | 62.5 | 543.0 | 1.000 | 0.524 |
| 301 | 11.10 | 8.90 | 9.2 | 7.2 | 108.0 | 1.92 | 7.50 | 62.0 | 566.8 | 1.025 | 0.975 |
| 302 | 11.50 | 8.50 | 10.4 | 8.0 | 111.0 | 3.24 | 13.00 | 61.5 | 598.8 | 1.103 | 1.676 |
| 303 | 12.00 | 8.00 | 11.6 | 7.0 | 114.0 | 4.82 | 17.00 | 62.0 | 641.9 | 1.182 | 2.210 |
| 304 | 12.00 | 8.00 | 13.0 | 7.0 | 119.0 | 6.12 | 20.00 | 63.0 | 715.9 | 1.318 | 2.642 |
| 305 | 10.80 | 9.20 | 7.8 | 7.6 | 107.0 | 1.20 | 4.00 | 43.0 | 543.0 | 1.000 | 0.361 |
| 306 | 11.50 | 8.50 | 8.2 | 7.8 | 107.0 | 1.92 | 7.50 | 43.0 | 543.0 | 1.000 | 0.676 |
| 307 | 12.10 | 7.90 | 9.0 | 8.0 | 108.0 | 3.24 | 14.00 | 42.0 | 556.8 | 1.025 | 1.233 |
| 308 | 12.80 | 7.20 | 9.8 | 7.8 | 110.0 | 4.82 | 20.00 | 42.0 | 584.7 | 1.077 | 1.761 |
| 309 | 13.00 | 7.00 | 10.2 | 7.8 | 113.0 | 6.12 | 25.00 | 41.5 | 627.4 | 1.155 | 2.175 |
| 310 | 13.00 | 7.00 | 11.1 | 7.9 | 117.0 | 8.04 | 30.00 | 41.5 | 685.9 | 1.263 | 2.610 |
| 311 | 10.50 | 9.50 | 7.9 | 7.7 | 107.0 | 1.20 | 3.50 | 37.5 | 543.0 | 1.000 | 0.275 |
| 312 | 11.10 | 8.90 | 8.0 | 7.8 | 107.0 | 1.92 | 6.00 | 37.5 | 543.0 | 1.000 | 0.472 |
| 313 | 12.00 | 8.00 | 8.4 | 7.8 | 107.0 | 3.24 | 12.00 | 36.5 | 543.0 | 1.000 | 0.957 |
| 314 | 12.50 | 7.50 | 8.9 | 7.9 | 109.0 | 4.82 | 18.00 | 35.5 | 570.7 | 1.051 | 1.340 |
| 315 | 13.50 | 6.50 | 9.6 | 7.8 | 111.0 | 6.12 | 24.25 | 34.5 | 598.8 | 1.103 | 1.754 |
| 316 | 13.50 | 6.50 | 9.9 | 7.9 | 113.0 | 8.04 | 29.00 | 34.5 | 627.4 | 1.155 | 2.100 |

TEST NO. 21

| RUN NO. | STEAM PRESS. PSIG. MAX | STEAM PRESS. PSIG. MIN | UPSTREAM SURGE PRESS. MAX | UPSTREAM SURGE PRESS. MIN | WATER TEMP. OUT DEG.F. | GAS FLOW SCFM | UPSTREAM DISPL. INS. | FREQ. C/MIN. | OVERALL UPU | URATIO UPU / UST | DPV |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 317 | 2.40 | 1.60 | 9.9 | 8.9 | 88.0 | 1.20 | 3.50 | 64.0 | 542.2 | 1.000 | 0.417 |
| 318 | 2.80 | 1.20 | 10.2 | 8.8 | 89.0 | 1.92 | 6.50 | 64.0 | 558.6 | 1.030 | 0.775 |
| 319 | 3.00 | 1.00 | 11.8 | 8.8 | 91.0 | 3.24 | 11.25 | 64.0 | 591.8 | 1.091 | 1.341 |
| 320 | 3.10 | 0.90 | 12.6 | 8.4 | 93.0 | 4.82 | 15.50 | 64.0 | 625.5 | 1.154 | 1.848 |
| 321 | 2.50 | 1.50 | 9.2 | 9.0 | 88.0 | 1.20 | 3.50 | 44.5 | 542.2 | 1.000 | 0.290 |
| 322 | 2.80 | 1.20 | 9.4 | 9.0 | 88.0 | 1.92 | 8.25 | 44.0 | 542.2 | 1.000 | 0.676 |
| 323 | 3.20 | 0.80 | 10.2 | 9.0 | 88.0 | 3.24 | 12.50 | 43.5 | 542.2 | 1.000 | 1.013 |
| 324 | 3.40 | 0.60 | 11.0 | 9.0 | 90.0 | 4.82 | 18.00 | 42.5 | 575.2 | 1.000 | 1.425 |
| 325 | 3.80 | 0.20 | 11.8 | 9.0 | 91.0 | 6.12 | 23.75 | 42.0 | 575.2 | 1.091 | 1.858 |
| 326 | 3.80 | 0.20 | 12.4 | 9.0 | 93.0 | 8.04 | 27.50 | 42.0 | 625.5 | 1.154 | 2.152 |
| 327 | 2.50 | 1.50 | 9.3 | 9.1 | 88.0 | 1.20 | 2.75 | 39.0 | 542.2 | 1.000 | 0.205 |
| 328 | 2.80 | 1.20 | 9.4 | 9.2 | 88.0 | 1.92 | 5.25 | 38.0 | 542.2 | 1.000 | 0.382 |
| 329 | 3.20 | 0.80 | 9.9 | 9.1 | 88.0 | 3.24 | 10.50 | 37.5 | 542.2 | 1.000 | 0.734 |
| 330 | 3.40 | 0.60 | 10.5 | 9.3 | 88.0 | 4.82 | 16.50 | 36.0 | 542.2 | 1.000 | 1.137 |
| 331 | 3.80 | 0.20 | 10.8 | 9.4 | 88.0 | 6.12 | 22.00 | 36.0 | 542.2 | 1.000 | 1.496 |
| 332 | 4.00 | 0.00 | 11.4 | 9.4 | 89.0 | 8.04 | 46.00 | 35.5 | 558.6 | 1.030 | 1.720 |

TEST NO. 22

| RUN NO. | STEAM PRESS. PSIG. MAX | STEAM PRESS. PSIG. MIN | UPSTREAM SURGE PRESS. MAX | UPSTREAM SURGE PRESS. MIN | WATER TEMP. OUT DEG.F. | GAS FLOW SCFM | UPSTREAM DISPL. INS. | FREQ. C/MIN. | OVERALL UPU | URATIO UPU / UST | DPV |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 333 | 10.80 | 9.20 | 10.0 | 9.0 | 100.0 | 1.20 | 3.50 | 64.0 | 584.5 | 1.000 | 0.417 |
| 334 | 11.00 | 9.00 | 10.4 | 8.8 | 100.0 | 1.92 | 6.50 | 64.0 | 584.5 | 1.000 | 0.775 |
| 335 | 11.50 | 8.50 | 11.8 | 8.8 | 102.0 | 3.24 | 11.00 | 64.0 | 614.1 | 1.051 | 1.312 |
| 336 | 12.00 | 8.00 | 12.1 | 8.7 | 105.0 | 4.82 | 15.75 | 64.0 | 659.3 | 1.128 | 1.878 |
| 337 | 10.50 | 9.50 | 9.4 | 9.0 | 100.0 | 1.20 | 3.00 | 44.5 | 584.5 | 1.000 | 0.249 |
| 338 | 11.20 | 8.80 | 9.8 | 9.0 | 100.0 | 1.92 | 6.25 | 44.0 | 584.5 | 1.000 | 0.512 |
| 339 | 12.00 | 8.00 | 10.2 | 9.0 | 100.0 | 3.24 | 12.25 | 43.5 | 584.5 | 1.000 | 0.993 |
| 340 | 12.80 | 7.20 | 11.0 | 9.0 | 100.0 | 4.82 | 17.25 | 42.5 | 584.5 | 1.000 | 1.366 |
| 341 | 13.00 | 7.00 | 11.9 | 9.1 | 103.0 | 6.12 | 23.50 | 42.0 | 629.0 | 1.076 | 1.839 |
| 342 | 13.20 | 6.80 | 12.6 | 9.2 | 106.0 | 8.04 | 28.00 | 42.0 | 674.6 | 1.154 | 2.191 |
| 343 | 10.50 | 9.50 | 9.6 | 9.4 | 100.0 | 1.20 | 2.75 | 40.0 | 584.5 | 1.000 | 0.205 |
| 344 | 11.00 | 9.00 | 9.8 | 9.4 | 100.0 | 1.92 | 5.00 | 39.5 | 584.5 | 1.000 | 0.368 |
| 345 | 12.10 | 7.90 | 10.0 | 9.6 | 100.0 | 3.24 | 10.50 | 38.0 | 584.5 | 1.000 | 0.743 |
| 346 | 12.80 | 7.20 | 10.5 | 9.5 | 101.0 | 4.82 | 26.50 | 37.0 | 599.2 | 1.025 | 1.137 |
| 347 | 13.20 | 6.80 | 11.0 | 9.6 | 102.0 | 6.12 | 21.00 | 36.5 | 614.1 | 1.051 | 1.428 |
| 348 | 14.00 | 6.00 | 11.6 | 9.8 | 103.0 | 8.04 | 27.00 | 35.5 | 629.0 | 1.076 | 1.786 |

| RUN NO. | STEAM PRESS. PSIG. MAX | MIN | UPSTREAM SURGE PRESS. MAX | MIN | WATER TEMP. OUT DEG.F. | GAS FLOW SCFM | UPSTREAM DISPL. INS. | FREQ. C/MIN. | OVERALL UPU | URATIO UPU --- UST | DPV |
|---|---|---|---|---|---|---|---|---|---|---|---|

TEST NO. 23

| RUN NO. | STEAM PRESS. PSIG. MAX | MIN | UPSTREAM SURGE PRESS. MAX | MIN | WATER TEMP. OUT DEG.F. | GAS FLOW SCFM | UPSTREAM DISPL. INS. | FREQ. C/MIN. | OVERALL UPU | URATIO UPU --- UST | DPV |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 349 | 2.60 | 1.40 | 8.2 | 6.4 | 111.0 | 1.20 | 7.25 | 58.0 | 474.1 | 1.070 | 1.410 |
| 350 | 2.90 | 1.10 | 9.1 | 6.5 | 117.0 | 1.92 | 11.25 | 58.5 | 540.1 | 1.221 | 2.207 |
| 351 | 3.10 | 0.90 | 10.4 | 6.2 | 124.0 | 3.24 | 16.50 | 59.5 | 622.2 | 1.406 | 3.292 |
| 352 | 3.10 | 0.90 | 11.8 | 6.2 | 129.0 | 4.82 | 20.00 | 60.0 | 684.7 | 1.547 | 4.023 |
| 353 | 3.10 | 0.90 | 13.0 | 6.4 | 132.0 | 6.12 | 22.75 | 61.5 | 723.9 | 1.636 | 4.691 |
| 354 | 3.10 | 0.90 | 14.4 | 6.6 | 134.0 | 8.04 | 24.00 | 63.0 | 750.8 | 1.697 | 5.070 |
| 355 | 2.90 | 1.10 | 7.8 | 7.0 | 108.0 | 1.20 | 7.50 | 41.5 | 442.5 | 1.000 | 1.044 |
| 356 | 3.20 | 0.80 | 8.0 | 7.0 | 110.0 | 1.92 | 12.50 | 40.5 | 483.5 | 1.047 | 1.697 |
| 357 | 3.40 | 0.60 | 8.8 | 7.2 | 116.0 | 3.24 | 18.00 | 41.0 | 528.8 | 1.195 | 2.474 |
| 358 | 3.60 | 0.40 | 9.4 | 7.0 | 122.0 | 4.82 | 26.50 | 40.0 | 598.1 | 1.352 | 3.554 |
| 359 | 3.60 | 0.40 | 10.4 | 7.4 | 125.0 | 6.12 | 30.00 | 40.0 | 634.4 | 1.434 | 4.023 |
| 360 | 3.60 | 0.40 | 11.5 | 7.5 | 127.0 | 8.04 | 31.00 | 41.0 | 659.3 | 1.490 | 4.261 |
| 361 | 3.00 | 1.00 | 7.4 | 7.2 | 108.0 | 1.20 | 6.25 | 35.5 | 442.5 | 1.000 | 0.744 |
| 362 | 3.10 | 0.90 | 7.8 | 7.2 | 108.0 | 1.92 | 10.75 | 34.5 | 442.5 | 1.000 | 1.244 |
| 363 | 3.50 | 0.50 | 8.2 | 7.2 | 112.0 | 3.24 | 18.50 | 33.5 | 484.9 | 1.096 | 2.078 |
| 364 | 3.80 | 0.20 | 8.8 | 7.4 | 116.0 | 4.82 | 19.50 | 33.5 | 528.8 | 1.195 | 2.920 |
| 365 | 3.80 | 0.20 | 9.5 | 7.5 | 120.0 | 6.12 | 29.50 | 33.0 | 574.6 | 1.298 | 3.264 |

TEST NO. 24

| RUN NO. | STEAM PRESS. PSIG. MAX | MIN | UPSTREAM SURGE PRESS. MAX | MIN | WATER TEMP. OUT DEG.F. | GAS FLOW SCFM | UPSTREAM DISPL. INS. | FREQ. C/MIN. | OVERALL UPU | URATIO UPU --- UST | DPV |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 366 | 11.00 | 9.00 | 8.1 | 6.5 | 20.0 | 1.20 | 7.75 | 58.5 | 488.6 | 1.040 | 1.520 |
| 367 | 11.40 | 8.60 | 9.0 | 6.4 | 126.0 | 1.92 | 11.25 | 58.5 | 547.3 | 1.165 | 2.201 |
| 368 | 11.40 | 8.60 | 10.5 | 6.5 | 135.0 | 3.24 | 16.25 | 59.5 | 641.3 | 1.365 | 3.242 |
| 369 | 11.40 | 8.60 | 11.8 | 6.2 | 142.0 | 4.82 | 19.75 | 60.5 | 720.1 | 1.533 | 4.006 |
| 370 | 11.40 | 8.60 | 13.1 | 6.5 | 146.0 | 6.12 | 22.00 | 62.0 | 767.8 | 1.635 | 4.573 |
| 371 | 11.40 | 8.60 | 14.4 | 6.0 | 149.0 | 8.04 | 24.00 | 63.0 | 804.8 | 1.713 | 5.069 |
| 372 | 11.10 | 8.90 | 7.8 | 7.0 | 120.0 | 1.20 | 7.75 | 41.0 | 488.6 | 1.040 | 1.065 |
| 373 | 11.60 | 8.40 | 8.1 | 7.1 | 121.0 | 1.92 | 12.50 | 40.5 | 498.2 | 1.061 | 1.697 |
| 374 | 12.00 | 8.00 | 8.9 | 7.1 | 128.0 | 3.24 | 19.25 | 40.0 | 567.5 | 1.208 | 2.582 |
| 375 | 12.20 | 7.80 | 9.8 | 7.2 | 134.0 | 4.82 | 25.00 | 40.0 | 630.4 | 1.342 | 3.353 |
| 376 | 12.20 | 7.80 | 10.4 | 7.2 | 137.0 | 6.12 | 30.00 | 39.5 | 663.2 | 1.412 | 3.973 |
| 377 | 12.50 | 7.50 | 11.6 | 8.0 | 140.0 | 8.04 | 31.50 | 41.0 | 697.0 | 1.484 | 4.330 |
| 378 | 11.20 | 8.80 | 7.4 | 7.0 | 118.0 | 1.20 | 7.25 | 34.5 | 469.7 | 1.000 | 0.839 |
| 379 | 11.80 | 8.20 | 7.6 | 7.0 | 120.0 | 1.92 | 11.50 | 34.0 | 488.6 | 1.040 | 1.311 |
| 380 | 12.20 | 7.80 | 8.1 | 7.1 | 124.0 | 3.24 | 19.00 | 33.5 | 527.4 | 1.123 | 2.134 |
| 381 | 12.50 | 7.50 | 8.8 | 7.2 | 129.0 | 4.82 | 26.00 | 34.0 | 577.7 | 1.230 | 2.964 |
| 382 | 12.50 | 7.50 | 8.8 | 7.7 | 133.0 | 6.12 | 29.00 | 33.5 | 619.7 | 1.319 | 3.257 |

| RUN NO. | STEAM PRESS. PSIG. MAX | MIN | UPSTREAM SURGE PRESS. MAX | MIN | WATER TEMP. OUT DEG.F. | GAS FLOW SCFM | UPSTREAM DISPL. INS. | FREQ. C/MIN. | OVERALL UPU | URATIO UPU / UST | DPV |
|---|---|---|---|---|---|---|---|---|---|---|---|
| TEST NO. 25 | | | | | | | | | | | |
| 383 | 2.40 | 1.60 | 2.8 | 1.4 | 164.0 | 1.20 | 8.00 | 54.5 | 478.9 | 1.430 | 3.656 |
| 384 | 2.50 | 1.50 | 3.0 | 1.4 | 170.0 | 1.92 | 8.50 | 56.0 | 532.8 | 1.591 | 4.931 |
| 385 | 2.60 | 1.40 | 3.6 | 1.4 | 177.0 | 3.24 | 12.50 | 56.5 | 604.8 | 1.806 | 5.923 |
| 386 | 2.60 | 1.40 | 4.0 | 1.6 | 179.0 | 4.82 | 14.25 | 58.0 | 627.7 | 1.874 | 6.931 |
| 387 | 2.60 | 1.40 | 4.4 | 1.6 | 181.0 | 6.12 | 15.75 | 58.5 | 651.7 | 1.946 | 7.727 |
| 388 | 2.60 | 1.40 | 4.9 | 1.5 | 184.0 | 8.04 | 17.25 | 59.5 | 690.4 | 2.061 | 8.607 |
| 389 | 2.80 | 1.20 | 2.1 | 1.5 | 162.0 | 1.20 | 11.75 | 36.5 | 462.3 | 1.380 | 3.903 |
| 390 | 2.90 | 1.10 | 2.4 | 1.4 | 168.0 | 1.92 | 15.75 | 37.5 | 514.1 | 1.535 | 4.953 |
| 391 | 3.00 | 1.00 | 2.9 | 1.3 | 174.0 | 3.04 | 18.25 | 38.5 | 572.6 | 1.709 | 6.054 |
| 392 | 3.00 | 1.00 | 3.0 | 1.4 | 176.0 | 4.82 | 21.50 | 39.0 | 593.8 | 1.773 | 7.032 |
| 393 | 3.00 | 1.00 | 3.3 | 1.5 | 179.0 | 6.12 | 24.40 | 39.5 | 627.7 | 1.874 | 8.116 |
| 394 | 3.00 | 1.00 | 3.6 | 1.5 | 180.0 | 8.04 | 26.25 | 40.0 | 639.6 | 1.909 | 8.805 |
| 395 | 2.80 | 1.20 | 2.0 | 1.6 | 158.0 | 1.20 | 12.00 | 31.0 | 430.8 | 1.286 | 3.120 |
| 396 | 2.90 | 1.10 | 2.1 | 1.5 | 165.0 | 1.92 | 16.50 | 31.5 | 487.5 | 1.455 | 4.359 |
| 397 | 3.00 | 1.00 | 2.3 | 1.5 | 172.0 | 3.24 | 21.50 | 32.0 | 552.2 | 1.649 | 5.770 |
| 398 | 3.10 | 0.90 | 2.8 | 1.6 | 174.0 | 4.82 | 24.75 | 32.5 | 572.6 | 1.709 | 6.746 |
| 399 | 3.20 | 0.80 | 2.9 | 1.7 | 176.0 | 6.12 | 27.50 | 33.0 | 593.8 | 1.773 | 7.610 |
| 400 | 3.20 | 0.80 | 3.0 | 1.8 | 178.0 | 8.04 | 30.00 | 33.5 | 616.1 | 1.839 | 8.428 |
| TEST NO. 26 | | | | | | | | | | | |
| 401 | 10.50 | 9.50 | 2.8 | 1.4 | 182.0 | 1.20 | 7.75 | 54.5 | 507.3 | 1.301 | 3.542 |
| 402 | 10.50 | 9.50 | 3.0 | 1.4 | 188.0 | 1.92 | 9.00 | 57.5 | 557.2 | 1.429 | 4.340 |
| 403 | 10.60 | 9.40 | 3.5 | 1.5 | 194.0 | 3.24 | 12.25 | 57.5 | 613.3 | 1.573 | 5.907 |
| 404 | 10.70 | 9.30 | 4.0 | 1.6 | 198.0 | 4.82 | 14.00 | 59.0 | 654.8 | 1.680 | 6.927 |
| 405 | 10.80 | 9.20 | 4.4 | 1.6 | 200.0 | 6.12 | 15.50 | 60.0 | 677.1 | 1.737 | 7.800 |
| 406 | 11.00 | 9.00 | 4.8 | 1.6 | 202.0 | 8.04 | 16.75 | 60.5 | 700.6 | 1.797 | 8.499 |
| 407 | 11.00 | 9.00 | 2.2 | 1.4 | 180.0 | 1.20 | 11.50 | 36.5 | 491.8 | 1.262 | 3.520 |
| 408 | 11.00 | 9.00 | 2.4 | 1.6 | 186.0 | 1.92 | 14.50 | 37.0 | 540.0 | 1.385 | 4.499 |
| 409 | 11.20 | 8.80 | 2.8 | 1.6 | 192.0 | 3.24 | 18.50 | 38.5 | 593.8 | 1.523 | 5.973 |
| 410 | 11.40 | 8.60 | 3.2 | 1.6 | 195.0 | 4.82 | 21.75 | 39.5 | 623.3 | 1.599 | 7.205 |
| 411 | 11.40 | 8.60 | 3.3 | 1.7 | 197.0 | 6.12 | 24.00 | 40.0 | 644.1 | 1.652 | 8.051 |
| 412 | 11.50 | 8.50 | 3.6 | 1.8 | 198.0 | 8.04 | 26.25 | 40.0 | 654.8 | 1.680 | 8.805 |
| 413 | 11.00 | 9.00 | 2.0 | 1.8 | 182.0 | 1.20 | 11.50 | 32.0 | 476.8 | 1.223 | 3.086 |
| 414 | 11.20 | 8.80 | 2.1 | 1.7 | 188.0 | 1.92 | 15.50 | 31.5 | 523.4 | 1.343 | 4.095 |
| 415 | 11.40 | 8.60 | 2.5 | 1.7 | 194.0 | 3.24 | 20.50 | 32.5 | 575.2 | 1.475 | 5.587 |
| 416 | 11.40 | 8.60 | 2.7 | 1.7 | 198.0 | 4.82 | 24.00 | 33.0 | 603.4 | 1.580 | 6.642 |
| 417 | 11.40 | 8.60 | 2.9 | 1.7 | 200.0 | 6.12 | 27.00 | 33.0 | 623.3 | 1.599 | 7.472 |
| 418 | 11.40 | 8.60 | 3.1 | 1.9 | 202.0 | 8.04 | 29.50 | 33.0 | 633.6 | 1.625 | 8.164 |

| RUN NO. | STEAM PRESS. PSIG. MAX | MIN | UPSTREAM SURGE PRESS. MAX | MIN | WATER TEMP. OUT DEG.F. | GAS FLOW SCFM | UPSTREAM DISPL. INS. | FREQ. C/MIN. | OVERALL UPU | URATIO UPU --- UST | DPV |
|---|---|---|---|---|---|---|---|---|---|---|---|
| TEST NO. 27 | | | | | | | | | | | |
| 419 | 2.30 | 1.70 | 2.0 | 1.2 | 149.0 | 0.89 | 4.75 | 52.0 | 357.9 | 1.257 | 2.071 |
| 420 | 2.30 | 1.70 | 2.2 | 1.2 | 154.0 | 1.00 | 6.25 | 52.0 | 392.3 | 1.378 | 2.725 |
| 421 | 2.30 | 1.70 | 2.4 | 1.2 | 158.0 | 1.11 | 7.00 | 53.0 | 421.8 | 1.482 | 3.111 |
| 422 | 2.50 | 1.50 | 1.8 | 1.4 | 147.0 | 0.89 | 6.50 | 36.5 | 344.9 | 1.212 | 1.990 |
| 423 | 2.60 | 1.40 | 2.0 | 1.4 | 152.0 | 1.00 | 9.00 | 36.5 | 378.3 | 1.329 | 2.755 |
| 424 | 2.80 | 1.20 | 2.1 | 1.5 | 156.0 | 1.11 | 10.50 | 36.5 | 406.8 | 1.429 | 3.214 |
| 425 | 2.50 | 1.50 | 1.7 | 1.5 | 144.0 | 0.89 | 6.25 | 31.0 | 326.0 | 1.145 | 1.625 |
| 426 | 2.80 | 1.20 | 1.9 | 1.5 | 149.0 | 1.00 | 9.00 | 31.0 | 357.9 | 1.257 | 2.340 |
| 427 | 2.80 | 1.20 | 1.9 | 1.5 | 152.0 | 1.11 | 10.50 | 31.0 | 378.3 | 1.329 | 2.730 |
| TEST NO. 28 | | | | | | | | | | | |
| 428 | 10.20 | 9.80 | 2.1 | 1.3 | 170.0 | 0.89 | 4.75 | 52.0 | 413.5 | 1.173 | 2.071 |
| 429 | 10.30 | 9.70 | 2.2 | 1.2 | 176.0 | 1.00 | 6.25 | 52.0 | 454.5 | 1.289 | 2.725 |
| 430 | 10.40 | 9.60 | 2.5 | 1.3 | 179.0 | 1.11 | 7.25 | 53.0 | 476.4 | 1.352 | 3.222 |
| 431 | 10.60 | 9.40 | 1.8 | 1.4 | 168.0 | 0.89 | 6.75 | 36.5 | 400.6 | 1.137 | 2.066 |
| 432 | 10.80 | 9.20 | 2.0 | 1.4 | 173.0 | 1.00 | 9.00 | 36.5 | 433.5 | 1.230 | 2.755 |
| 433 | 10.90 | 9.10 | 2.1 | 1.3 | 177.0 | 1.11 | 10.25 | 36.5 | 461.7 | 1.310 | 3.137 |
| 434 | 10.60 | 9.40 | 1.7 | 1.5 | 161.0 | 0.89 | 6.50 | 31.0 | 358.2 | 1.016 | 2.071 |
| 435 | 10.90 | 9.10 | 1.9 | 1.5 | 171.0 | 1.00 | 9.00 | 31.0 | 420.1 | 1.192 | 2.725 |
| 436 | 11.00 | 9.00 | 1.9 | 1.5 | 174.0 | 1.11 | 10.25 | 31.0 | 440.4 | 1.249 | 3.222 |

| RUN NO. | STEAM PRESS. PSIG. MAX | MIN | UPSTREAM SURGE PRESS. MAX | MIN | WATER TEMP. OUT DEG.F. | GAS FLOW SCFM | UPSTREAM DISPL. INS. | FREQ. C/MIN. | OVERALL UPU | URATIO UPU / UST | DPV |
|---|---|---|---|---|---|---|---|---|---|---|---|
| TEST NO. 29 | | | | | | | | | | | |
| 437 | 2.20 | 1.80 | 2.6 | 2.2 | 113.0 | 1.20 | 2.50 | 63.0 | 507.2 | 1.000 | 0.440 |
| 438 | 2.30 | 1.70 | 2.8 | 2.2 | 113.0 | 1.92 | 3.75 | 66.0 | 507.2 | 1.000 | 0.692 |
| 439 | 2.30 | 1.70 | 2.9 | 2.3 | 113.0 | 3.24 | 2.75 | 81.0 | 507.2 | 1.000 | 0.623 |
| 440 | 2.70 | 1.30 | 2.4 | 2.2 | 112.0 | 1.20 | 4.75 | 40.0 | 494.2 | .974 | 0.531 |
| 441 | 3.00 | 1.00 | 2.7 | 2.1 | 113.0 | 1.92 | 8.25 | 40.0 | 507.2 | 1.000 | 0.923 |
| 442 | 3.10 | 1.90 | 3.0 | 2.2 | 114.0 | 3.24 | 13.00 | 41.0 | 520.3 | 1.026 | 1.490 |
| 443 | 3.10 | 1.90 | 3.2 | 2.2 | 115.0 | 4.82 | 14.25 | 43.0 | 533.6 | 1.052 | 1.713 |
| 444 | 3.10 | 1.90 | 3.3 | 2.3 | 116.0 | 6.12 | 14.75 | 45.5 | 546.9 | 1.078 | 1.876 |
| 445 | 3.10 | 1.90 | 3.9 | 2.4 | 118.0 | 8.04 | 15.75 | 47.0 | 574.1 | 1.132 | 2.000 |
| 446 | 2.80 | 1.20 | 2.1 | 1.9 | 113.0 | 1.20 | 4.50 | 34.0 | 507.2 | 1.000 | 0.428 |
| 447 | 3.10 | 0.90 | 2.2 | 2.0 | 112.0 | 1.92 | 7.50 | 34.0 | 494.2 | .974 | 0.713 |
| 448 | 3.30 | 0.70 | 2.5 | 1.9 | 113.0 | 3.24 | 13.50 | 34.0 | 507.2 | 1.000 | 1.283 |
| 449 | 3.50 | 0.50 | 2.9 | 2.1 | 114.0 | 4.82 | 18.00 | 34.5 | 520.3 | 1.026 | 1.736 |
| 450 | 3.50 | 0.50 | 3.0 | 2.2 | 116.0 | 6.12 | 20.25 | 35.0 | 546.9 | 1.078 | 1.981 |
| 451 | 3.50 | 0.50 | 3.1 | 2.1 | 117.0 | 8.04 | 21.50 | 37.0 | 560.4 | 1.105 | 2.224 |
| TEST NO. 30 | | | | | | | | | | | |
| 452 | 10.30 | 9.70 | 2.6 | 2.0 | 123.0 | 1.20 | 2.50 | 64.0 | 544.2 | 1.000 | 0.447 |
| 453 | 10.30 | 9.70 | 2.6 | 2.1 | 124.0 | 1.92 | 3.75 | 66.0 | 555.9 | 1.022 | 0.692 |
| 454 | 10.20 | 9.80 | 2.9 | 2.1 | 124.0 | 3.24 | 3.50 | 82.0 | 555.9 | 1.022 | 0.573 |
| 455 | 10.80 | 9.20 | 2.5 | 2.1 | 123.0 | 1.20 | 4.75 | 40.0 | 544.2 | 1.000 | 0.531 |
| 456 | 11.10 | 8.90 | 2.7 | 2.1 | 123.0 | 1.92 | 8.00 | 40.0 | 544.2 | 1.000 | 0.895 |
| 457 | 11.50 | 8.50 | 3.0 | 2.2 | 124.0 | 3.24 | 13.00 | 41.0 | 555.9 | 1.022 | 1.490 |
| 458 | 11.50 | 8.50 | 3.2 | 2.2 | 124.0 | 4.82 | 14.25 | 43.0 | 555.9 | 1.022 | 1.713 |
| 459 | 11.60 | 8.40 | 3.5 | 2.5 | 125.0 | 6.12 | 14.75 | 45.5 | 567.8 | 1.043 | 1.876 |
| 460 | 11.60 | 8.40 | 3.7 | 2.5 | 126.0 | 8.04 | 15.75 | 47.0 | 579.8 | 1.065 | 2.069 |
| 461 | 10.80 | 9.20 | 2.6 | 2.4 | 123.0 | 1.20 | 4.00 | 35.0 | 544.1 | 1.000 | 0.391 |
| 462 | 11.10 | 8.90 | 2.7 | 2.5 | 123.0 | 1.92 | 7.00 | 35.0 | 544.1 | 1.000 | 0.685 |
| 463 | 11.90 | 8.10 | 2.9 | 2.3 | 124.0 | 3.24 | 13.00 | 34.5 | 555.9 | 1.022 | 1.254 |
| 464 | 12.10 | 7.90 | 3.1 | 2.3 | 125.0 | 4.82 | 18.25 | 34.5 | 567.8 | 1.043 | 1.760 |
| 465 | 12.10 | 7.90 | 3.2 | 2.4 | 127.0 | 6.12 | 20.75 | 35.5 | 591.9 | 1.088 | 2.059 |
| 466 | 12.10 | 7.90 | 3.5 | 2.5 | 128.0 | 8.04 | 22.25 | 37.0 | 604.0 | 1.110 | 2.301 |

| RUN NO. | STEAM PRESS. PSIG. MAX | STEAM PRESS. PSIG. MIN | UPSTREAM SURGE PRESS. MAX | UPSTREAM SURGE PRESS. MIN | WATER TEMP. OUT DEG.F. | GAS FLOW SCFM | UPSTREAM DISPL. INS. | FREQ. C/MIN. | OVERALL UPU | URATIO UPU --- UST | DPV |
|---|---|---|---|---|---|---|---|---|---|---|---|
| TEST NO. | 31 | | | | | | | | | | |
| 467 | 2.50 | 1.50 | 4.1 | 3.7 | 107.0 | 1.20 | 3.25 | 62.0 | 562.6 | 1.000 | 0.422 |
| 468 | 2.60 | 1.40 | 4.5 | 3.5 | 107.0 | 1.92 | 5.50 | 62.0 | 562.6 | 1.000 | 0.715 |
| 469 | 3.00 | 1.00 | 5.0 | 3.8 | 108.0 | 3.24 | 9.25 | 63.5 | 579.1 | 1.029 | 1.231 |
| 470 | 3.00 | 1.00 | 5.9 | 3.7 | 109.0 | 4.82 | 10.75 | 67.0 | 595.8 | 1.059 | 1.651 |
| 471 | 3.00 | 1.00 | 6.1 | 3.9 | 109.0 | 6.12 | 10.75 | 69.5 | 595.8 | 1.059 | 1.566 |
| 472 | 3.00 | 1.00 | 6.3 | 3.9 | 109.0 | 8.04 | 10.75 | 79.0 | 595.8 | 1.059 | 1.668 |
| 473 | 2.40 | 1.60 | 4.0 | 3.8 | 107.0 | 1.20 | 3.50 | 42.5 | 562.6 | 1.000 | 0.312 |
| 474 | 3.00 | 1.00 | 4.2 | 3.8 | 107.0 | 1.92 | 6.25 | 42.5 | 562.6 | 1.000 | 0.557 |
| 475 | 3.20 | 0.80 | 4.7 | 3.9 | 107.0 | 3.24 | 12.00 | 42.0 | 562.6 | 1.000 | 1.057 |
| 476 | 3.80 | 0.20 | 5.2 | 4.0 | 108.0 | 4.82 | 17.75 | 41.5 | 579.1 | 1.029 | 1.544 |
| 477 | 3.80 | 0.20 | 5.3 | 4.1 | 109.0 | 6.12 | 21.50 | 42.0 | 595.8 | 1.059 | 1.893 |
| 478 | 3.80 | 0.20 | 5.9 | 4.1 | 109.0 | 8.04 | 24.00 | 42.5 | 595.8 | 1.059 | 2.138 |
| 479 | 2.30 | 1.70 | 3.9 | 3.7 | 107.0 | 1.20 | 3.00 | 37.0 | 562.6 | 1.000 | 0.233 |
| 480 | 2.80 | 1.20 | 4.0 | 3.8 | 107.0 | 1.92 | 4.50 | 36.5 | 562.6 | 1.000 | 0.344 |
| 481 | 3.20 | 0.80 | 4.2 | 3.8 | 107.0 | 3.24 | 9.75 | 37.0 | 562.6 | 1.000 | 0.756 |
| 482 | 3.80 | 0.20 | 4.5 | 3.9 | 107.0 | 4.82 | 15.75 | 35.5 | 562.6 | 1.000 | 1.172 |
| 483 | 4.00 | 0.00 | 4.9 | 3.9 | 107.0 | 6.12 | 21.50 | 35.0 | 562.6 | 1.000 | 1.578 |
| 484 | 4.20 | -.20 | 5.1 | 3.9 | 108.0 | 8.04 | 26.50 | 34.0 | 579.1 | 1.029 | 1.889 |
| TEST NO. | 32 | | | | | | | | | | |
| 485 | 10.50 | 9.50 | 4.2 | 3.8 | 115.0 | 1.20 | 3.25 | 62.0 | 594.1 | 1.000 | 0.422 |
| 486 | 10.70 | 9.30 | 4.6 | 3.6 | 115.0 | 1.96 | 5.00 | 62.0 | 594.1 | 1.000 | 0.715 |
| 487 | 11.00 | 9.00 | 5.2 | 3.8 | 116.0 | 3.24 | 7.75 | 63.5 | 608.8 | 1.025 | 1.165 |
| 488 | 11.10 | 8.90 | 5.9 | 3.8 | 118.0 | 4.82 | 10.50 | 67.0 | 638.5 | 1.075 | 1.475 |
| 489 | 11.20 | 8.80 | 6.0 | 4.0 | 119.0 | 6.12 | 11.00 | 69.5 | 653.5 | 1.100 | 1.603 |
| 490 | 11.20 | 8.80 | 6.3 | 4.2 | 119.0 | 8.04 | 10.75 | 74.0 | 653.5 | 1.100 | 1.668 |
| 491 | 10.60 | 9.40 | 4.0 | 3.8 | 115.0 | 1.20 | 4.25 | 42.5 | 594.1 | 1.000 | 0.379 |
| 492 | 11.20 | 8.80 | 4.2 | 3.8 | 115.0 | 1.96 | 6.50 | 42.5 | 594.1 | 1.000 | 0.579 |
| 493 | 11.70 | 8.30 | 4.7 | 3.7 | 115.0 | 3.24 | 12.50 | 42.0 | 594.1 | 1.000 | 1.101 |
| 494 | 12.80 | 7.20 | 5.2 | 3.8 | 116.0 | 4.82 | 18.00 | 41.5 | 608.8 | 1.025 | 1.566 |
| 495 | 12.80 | 7.20 | 5.6 | 3.8 | 118.0 | 6.12 | 21.50 | 42.0 | 638.5 | 1.075 | 1.893 |
| 496 | 12.80 | 7.20 | 5.9 | 3.9 | 120.0 | 8.04 | 24.00 | 42.5 | 668.7 | 1.126 | 2.138 |
| 497 | 10.60 | 9.40 | 4.0 | 3.8 | 115.0 | 1.20 | 3.00 | 37.0 | 594.1 | 1.000 | 0.223 |
| 498 | 11.00 | 9.00 | 4.1 | 3.9 | 115.0 | 1.96 | 5.50 | 37.0 | 594.1 | 1.000 | 0.427 |
| 499 | 11.50 | 8.50 | 4.2 | 4.0 | 115.0 | 3.24 | 10.25 | 36.5 | 594.1 | 1.000 | 0.784 |
| 500 | 12.50 | 7.50 | 4.8 | 4.0 | 115.0 | 4.82 | 18.75 | 35.5 | 594.1 | 1.000 | 1.396 |
| 501 | 13.00 | 7.00 | 5.0 | 4.1 | 116.0 | 6.12 | 21.50 | 35.5 | 608.8 | 1.025 | 1.600 |
| 502 | 13.50 | 6.50 | 5.2 | 4.0 | 119.0 | 8.04 | 26.50 | 35.0 | 653.6 | 1.100 | 1.945 |

| RUN NO. | STEAM PRESS. PSIG. | | UPSTREAM SURGE PRESS. | | WATER TEMP. OUT DEG.F. | GAS FLOW SCFM | UPSTREAM DISPL. INS. | FREQ. C/MIN. | OVERALL UPU | URATIO UPU --- UST | DPV |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | MAX | MIN | MAX | MIN | | | | | | | |
| TEST NO. 33 | | | | | | | | | | | |
| 503 | 2.30 | 1.70 | 5.4 | 5.2 | 99.0 | 1.20 | 3.25 | 49.5 | 707.0 | 1.000 | 0.675 |
| 504 | 2.50 | 1.50 | 5.5 | 5.3 | 99.0 | 1.92 | 5.75 | 49.0 | 707.0 | 1.000 | 1.181 |
| 505 | 2.60 | 1.40 | 6.0 | 5.6 | 102.0 | 3.24 | 9.25 | 49.0 | 777.0 | 1.099 | 1.901 |
| 506 | 2.50 | 1.50 | 6.4 | 5.8 | 106.0 | 4.82 | 11.75 | 51.0 | 873.3 | 1.235 | 2.513 |
| 507 | 2.40 | 1.60 | 6.8 | 6.0 | 108.0 | 6.12 | 12.50 | 53.5 | 922.7 | 1.305 | 2.804 |
| 508 | 2.30 | 1.70 | 7.2 | 6.2 | 108.0 | 8.04 | 12.75 | 56.0 | 947.7 | 1.340 | 2.994 |
| 509 | 2.30 | 1.70 | 5.1 | 5.0 | 99.0 | 1.20 | 3.00 | 35.0 | 707.0 | 1.000 | 0.440 |
| 510 | 2.40 | 1.60 | 5.6 | 5.2 | 99.0 | 1.92 | 4.75 | 35.0 | 707.0 | 1.000 | 0.697 |
| 511 | 2.70 | 1.30 | 6.2 | 5.4 | 99.0 | 3.24 | 9.75 | 33.5 | 707.0 | 1.000 | 1.370 |
| 512 | 2.80 | 1.20 | 6.9 | 5.9 | 102.0 | 4.82 | 14.00 | 33.5 | 777.0 | 1.099 | 1.967 |
| 513 | 2.70 | 1.30 | 7.4 | 6.0 | 104.0 | 6.12 | 16.00 | 33.5 | 824.7 | 1.167 | 2.247 |
| 514 | 2.80 | 1.20 | 7.8 | 6.2 | 106.0 | 8.04 | 18.50 | 34.5 | 873.3 | 1.235 | 2.676 |
| 515 | 2.20 | 1.80 | 5.3 | 4.9 | 99.0 | 1.20 | 2.00 | 32.0 | 707.0 | 1.000 | 0.268 |
| 516 | 2.30 | 1.70 | 6.0 | 5.0 | 99.0 | 1.92 | 3.50 | 31.5 | 707.0 | 1.000 | 0.462 |
| 517 | 2.70 | 1.30 | 7.0 | 5.0 | 99.0 | 3.24 | 7.50 | 31.0 | 707.0 | 1.000 | 0.975 |
| 518 | 2.90 | 1.10 | 8.2 | 5.2 | 99.0 | 4.82 | 11.50 | 29.0 | 707.0 | 1.000 | 1.398 |
| 519 | 2.90 | 1.10 | 9.0 | 6.4 | 101.0 | 6.12 | 15.75 | 28.5 | 753.5 | 1.066 | 1.882 |
| 520 | 2.90 | 1.10 | 9.5 | 5.9 | 102.0 | 8.04 | 19.50 | 29.0 | 777.0 | 1.099 | 2.250 |
| TEST NO. 34 | | | | | | | | | | | |
| 521 | 10.20 | 9.80 | 5.4 | 5.0 | 104.0 | 1.20 | 3.00 | 49.5 | 707.0 | 1.000 | 0.623 |
| 522 | 10.70 | 9.30 | 6.0 | 5.0 | 105.0 | 1.92 | 6.50 | 49.0 | 727.3 | 1.029 | 1.336 |
| 523 | 10.80 | 9.20 | 7.1 | 5.1 | 108.0 | 3.24 | 9.25 | 49.5 | 788.9 | 1.116 | 1.920 |
| 524 | 10.80 | 9.20 | 8.2 | 5.4 | 112.0 | 4.82 | 11.50 | 51.0 | 873.3 | 1.235 | 2.460 |
| 525 | 10.70 | 9.30 | 9.0 | 5.8 | 114.0 | 6.12 | 12.50 | 53.5 | 916.4 | 1.296 | 2.804 |
| 526 | 10.60 | 9.40 | 9.8 | 6.0 | 116.0 | 8.04 | 12.75 | 56.5 | 960.3 | 1.358 | 3.021 |
| 527 | 10.20 | 9.80 | 5.5 | 5.3 | 104.0 | 1.20 | 3.00 | 35.0 | 707.0 | 1.000 | 0.440 |
| 528 | 10.70 | 9.30 | 5.7 | 5.3 | 104.0 | 1.92 | 4.75 | 35.0 | 707.0 | 1.000 | 0.697 |
| 529 | 11.00 | 9.00 | 6.2 | 5.4 | 104.0 | 3.24 | 9.50 | 34.0 | 707.0 | 1.000 | 1.354 |
| 530 | 11.10 | 8.90 | 7.0 | 5.8 | 108.0 | 4.82 | 13.75 | 34.0 | 788.9 | 1.116 | 1.960 |
| 531 | 11.10 | 8.90 | 7.4 | 6.0 | 110.0 | 6.12 | 16.25 | 34.5 | 830.7 | 1.175 | 2.351 |
| 532 | 11.00 | 9.00 | 8.0 | 6.2 | 112.0 | 8.04 | 17.75 | 35.5 | 873.3 | 1.235 | 2.642 |
| 533 | 10.20 | 9.80 | 5.1 | 4.9 | 104.0 | 1.20 | 2.00 | 32.0 | 707.0 | 1.000 | 0.268 |
| 534 | 10.50 | 9.50 | 5.2 | 5.0 | 104.0 | 1.92 | 3.25 | 31.0 | 707.0 | 1.000 | 0.422 |
| 535 | 11.00 | 9.00 | 5.6 | 5.2 | 104.0 | 3.24 | 7.25 | 31.0 | 707.0 | 1.000 | 0.912 |
| 536 | 11.10 | 8.90 | 6.0 | 5.4 | 104.0 | 4.82 | 11.50 | 29.0 | 707.0 | 1.000 | 1.398 |
| 537 | 11.10 | 8.90 | 6.4 | 5.6 | 106.0 | 6.12 | 15.50 | 28.5 | 747.6 | 1.058 | 1.912 |
| 538 | 11.20 | 8.80 | 7.2 | 6.2 | 109.0 | 8.04 | 18.50 | 29.0 | 809.7 | 1.145 | 2.250 |

| RUN NO. | STEAM PRESS. PSIG. | | UPSTREAM SURGE PRESS. | | WATER TEMP. OUT DEG.F. | GAS FLOW SCFM | UPSTREAM DISPL. INS. | FREQ. C/MIN. | OVERALL UPU | URATIO UPU / UST | DPV |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | MAX | MIN | MAX | MIN | | | | | | | |
| TEST NO. | 35 | | | | | | | | | | |
| 539 | 2.40 | 1.60 | 3.9 | 3.1 | 105.0 | 1.20 | 4.75 | 45.5 | 637.2 | 1.029 | 1.207 |
| 540 | 2.40 | 1.60 | 4.4 | 3.2 | 108.0 | 1.92 | 7.00 | 46.5 | 692.5 | 1.119 | 1.818 |
| 541 | 2.40 | 1.60 | 5.1 | 3.5 | 113.0 | 3.24 | 9.00 | 49.5 | 788.3 | 1.273 | 2.489 |
| 542 | 2.40 | 1.60 | 5.4 | 3.8 | 115.0 | 4.82 | 9.50 | 54.0 | 827.9 | 1.337 | 2.866 |
| 543 | 2.40 | 1.60 | 6.0 | 4.0 | 117.0 | 6.12 | 10.25 | 56.0 | 868.2 | 1.403 | 3.207 |
| 544 | 2.30 | 1.70 | 6.6 | 4.4 | 118.0 | 8.04 | 10.75 | 58.0 | 888.7 | 1.436 | 3.483 |
| 545 | 2.40 | 1.60 | 3.4 | 3.2 | 104.0 | 1.20 | 4.50 | 32.0 | 619.0 | 1.000 | 0.804 |
| 546 | 2.70 | 1.30 | 3.7 | 3.3 | 105.0 | 1.92 | 7.50 | 31.5 | 673.2 | 1.029 | 1.320 |
| 547 | 2.80 | 1.20 | 4.2 | 3.4 | 109.0 | 3.24 | 12.50 | 31.5 | 711.3 | 1.149 | 2.200 |
| 548 | 2.70 | 1.30 | 4.6 | 3.6 | 112.0 | 4.82 | 15.00 | 33.0 | 768.8 | 1.242 | 2.765 |
| 549 | 2.60 | 1.40 | 4.9 | 3.9 | 114.0 | 6.12 | 16.25 | 34.0 | 808.0 | 1.305 | 3.087 |
| 550 | 2.60 | 1.40 | 5.1 | 3.9 | 116.0 | 8.04 | 16.75 | 36.0 | 848.0 | 1.370 | 3.369 |
| 551 | 2.40 | 1.60 | 3.4 | 3.2 | 104.0 | 1.20 | 3.50 | 28.5 | 619.0 | 1.000 | 0.557 |
| 552 | 2.70 | 1.30 | 3.5 | 3.3 | 104.0 | 1.92 | 6.25 | 28.0 | 619.0 | 1.000 | 0.978 |
| 553 | 2.90 | 1.10 | 3.9 | 3.5 | 106.0 | 3.24 | 11.50 | 27.5 | 655.5 | 1.059 | 1.767 |
| 554 | 2.90 | 1.10 | 4.2 | 3.6 | 110.0 | 4.82 | 16.00 | 27.5 | 730.3 | 1.180 | 2.458 |
| 555 | 2.70 | 1.30 | 4.6 | 3.8 | 112.0 | 6.12 | 17.25 | 28.0 | 768.8 | 1.242 | 2.698 |
| 556 | 2.70 | 1.30 | 4.8 | 4.0 | 114.0 | 8.04 | 18.00 | 29.5 | 808.0 | 1.305 | 2.966 |
| TEST NO. | 36 | | | | | | | | | | |
| 557 | 10.40 | 9.60 | 3.8 | 3.0 | 112.0 | 1.20 | 4.50 | 45.5 | 655.5 | 1.051 | 1.144 |
| 558 | 10.60 | 9.40 | 4.2 | 3.2 | 115.0 | 1.92 | 7.00 | 46.0 | 704.3 | 1.130 | 1.799 |
| 559 | 10.50 | 9.50 | 5.0 | 3.4 | 120.0 | 3.24 | 9.00 | 49.5 | 788.3 | 1.264 | 2.490 |
| 560 | 10.40 | 9.60 | 5.3 | 3.7 | 123.0 | 4.82 | 9.25 | 54.0 | 840.4 | 1.348 | 2.490 |
| 561 | 10.30 | 9.70 | 6.0 | 4.0 | 125.0 | 6.12 | 7.00 | 56.5 | 875.9 | 1.405 | 3.790 |
| 562 | 10.30 | 9.70 | 6.3 | 4.1 | 126.0 | 8.04 | 10.75 | 58.0 | 893.9 | 1.434 | 3.156 |
| 563 | 10.80 | 9.20 | 4.2 | 3.0 | 110.0 | 1.20 | 4.25 | 32.0 | 623.5 | 1.000 | 0.760 |
| 564 | 10.90 | 9.10 | 4.5 | 3.1 | 110.0 | 1.92 | 7.50 | 31.5 | 639.4 | 1.026 | 1.320 |
| 565 | 11.00 | 9.00 | 4.1 | 3.3 | 115.0 | 3.24 | 12.25 | 31.5 | 704.3 | 1.130 | 2.160 |
| 566 | 10.90 | 9.10 | 4.5 | 3.5 | 119.0 | 4.82 | 14.50 | 32.5 | 771.2 | 1.237 | 2.633 |
| 567 | 10.90 | 9.10 | 4.8 | 3.8 | 122.0 | 6.12 | 16.25 | 33.5 | 822.9 | 1.320 | 3.041 |
| 568 | 10.90 | 9.10 | 5.1 | 3.9 | 124.0 | 8.04 | 16.50 | 35.5 | 858.1 | 1.376 | 3.272 |
| 569 | 10.40 | 9.60 | 3.5 | 3.3 | 110.0 | 1.20 | 3.25 | 28.0 | 623.5 | 1.000 | 0.508 |
| 570 | 11.00 | 9.00 | 3.6 | 3.4 | 110.0 | 1.92 | 5.75 | 28.0 | 623.5 | 1.000 | 0.895 |
| 571 | 11.20 | 8.80 | 4.0 | 3.6 | 112.0 | 3.24 | 10.75 | 27.5 | 655.5 | 1.051 | 1.651 |
| 572 | 11.00 | 9.00 | 4.3 | 3.7 | 117.0 | 4.82 | 14.75 | 27.5 | 737.5 | 1.183 | 2.260 |
| 573 | 11.00 | 9.00 | 4.7 | 3.9 | 118.0 | 6.12 | 17.00 | 28.0 | 754.3 | 1.210 | 2.659 |
| 574 | 11.00 | 9.00 | 4.9 | 4.1 | 120.0 | 8.04 | 18.00 | 29.0 | 788.3 | 1.264 | 2.916 |

these flowrates, pulsation degenerated to two-phase flow. With a 0.5 in. discharge diameter water flows were limited to a maximum of about 106.3 lb./min. ($\overline{V}_{ST}$ = 1.56 ft./sec.) due to excessively high pressure in the upstream surge volume. With a 0.75 in. discharge diameter tests were done only with water flowrates of 127.5 and 170.0 lbs./min. ($\overline{V}_{ST}$ = 1.88 and 2.50 ft./sec.).

Figure 7 shows this effect of discharge diameter on the range of possible flowrates. The maximum and minimum flowrates at each discharge diameter in this work are compared to the pulsing range found by Milburn(7). The only significant difference between the two sets of data are at a discharge diameter of 0.75 in. With this discharge size Milburn(7) obtained pulse flow at much higher flowrates because he allowed higher pressure to develop in the upstream riser.

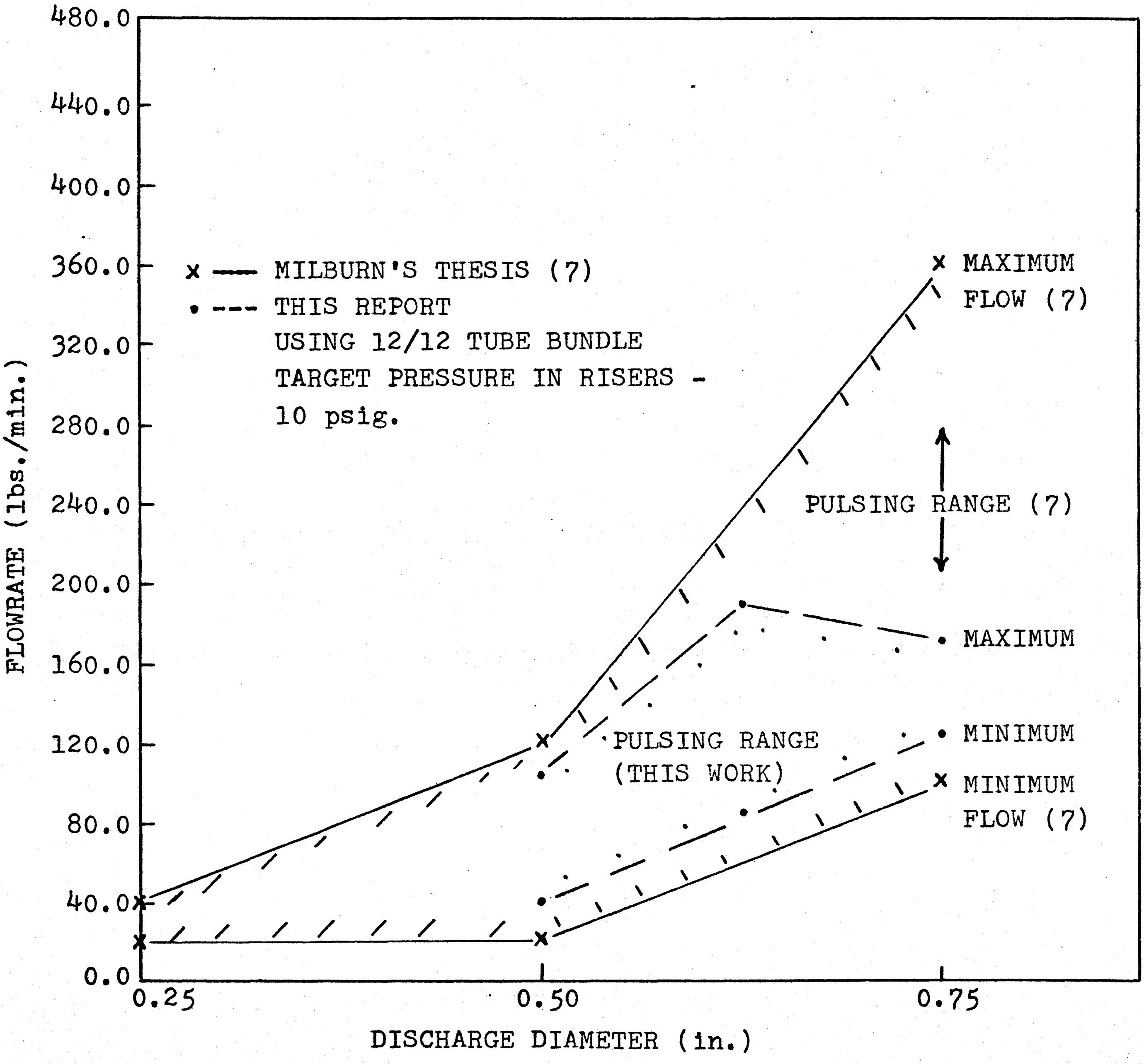
Some pulsed flow tests were carried out with a 12/4 and a 36/4 bundle for which best operation could be obtained with a 0.5 in. discharge diameter and flowrates of 31.8 to 106.3 lb./min. ($\overline{V}_{ST}$ = 1.40 to 4.69 ft./sec.).

### 1) Treatment of the Data

The data were treated by plotting the ratio of the enhancement in the overall heat transfer coefficients ($U_{PU}/U_{ST}$) as a function of the corresponding experimental values of the DPV for each test. On the same graphs the predictions of the quasi-steady theory were also plotted. Data from 16 tests only

# FIGURE 7

## EFFECT OF DISCHARGE DIAMETER ON PULSING RANGE



have been selected and are shown on the following Figures:

| Figure No. | Test Nos. |
|---|---|
| 8 | 5, 6 |
| 9 | 9, 10 |
| 10 | 11, 12 |
| 11 | 17, 18 |
| 12 | 23, 24 |
| 13 | 25, 26, 27, 28 |
| 14 | 33, 34 |

The data for tests 1, 2, 21, 22, 29, 30, 31 and 32 are not shown on figures because most of the DPV values were in a range from 0 to 2.0 with little or no increase in $U_{PU}/U_{ST}$. The results from these tests reinforced the conclusion that, contrary to the theoretical prediction, heat transfer was not reduced by flow pulsations over this range of DPV.

The results of tests 3, 4, 7, 8, 13, 14, 15, 16, 19, 20, 35 and 36 are also not shown because their results are duplicated by the results obtained in other tests. For example a plot of $U_{PU}/U_{ST}$ versus DPV for tests 7, 8 is almost identical to those of tests 5, 6.

### 2) Results

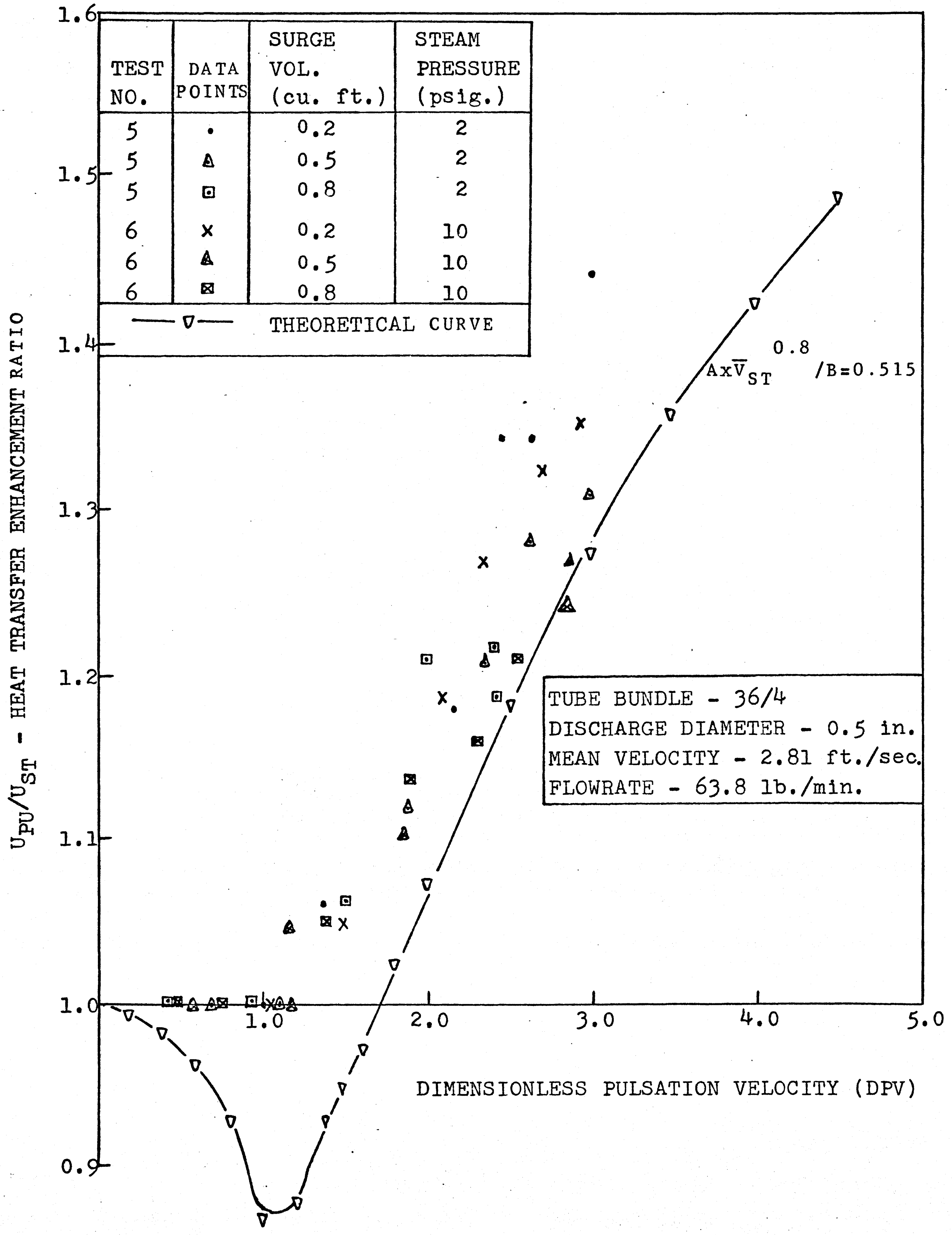
The results of the pulsed flow tests showed the following:

a) Enhancement of the overall steady state heat transfer coefficient occurred in all but eight of the thirty-six pulsed flow tests. Enhancement normally took place whenever the

FIGURE 8

EFFECT OF PULSATION ON HEAT TRANSFER

(PULSE TEST NOS. 5 AND 6)



## FIGURE 9

## EFFECT OF PULSATION ON HEAT TRANSFER

## (PULSE TEST NOS. 9 AND 10)

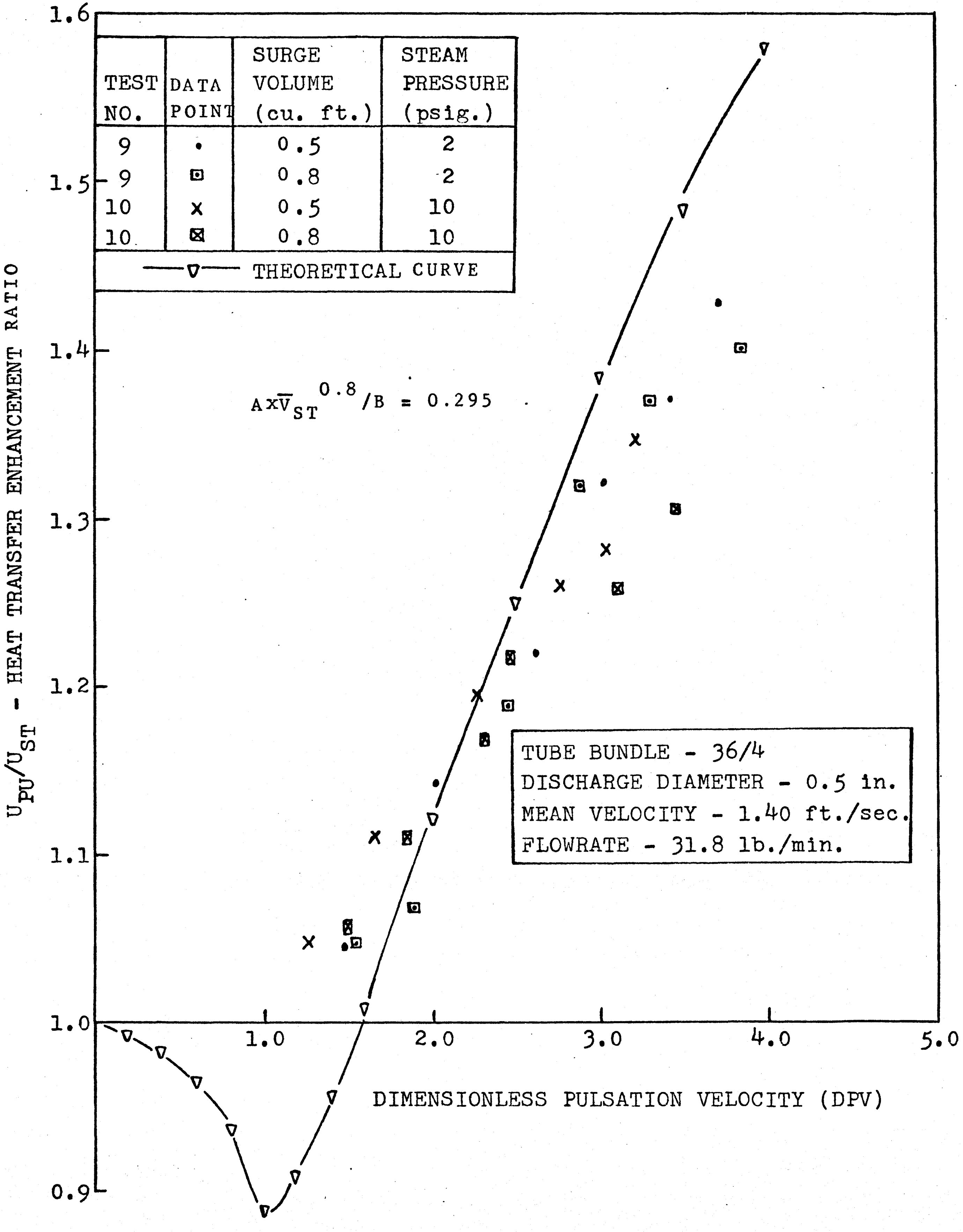


FIGURE 10

EFFECT OF PULSATION ON HEAT TRANSFER

(PULSE TEST NOS. 11 AND 12)

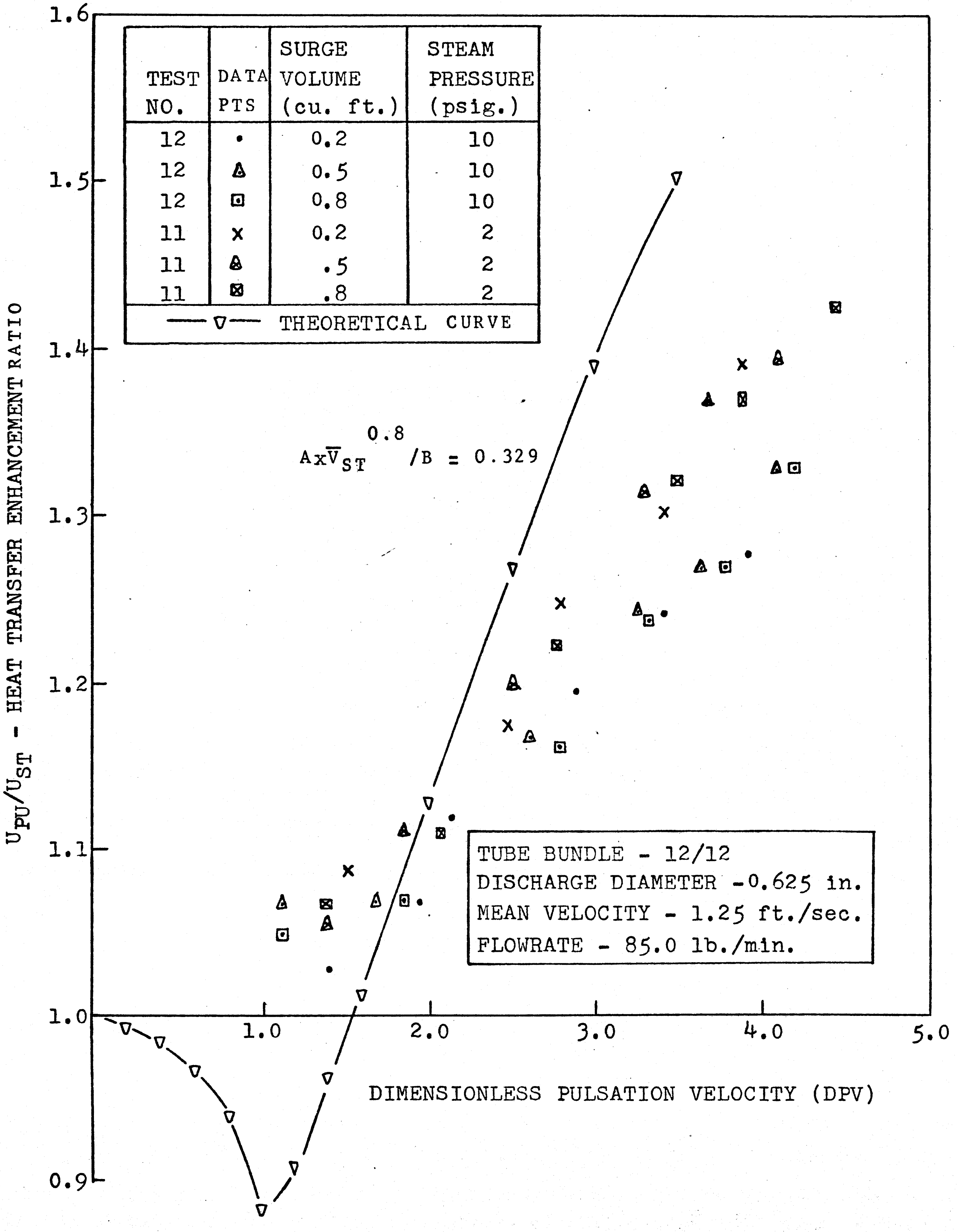


FIGURE 11

EFFECT OF PULSATION ON HEAT TRANSFER

(PULSE TEST NOS. 17 AND 18)

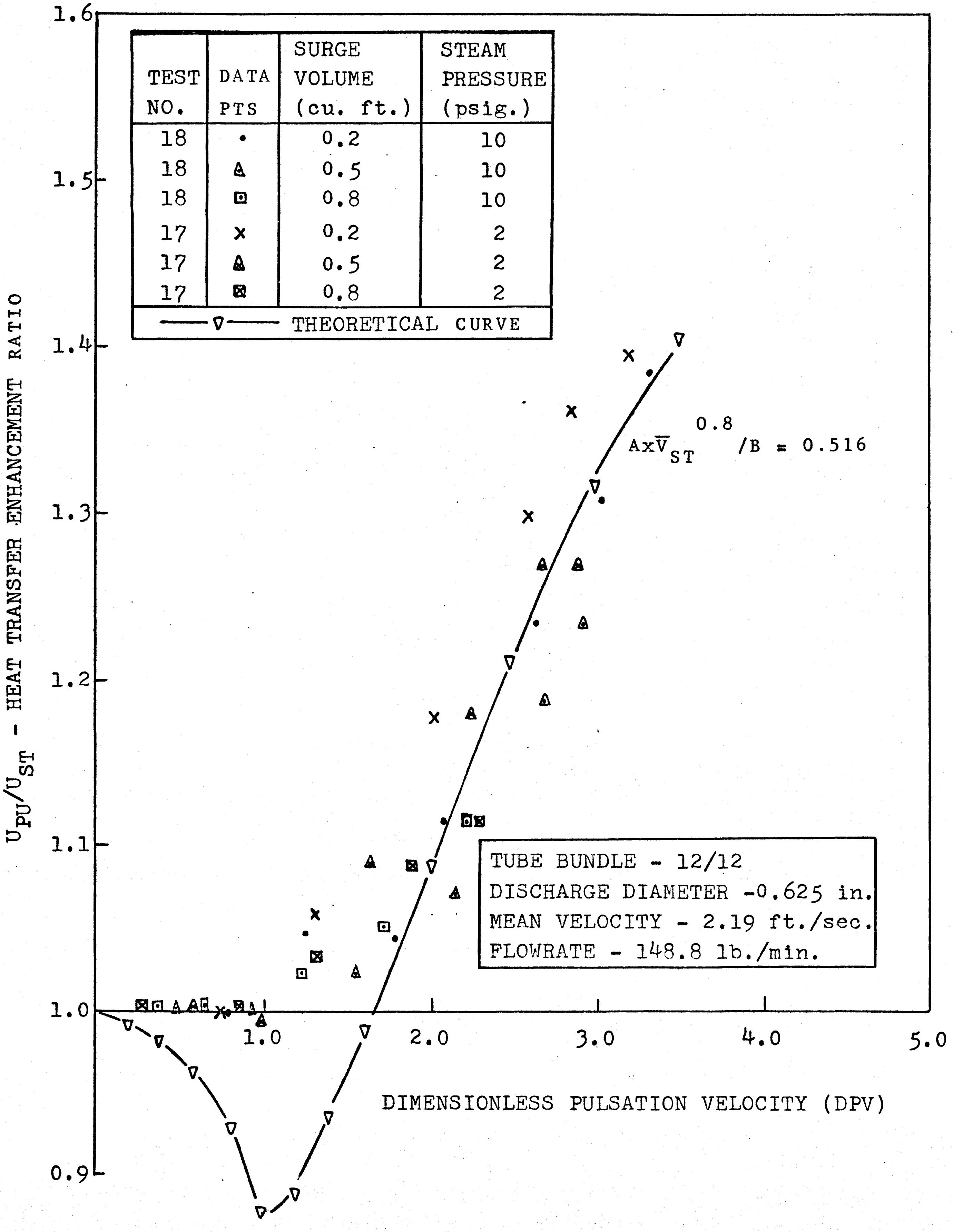


FIGURE 12

EFFECT OF PULSATION ON HEAT TRANSFER

(PULSE TEST NOS. 23 AND 24)

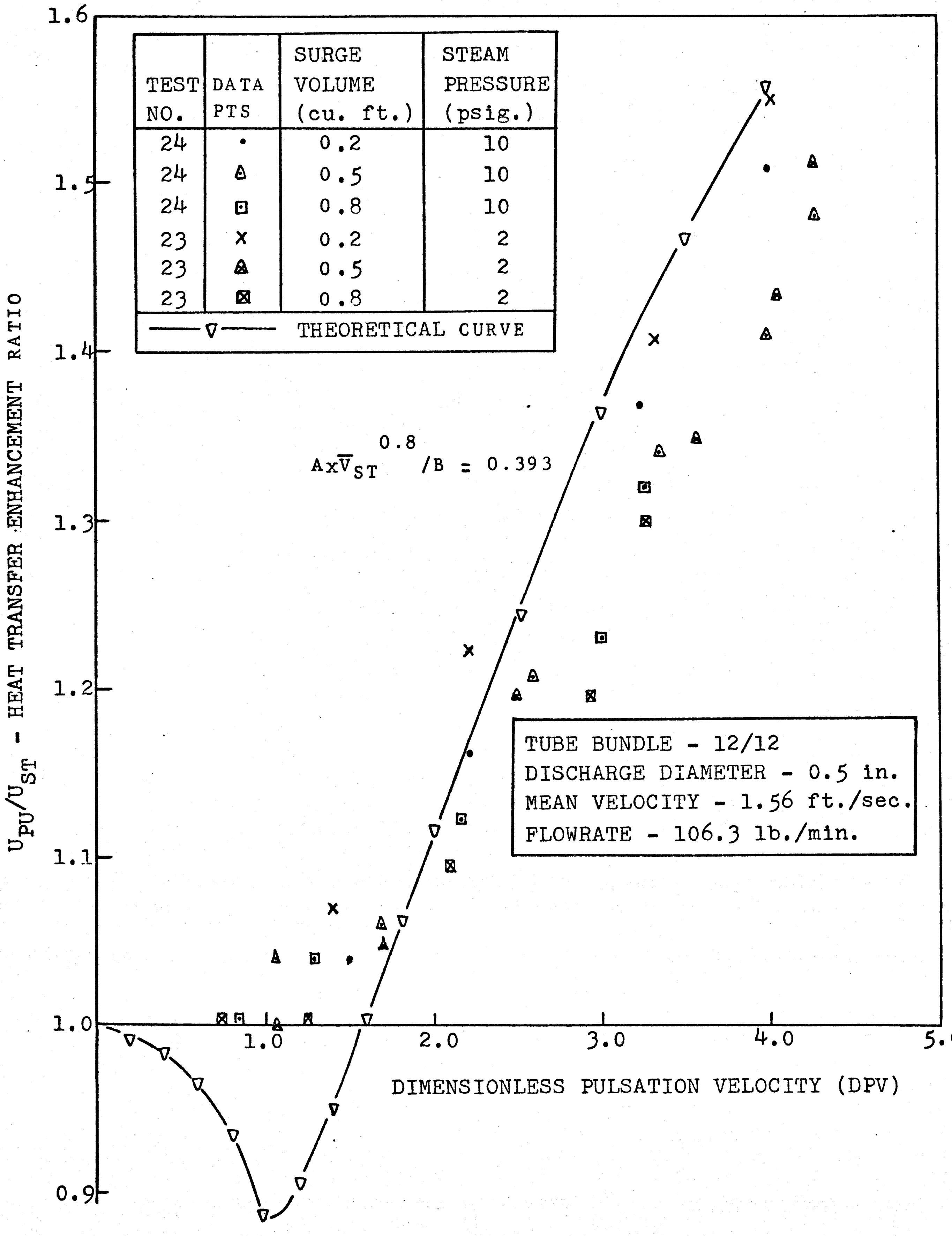


FIGURE 13

EFFECT OF PULSATION ON HEAT TRANSFER

(PULSE TEST NOS. 25, 26, 27 AND 28)

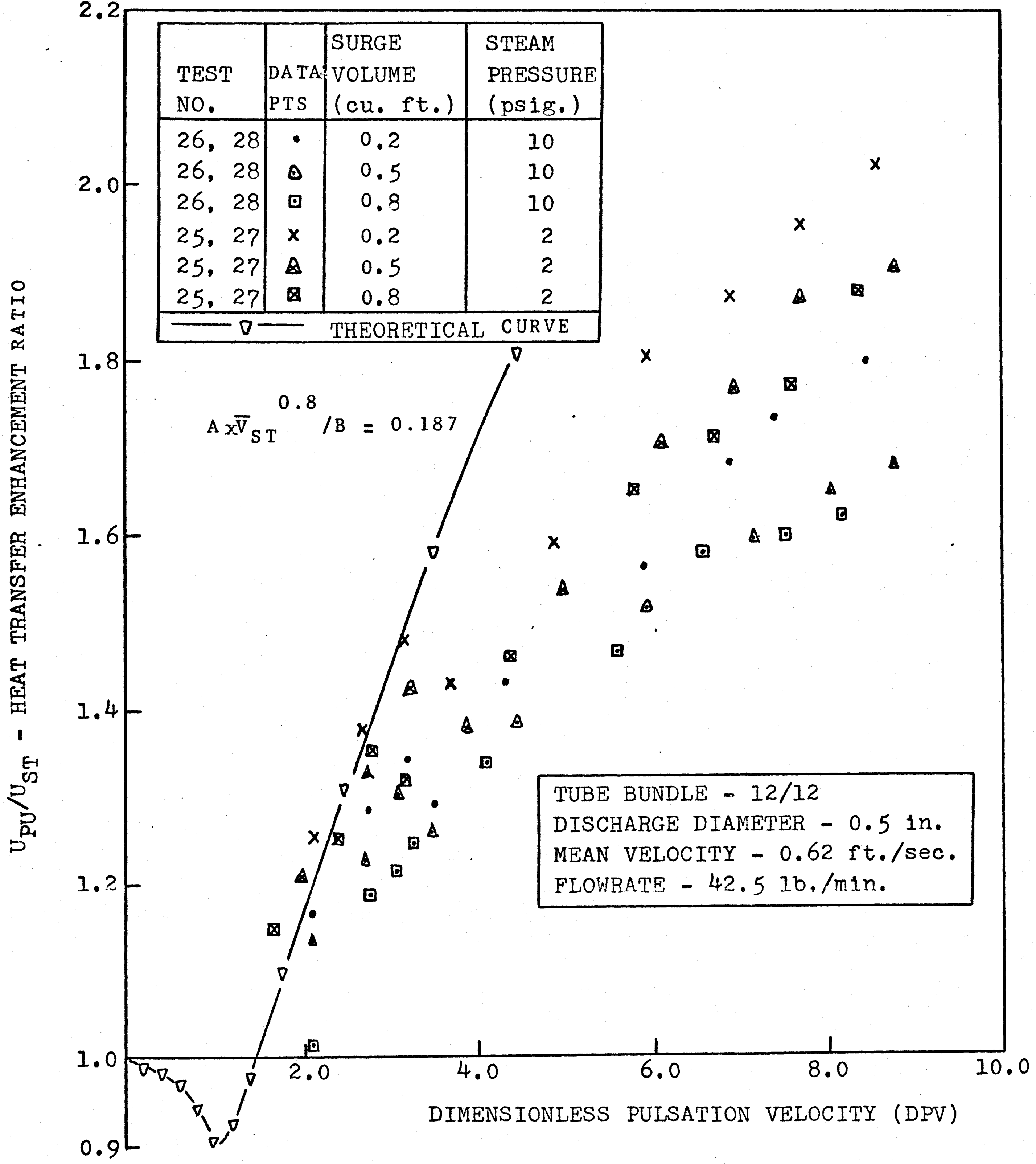
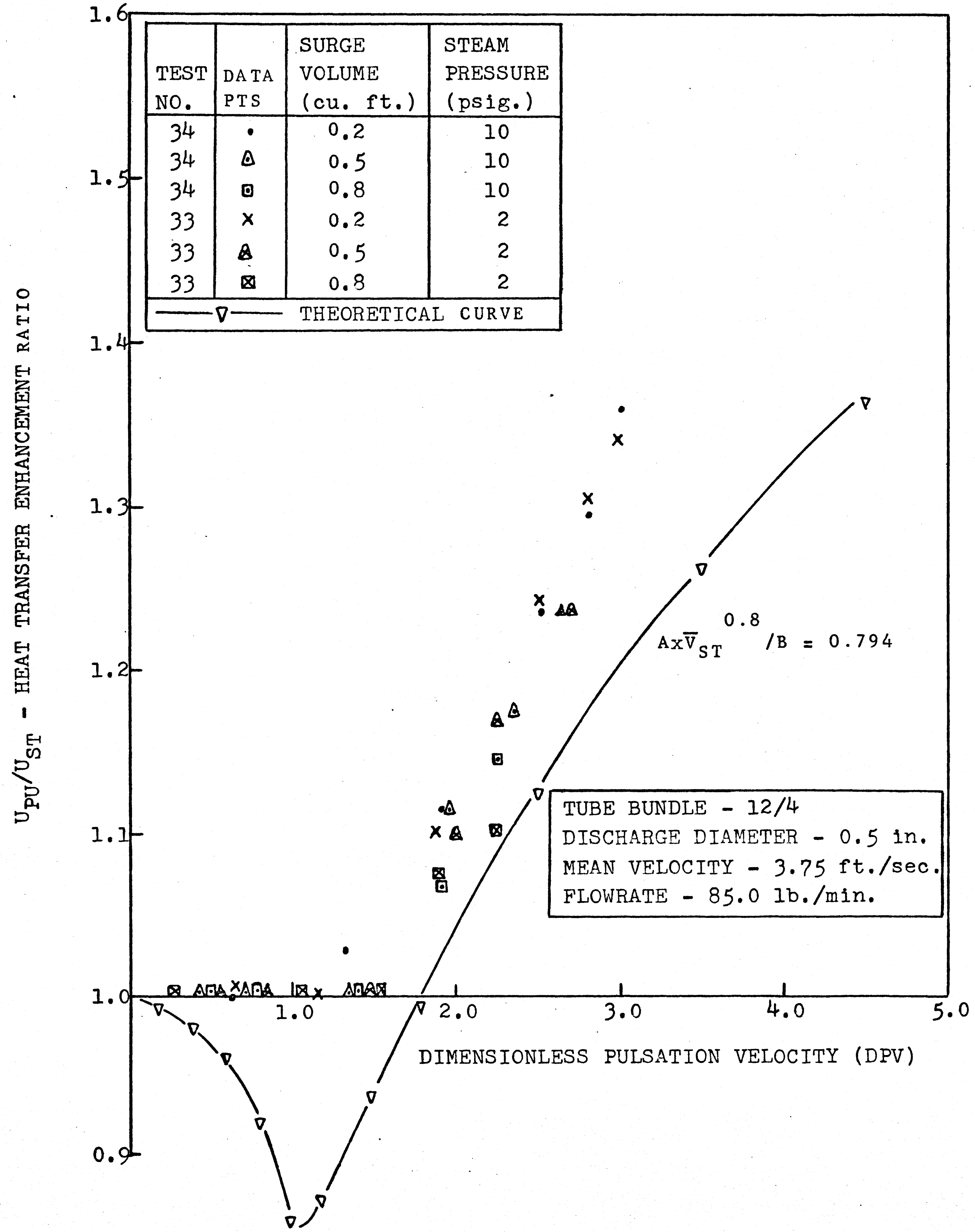


FIGURE 14

EFFECT OF PULSATION ON HEAT TRANSFER

(PULSE TEST NOS. 33 AND 34)



DPV exceeded 1.0 and increased with increasing DPV. In many cases there is practically a linear increase in $U_{PU}/U_{ST}$ over a range of DPV from 1.0 to approximately 4.0. The ratio of $U_{PU}/U_{ST}$ increases by almost 40% over this range of the DPV.

b) The predictions of the quasi-steady state theory and experimental results were usually not in agreement. For DPV values greater than 2.0, theoretical values of $U_{PU}/U_{ST}$ were in some cases in accord with experimental results (see Figures 11 and 12). However the theory often overestimated the $U_{PU}/U_{ST}$ when mean flow velocities were less than about 2.0 ft./sec. (see Figure 10) and underestimated $U_{PU}/U_{ST}$ when mean flow velocities were greater than about 2.0 ft./sec. (see Figure 14). The differences between theoretical and experimental results could not be explained by experimental error, as will be discussed later. For low values of $\overline{V}_{ST}$ the most likely explanation for the deviation is the effect of poor fluid distribution in the tubes. The effective mean fluid velocity is much higher than the calculated average. Due to insufficient data it is not possible to speculate on the reasons for the poor agreement between experimental and theoretical results at mean velocities above 3.0 ft./sec. Future work should be directed towards determining $U_{PU}/U_{ST}$ in pulsed flow when mean velocities are well above this level.

c) For mean fluid velocities above 1.0 ft./sec. no factors (such as steam pressure or discharge diameter) other than DPV can be said to have a major effect on $U_{PU}/U_{ST}$. However the results, for tests 25, 26, 27 and 28 (figure 13) which were done at a mean fluid velocity of 0.62 ft./sec., were also affected by the shell steam pressure. The overall heat transfer enhancement ratio ($U_{PU}/U_{ST}$) showed greater improvement at 2 psig. shell side steam pressure than at 10 psig. steam pressure. For these tests, the values of $U_{ST}$ were significantly lower at 2 psig. than at 10 psig. shell side steam pressure. In this case the overall heat transfer coefficients tended to be equalized by the pulsating flow. This would be consistent with a fluid mechanical effect whereby the fluid distribution is improved by pulsation. Thus in pulsed flow the effect of steam pressure on the heat transfer coefficient is less than in the case of steady flow (see Table 5, page 5, and Figure 5, page 31).

### 3) Discussion of Errors

The calculation of $U_{PU}/U_{ST}$ depends only upon the temperature of the entering and leaving fluid streams, and the steam temperature, assuming all other factors remain constant and can be calculated from equation (7).

$$\frac{U_{PU}}{U_{ST}} = \frac{\ln\left[\dfrac{T_{SM} - T_1}{T_{SM} - T_o}\right] \text{ PULSATING FLOW}}{\ln\left[\dfrac{T_{SM} - T_1}{T_{SM} - T_o}\right] \text{ STEADY FLOW}} \qquad (7)$$

where $T_{SM}$ = steam temperature

$T_o$ = outlet fluid temperature

$T_1$ = inlet fluid temperature

The values, $T_o$ and $T_1$ were measured to within ± 1.0 °F but a larger source of error probably occurred in estimating the shell steam temperature, $T_{SM}$ which was based on the steam pressure in the heat exchanger shell. In the pulsed flow tests pressures varied as much as ± 3 psig., which corresponds to approximately ± 6 °F. However an average deviation would be less than this. Assuming a maximum deviation of ± 3 °F, calculations show that $U_{PU}/U_{ST}$ could be in error by as much as ± 20%. This most likely explains the wide scatter of points in Figures 8, 9, 10, 11 and 12.

Some fluctuations in water outlet temperature were noticeable in tests with the 12/12 bundle. It is believed these were caused by buildup of condensate in the shell side of the heat exchanger with condensate covering some tubes. Care was taken in these tests to conduct the experiments only when the steam trap was blowing steam and to read maximum obtainable discharge water temperatures.

The calculation of the Dimensionless Pulsation Velocity (DPV) depends on three independent variables. It is proportional to the frequency and upstream stroke of pulsation and inversely proportional to the flowrate. The upstream stroke could be measured to within ± 0.25 in. at levels from 0 to about 20 inches. Above this, the stroke was more difficult to read. It is estimated that strokes above 20 inches were accurate to within ± 0.5 in. The frequency of pulsation could be obtained to within ±0.5 per minute. Assuming maximum deviations the value of the DPV was calculated to be correct to within ±5.0%. Compared to the errors that could exist in the calculation of $U_{PU}/U_{ST}$ (equation 7), errors in the calculation of the DPV were not considered significant.

## 4) Air Requirements

One of the purposes of this work was to make an estimate of the air requirement that could be expected in a "Water Blow" Pulsation Generator. As previously explained, compressed air was fed to the generator through a calibrated rotameter. The air pressure was noted and thus from Figure 4 the flow of air (in scfm) to the generator could be determined.

To show some of the factors affecting air requirement the data from twelve pulsed flow tests have been selected and are shown on Figures 15, 16, 17, 18, 19 and 20. The air consumption is defined as the volume of air (scf) used per volume of water flowing and is plotted on the abscissa. The ordinate is the corresponding $U_{PU}/U_{ST}$.

Figure 15 (pulse tests 25, 26) contains typical curves obtained from the tests. Some observations that can be made are:

## FIGURE 15

## AIR REQUIREMENTS FOR OVERALL HEAT TRANSFER ENHANCEMENT

## (DATA FROM PULSE TEST NOS. 25 AND 26)

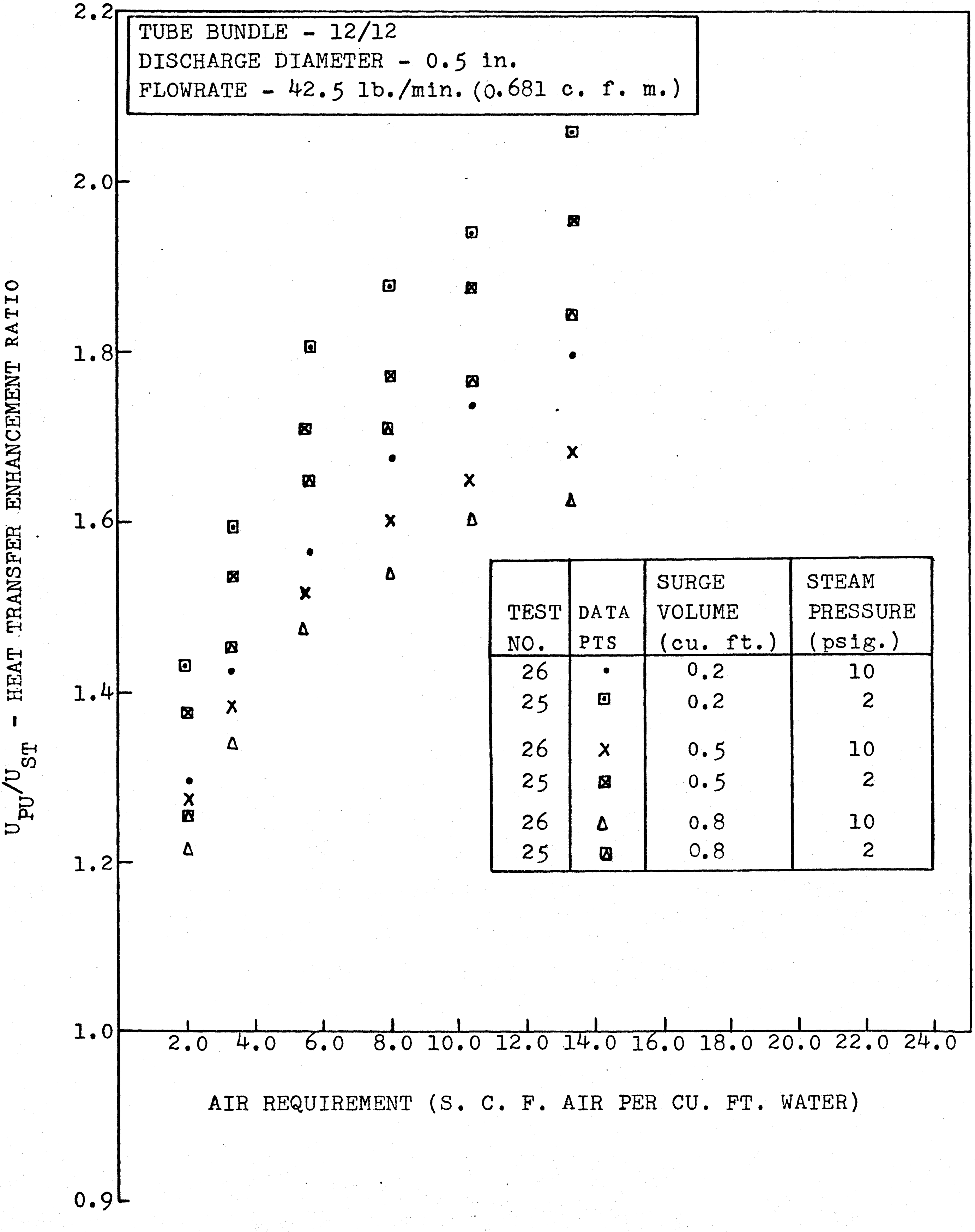


FIGURE 16

AIR REQUIREMENTS FOR OVERALL HEAT TRANSFER ENHANCEMENT

(DATA FROM PULSE TEST NOS. 12, 14, 16, 18, 20, 22)

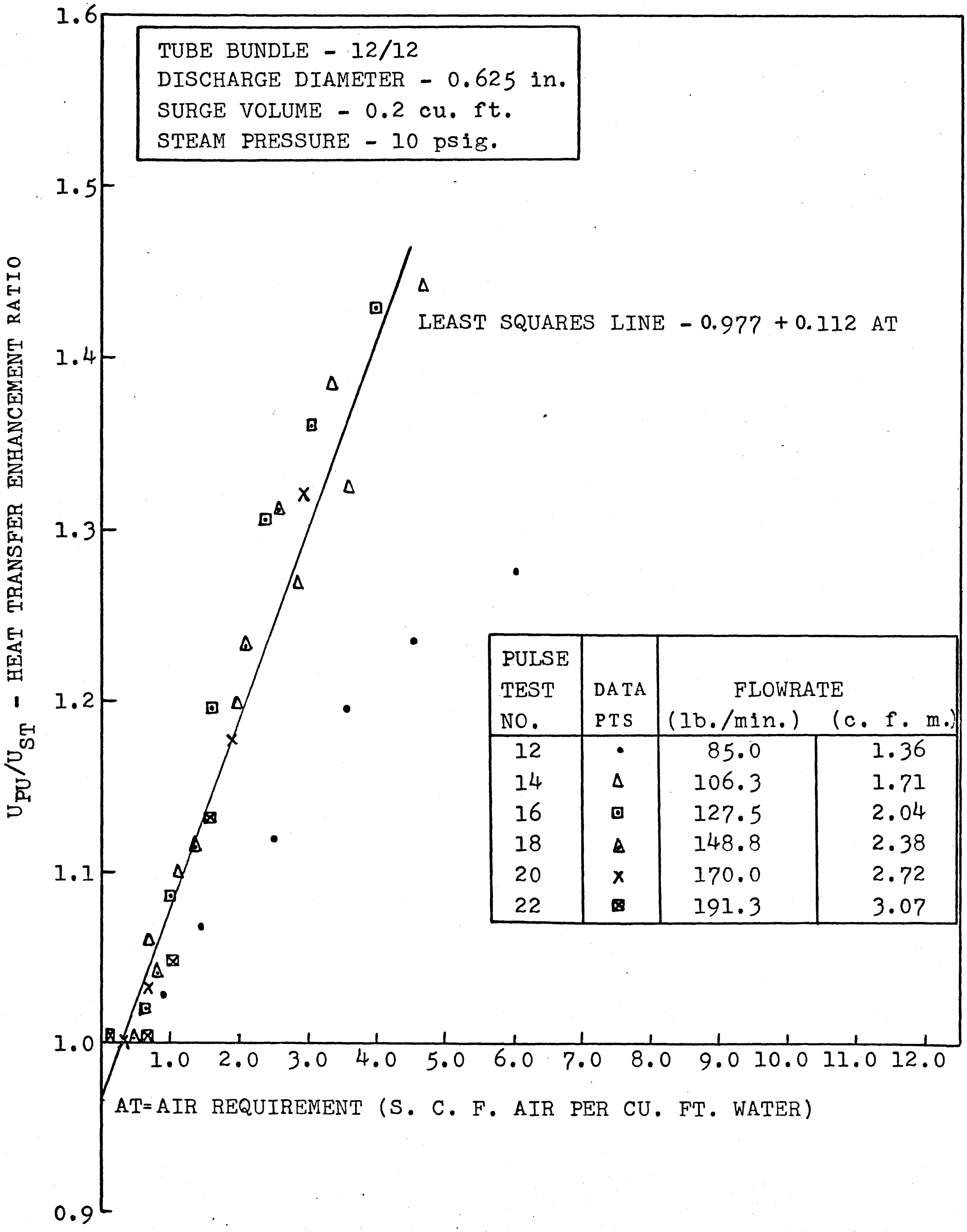
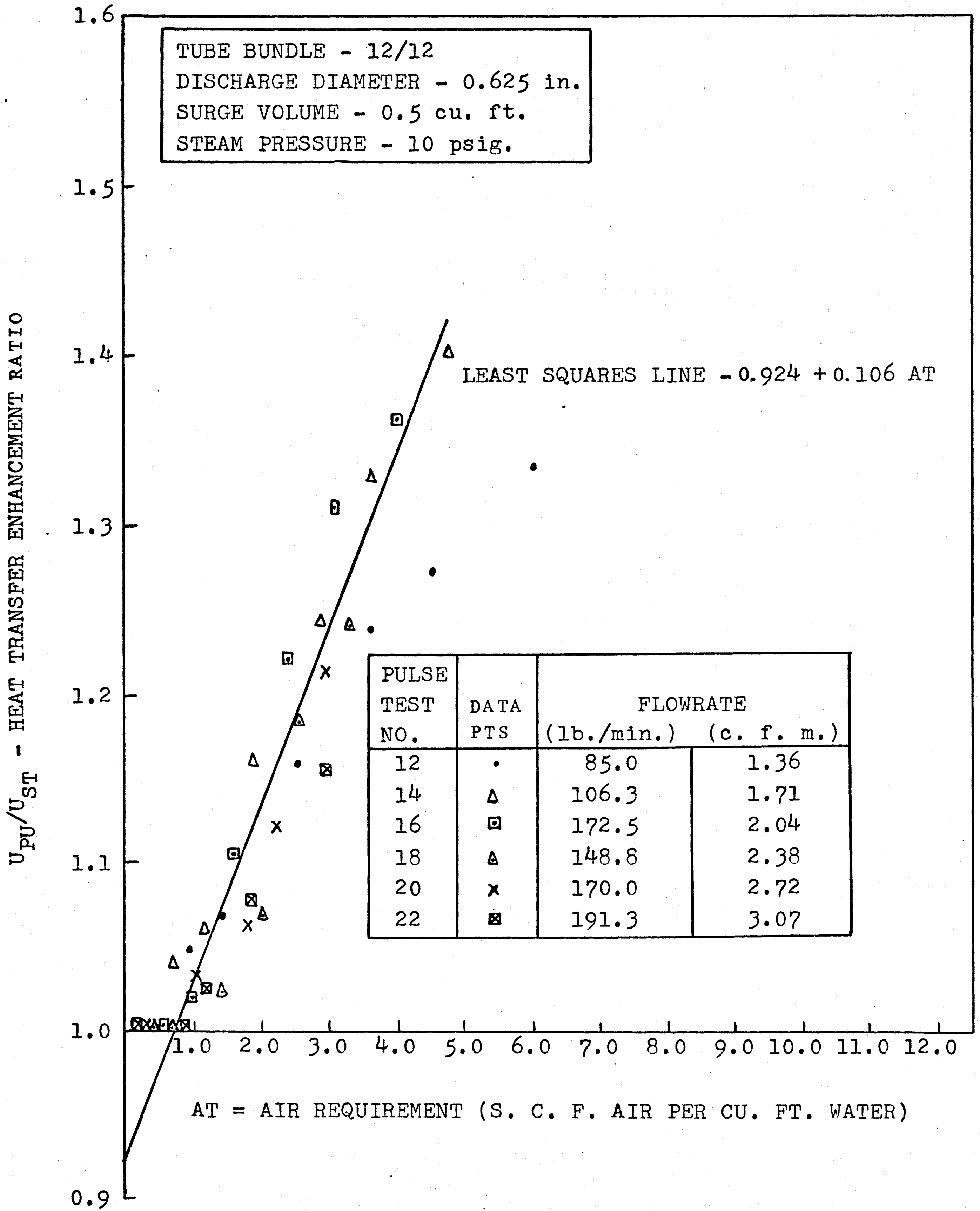


FIGURE 17

AIR REQUIREMENTS FOR OVERALL HEAT TRANSFER ENHANCEMENT

(DATA FROM PULSE TESTS NOS. 12, 14, 16, 18, 20, 22)

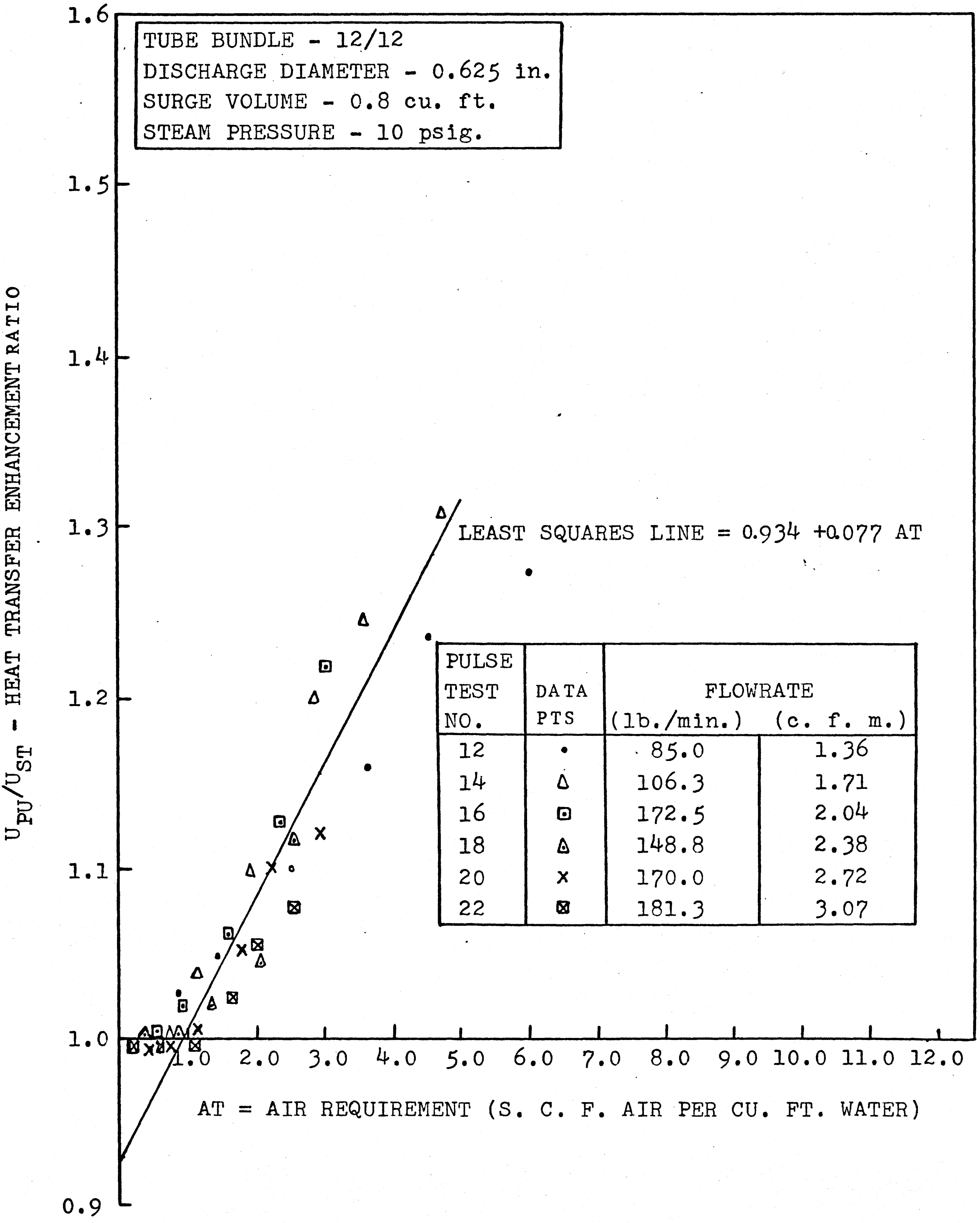


| PULSE TEST NO. | DATA PTS | FLOWRATE (lb./min.) | (c. f. m.) |
|---|---|---|---|
| 12 | • | 85.0 | 1.36 |
| 14 | Δ | 106.3 | 1.71 |
| 16 | ⊡ | 172.5 | 2.04 |
| 18 | Δ | 148.8 | 2.38 |
| 20 | × | 170.0 | 2.72 |
| 22 | ⊠ | 191.3 | 3.07 |

FIGURE 18

AIR REQUIREMENTS FOR OVERALL HEAT TRANSFER ENHANCEMENT

(DATA FROM PULSE TEST NOS. 12, 14, 16, 18, 20, 22)

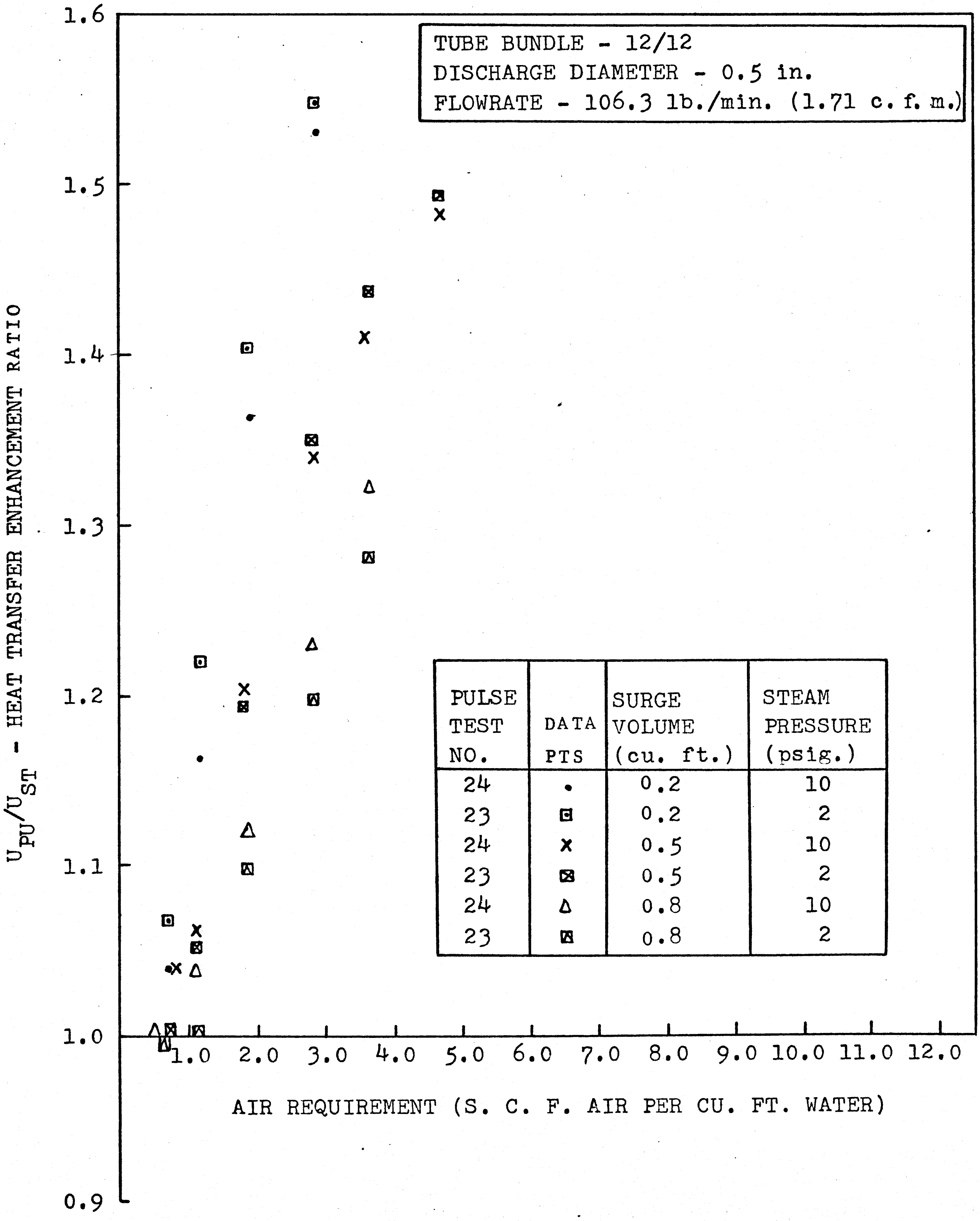


| PULSE TEST NO. | DATA PTS | FLOWRATE (lb./min.) | FLOWRATE (c. f. m.) |
|---|---|---|---|
| 12 | • | 85.0 | 1.36 |
| 14 | Δ | 106.3 | 1.71 |
| 16 | ⊡ | 172.5 | 2.04 |
| 18 | Δ | 148.8 | 2.38 |
| 20 | × | 170.0 | 2.72 |
| 22 | ⊠ | 181.3 | 3.07 |

## FIGURE 19

## AIR REQUIREMENTS FOR OVERALL HEAT TRANSFER ENHANCEMENT

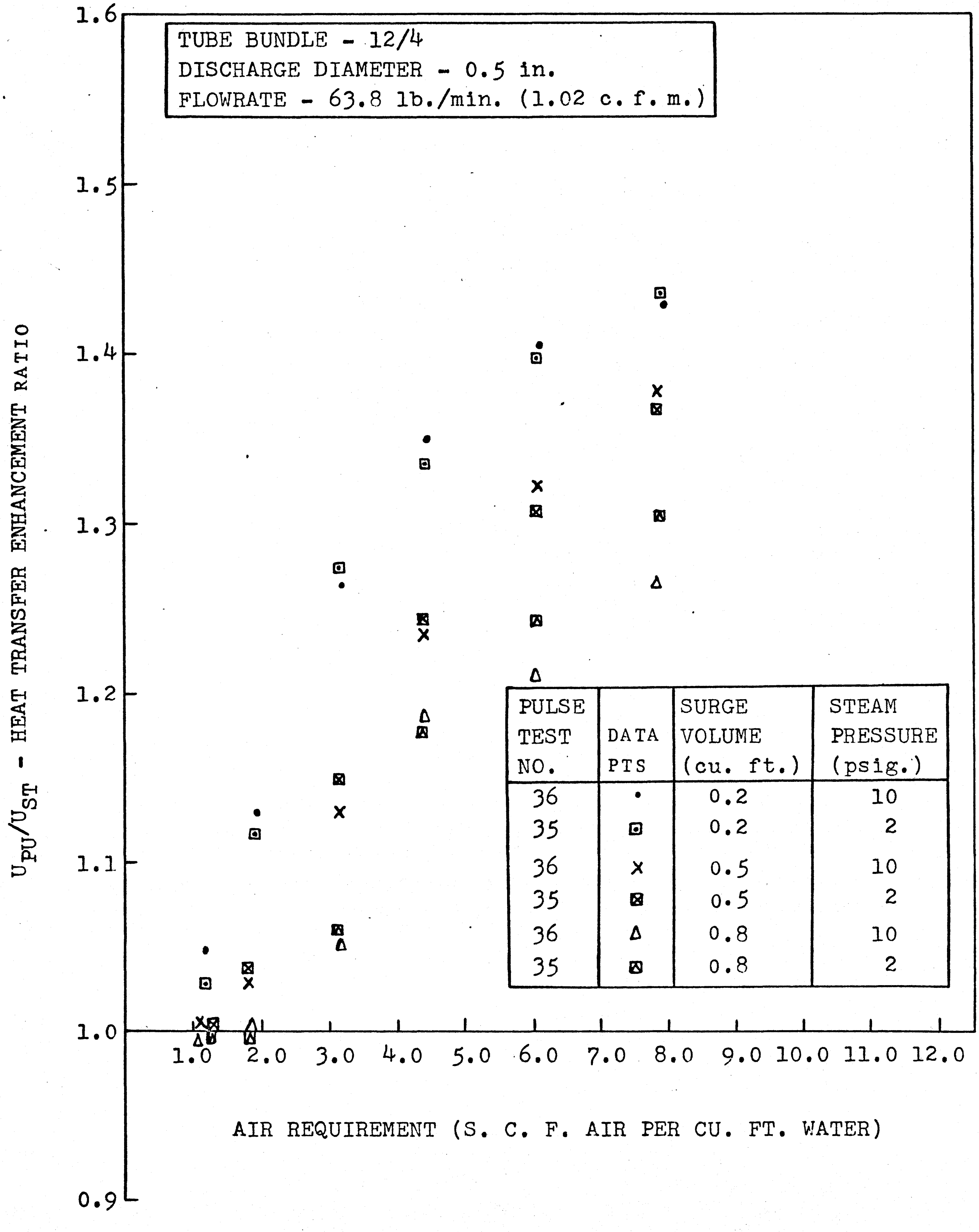
## (DATA FROM PULSE TEST NOS. 23 AND 24)



## FIGURE 20

## AIR REQUIREMENTS FOR OVERALL HEAT TRANSFER ENHANCEMENT

## (DATA FROM PULSE TEST NOS. 35 AND 36)



a) For each specific test increasing the air requirement causes the change in $U_{PU}/U_{ST}$ to decrease until a limiting value of $U_{PU}/U_{ST}$ is approached.

b) The smaller the surge volume used (minimum of 0.2 cu. ft.) the greater the value of $U_{PU}/U_{ST}$ for any DPV.

c) In this case there is an apparent effect of shell steam pressure. The cause is actually an equalization of overall heat transfer coefficients due to pulsed flow that was discussed on p. 69.

The data from pulse tests 12, 14, 16, 18, 20 and 22 are shown in each of Figures 16, 17 and 18. The Figures correspond to using surge volumes of 0.2, 0.5 and 0.8 cu. ft. respectively.

In each of these three Figures the data from pulse test 12 gave the typical curve as described above. However for the data from pulse tests 14, 16, 18, 20 and 22 it appeared that they could be well represented by a straight line over a range of air requirement from 0 to about 4.5. Minimum air requirement for a desired $U_{PU}/U_{ST}$ was achieved with the surge volume of 0.2 cu. ft. (see Figure 16). A least squares calculation was used to calculate the best straight line. The computer program which was used is given in Appendix I. For the data in Figure 16 an increase of 1.0 in air requirement increased $U_{PU}/U_{ST}$ by about 11.0%. The least squares lines for surge volumes of 0.5 and 0.8 cu. ft. give lower increases in $U_{PU}/U_{ST}$ and are shown on Figures 17 and 18.

The minimum air requirement to obtain a desired heat transfer enhancement ratio was found from the data of pulse tests 23, 24 (see Figure 19). In these tests the upstream surge pressure was allowed to rise above the limit of 10 psig. in order to make runs over the complete range of flowrate calibration. The result was that these tests were run under the conditions of both the highest surge volume pressure and highest fluctuation in the surge volume pressure at any fixed air flow. It was not within the scope of this work to determine the effect of any further increase in surge volume pressures and pressure fluctuations.

Pulse tests 23, 24 again showed that the highest heat transfer enhancement ratio at a fixed air requirement was obtained by using the smallest surge volume of 0.2 cu. ft.

The results in this section up to now have been concerned with data from the 12/12 tube bundle. The results from pulse tests 35 and 36 (see Figure 20), however are from data taken from the 12/4 tube bundle. The results produced the typical curves already described. As with the 12/12 tube bundle highest heat transfer enhancement ratio was obtained, at any fixed air requirement by using the 0.2 cu. ft. surge volume.

## V CONCLUSIONS

The "Water Blow" Pulsation Generator has been used successfully to produce fluid pulsations in an industrial single pass heat exchanger. Tests have repeatedly shown that improvements in the time-averaged overall heat transfer coefficient of up to 40% were possible using Dimensionless Pulsation Velocities (DPV) from 1.0 to approximately 4.0. The tests were limited to a range of mean fluid velocities from .62 to about 4.5 feet per second. In one test at the mean fluid velocity of 0.62 ft./sec. an improvement in the coefficient of over 100% was achieved.

The majority of the pulse flow tests were run with an air requirement which varied between approximately 0.3 to 5.0 standard cu. ft. air per cu. ft. water. When the pulsation generator was operating under good working conditions of discharge diameter (0.625 in.), flowrate (106.3 to 191.3 lb./min.) and surge volume (0.2 cu. ft.), the overall heat transfer coefficient increased 10 to 11% per unit of air required (s. cu. ft. air/cu. ft. water passed).

The quasi-steady state theory was not completely successful in predicting the results of the tests. The theory often underestimated coefficients at high mean fluid velocities and overestimated coefficients at low mean fluid velocities. The prediction that $U_{PU}/U_{ST}$ decreases at DPV values between

0 and about 2.0 was not observed during experimental testing. On the other hand, as predicted by the theory DPV was the major variable affecting the improvement in the heat transfer coefficient.

Future investigations should be directed towards working with high mean velocities (well above 4.0 ft./sec.) in the tubes, while maintaining high fluid flowrates. This would require some changes in the present "Water Blow" Pulsation Generator, in particular an all-metal construction capable of containing higher pressures. Glass construction was retained in this work to facilitate measurement and observation.

A preliminary cost estimate has been done using the Guthrie(11) method of calculation. The estimates are for steady state water flows of 10 cfm and 1,000 cfm. The calculations shown in Appendix III indicate that costs would be about \$125 /cfm year at 10 cfm flow and about \$ 24.94/cfm year at the 1,000 cfm level of flow. It should be pointed out that these costs will be reduced if compressor capacity is already available. The costs would be approximately \$104/cfm year at 10 cfm flow and about 19.40/cfm year for 1000 cfm flow. These costs would include all expenses except the capital cost of the compressor.

# NOMENCLATURE

| Symbols | Meaning (Units) |
|---|---|
| U | Overall heat transfer coefficient (BTU/hr. sq. ft. °F) |
| T | Temperature (°F) |
| AR | Heat transfer area (sq. ft.) |
| $\Delta T_{ln}$ | Natural log mean temperature difference (°F) |
| M | Mass flowrate (lb./hr.) |
| $\Delta T$ | Temperature gain or loss of the flowing fluid (°F) |
| h | Individual heat transfer coefficient (BTU/hr. sq. ft. °F) |
| D | Tube diameter (ft.) |
| k | Thermal conductivity (BTU/hr. ft. °F) |
| $\mu$ | Fluid viscosity (lb./ft./hr.) |
| $C_p$ | Thermal heat capacity (BTU/lb. °F) |
| $\rho$ | Density (lb./cu. ft.) |
| V | Fluid velocity (ft./sec.) |
| $\bar{V}$ | Mean fluid velocity (ft./sec.) |
| $\alpha$ = DPV | Dimensionless Pulsation velocity = Ratio of Maximum velocity fluctuation to the Mean fluid velocity = $\pi$ x (S) x (F)/$\bar{V}_{ST}$ |
| $\pi$ | 3.1416 |
| S | Stroke = (Maximum amplitude - Minimum amplitude) (ins.) |
| F | Pulsation frequency (cycles/minute) |
| A | Shell side heat transfer resistance, intercept of the Wilson Plot (hr. sq. ft. °F/BTU) |

## NOMENCLATURE CONT.

| Symbols | Meaning (Units) |
|---|---|
| w | Angular frequency (radians/sec.) |
| B | Represents the non varying factors in the expression for the film side heat transfer coefficient |
| 36/36 | Tube bundle = 36 tubes with 36 active |
| 36/4 | Tube bundle = 36 tubes with only 4 active |
| 12/12 | Tube bundle = 12 tubes with 12 active |
| 12/4 | Tube bundle = 12 tubes with only 4 active |
| AT | Air requirements (standard cu. ft. air/cu. ft. water) |
| SM | Dry saturated steam temperature or pressure (°F or psig.) |
| ST | Under steady state conditions |
| PU | Under pulsed flow conditions |
| h | Tube side heat transfer coefficient |
| s | Shell side heat transfer coefficient |
| 1 | Entering conditions |
| o | Exit conditions |
| G | $\rho \bar{V}_{ST}$ (lb./sq. ft. sec.) |
| q | Rate of heat transfer (BTU/hr. sq. ft. °F) |

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# APPENDIX I

## Computer Programs

1) Calculation of Results for the Steady State Tests
2) Calculation of Theoretical Heat Transfer Enhancement Ratio as a Function of the DPV
3) Calculation of Results for the Pulsation Tests
4) Calculation of Best Straight Line by the Method of Least Squares

## 1) CALCULATION OF RESULTS FOR THE STEADY STATE TESTS

```
      DIMENSION UST(50), VS(50)
      COMMON N,M, USTI(50),VSI(50),X(50), Y(50)
C     CALCULATE AREAS AHT=HEAT TRANSFER AREA AXT=TUBE CROSS SECTION AREA
C     AXR=RISER CROSS SECTION AREA
C     TDI=INSIDE TUBE DIAMETER IN FEET
C     TDO= OUTSIDE TUBE DIAMETER IN FEET
C     TN=NUMBER OF TUBES
C     TL=TUBELENGTH IN FEET
      TDI=.527/12.
      TDO=.625/12.
      TL=37.0/12.
      TN=4.
      AHT=TL*((TDI+TDO)/2.)*3.1416*TN
      AXT=3.1416*TDI*TDI*TN/4.
C     RD=RISER DIAMETER IN FEET
      RD=2./12.
      AXR=3.1416*RD*RD/4.
C     CP= HEAT CAPACITY
      CP=1.0
C     TS=STEAM TEMPERATURE
C     TO=WATER OUTLET TEMPERATURE
C     TI=WATER INLET TEMPERATURE
C     WF=WATER FLOW IN POUNDS PER MINUTE
      MM=1
      READ(5,999) M
C     M=NUMBER OF SETS OF DATA
  999 FORMAT(1I5)
  100 WRITE(6,998) MM
  998 FORMAT(1H1,8HTEST NO.,I5//)
      WRITE(6,1000)
 1000 FORMAT(4X,4HUSTI,8X,3HVSI,9X,3HUST,10X,2HVS,5X//)
      READ(5,1001) N
 1001 FORMAT(1I5)
      DO 10 I=1,N
C     N=NUMBER OF SETS OF DATA POINTS
      READ(5,1002) TS,TO,TI,WF
 1002 FORMAT(4F10.4)
C     CALCULATION OF LN MEAN TEMPERATURE DIFFERENCE-TELN
      TELN=((TS-TI)-(TS-TO))/ LOGF((TS-TI)/(TS-TO))
C     CALCULATE OVERALL HEAT TRANSFER COEFFICIENT-UST
C     USTI=1.0/UST
      UST(I)=(WF*60.*CP*(TO-TI))/(TELN*AHT)
      USTI(I)=1.0/UST(I)
C     CALCULATE WATER FLOW VELOCITY IN TUBES IN FEET/SEC.-VS
C     VSI=1.0/VS
      VS(I)=WF/(62.4*AXT*60.)
      VSI(I)=1.0/(VS(I)**0.8)
      WRITE(6,1003) USTI(I),VSI(I),UST(I),VS(I)
 1003 FORMAT(4F12.5)
   10 CONTINUE
      MM=MM+1
      IF(MM-M) 100,100,101
  101 STOP
      END
```

## 2) CALCULATION OF THEORETICAL HEAT TRANSFER ENHANCEMENT RATIO AS A FUNCTION OF THE DPV

```
C     INTEGRATION OVER ONE CYCLE USES A THIRD ORDER RUNGE KUTTA
C     X=PHASE ANGLE IN RADIANS
C     H=INCREMENT IN PHASE ANGLE
C     XF=FINAL VALUE OF PHASE ANGLE
C     Y=UPU/UST=ENHANCEMENT OF OVERALL HEAT TRANSFER COEFFICIENT DUE TO
C     PULSATION
C     AMP=DPV= DIMENSIONLESS PULSATION RATIO
C     A= SHELL SIDE HEAT TRANSFER RESISTANCE
C     B= NON VARYING FACTORS IN THE FILM SIDE HEAT TRANSFER COEFFICIENT
C     VST=MEAN STEADY STATE VELOCITY IN FEET PER SECOND
      READ(5,999) M
  999 FORMAT(I5)
      N=1
  200 WRITE(6,1000)
 1000 FORMAT(1H1,4HTEST,1X,5HCYCLE,5X,6HURATIO,7X,3HDPV)
      READ(5,2000)A,VST
 2000 FORMAT(2F10.0)
      B=.002382/(VST**0.8)
      CALL RK(A,B,N)
      N=N+1
      IF(N-M) 200,200,201
  201 STOP
      END


      SUBROUTINE RK(A,B,N)
      YVAL(Y,R1,R2,R3) = Y+H*(R1+4.*R2+R3)/6.
      F1(X,Y)=(1./(1.+((((ABS(1.+(AMP*(SIN(X)))))**-0.8)-1.)/
     +(1.0+(A/B))))))/6.2832
      X=0.
      Y=0.
      H=0.0168
      XF=6.2832
      AMP=1.0
      NS=(XF+.0168)/H
  101 DO 100 I=1,NS
      R1 = F1(X,Y)
      R2 = F1((X+H/2.) , (Y+R1*H/2.))
      R3=F1((X+H),(Y+2.*H*R2-H*R1))
      Y = YVAL(Y,R1,R2,R3)
      X=X+H
  100 CONTINUE
      WRITE(6,3000) N,X,Y,AMP
 3000 FORMAT(I5,3F10.4)
      X=0.0
      Y=0.0
      AMP=AMP+0.5
      IF(AMP-5.0) 101,101,102
  102 RETURN
      END
```

## 3) CALCULATION OF RESULTS FOR THE PULSATION TESTS

```
C     M=NUMBER OF TESTS WITH DIFFERENT FLOWRATES AND STEAM PRESSURES
C     MEANING OF CONSTANTS AND VARIABLES ARE THE SAME AS IN STEADY STATE
C     UPU=HEAT TRANSFER COEFFICIENT IN PULSED FLOW   URATIO=UPU/UST
C     MPV=MAXIMUM FLUCTUATION IN PULSATION VELOCITY
C     STRO=STROKE(INCHES)  FREQ=FREQUENCY(CYCLES PER MIN.)
      TDI=.527/12.
      TDO=.625/12.
      TL=37./12.
      TN=4.
      AHT=TL*((TDI+TDO)/2.)*3.1416*TN
      AXT=3.1416*TDI*TDI*TN/4.
      RD=2./12.
      AXR=3.1416*RD*RD/4.
      CP=1.0
      MM=1
C     CALCULATION OF STEADY STATE VALUES
      READ(5,999) M
  999 FORMAT(I5)
  100 WRITE(6,998) MM
  998 FORMAT(1H1,8HTEST NO.,I5//)
      WRITE(6,1000)
 1000 FORMAT(1H0,3X,3HUST,7X,3HVST//)
      READ(5,1002) TS,TO,TI,WF
 1002 FORMAT(4F10.4)
      TELN=((TS-TI)-(TS-TO))/LOGF((TS-TI)/(TS-TO))
      VST=WF/(62.4*AXT*60.)
      UST=(WF*60.*CP*(TO-TI))/(TELN*AHT)
      WRITE(6,1003) UST,VST
 1003 FORMAT(2F10.5)
      NNN=1
C     NN=NUMBER OF DIFFERENT SURGE VOLUMES TESTED
      READ(5,999) NN
C     N=NUMBER OF RUNS WITHIN A SURGE VOLUME
  200 READ(5,1001) N
 1001 FORMAT(I5)
      WRITE(6,1020)
 1020 FORMAT(3X,3HNO.,7X,3HUST,7X,3HUPU,6X,6HURATIO,6X,3HVST,
     +7X,3HMPV,7X,3HDPV/)
      DO 10 I=1,N
      READ(5,1040) TO,STRO,FREQ
 1040 FORMAT(3F10.0)
      TELN=((TS-TI)-(TS-TO))/LOGF((TS-TI)/(TS-TO))
      UPU=(WF*60.*CP*(TO-TI))/(TELN*AHT)
      XMPV=3.1416*STRO*FREQ*AXR/(720.*AXT)
      URATIO=UPU/UST
      DPV=XMPV/VST
      WRITE(6,1030) I,UST,UPU.URATIO.VST,XMPV,DPV
 1030 FORMAT(I6,2F12.4,4F10.4)
   10 CONTINUE
      NNN=NNN+1
      IF(NNN-NN) 200,200,201
  201 MM=MM+1
      IF(MM-M) 100,100,101
  101 STOP
      END
```

4) CALCULATION OF BEST STRAIGHT LINE BY THE METHOD OF LEAST SQUARES

```
C     NA=NUMBER OF SETS OF DATA
C     N=NUMBER OF DATA POINTS IN A SET
C     A=INTERCEPT
C     B=SLOPE OF LINE
C     X= DEPENDENT VARIABLE
C     Y= INDEPENDENT VARIABLE
      DIMENSION X(100), Y(100)
      NN=1
      READ(5,10) NA
   10 FORMAT(I5)
  100 WRITE(6,1010) NN
 1010 FORMAT(1H1,3X,8HTEST NO.,I5//)
      WRITE(6,1004)
 1004 FORMAT(5X,1HA,9X,1HB,9X,2HSX,8X,2HSY,8X,3HSXY,7X,3HSXX//)
      READ(5,10) N
      READ(5,20) (X(I),I=1,N)
      READ(5,20) (Y(I),I=1,N)
   20 FORMAT(6F10.0)
      SX=0.0
      SY=0.0
      SXY=0.0
      SXX=0.0
      DO 30 I=1,N
      SX=SX+X(I)
      SY=SY+Y(I)
      SXY=SXY+X(I)*Y(I)
      SXX=SXX+X(I)*X(I)
   30 CONTINUE
      B=(N*SXY-SX*SY)/(N*SXX-SX*SX)
      A =(SY-B*SX)/N
      WRITE(6,1005) A,B,SX,SY,SXY,SXX
 1005 FORMAT(6F10.6)
      AA=1.0/A
      BB=1.0/B
      WRITE(6,2000) AA,BB
 2000 FORMAT(2F10.4)
      NN=NN+1
      IF(NN-NA) 100,100,110
  110 STOP
      END
```

# APPENDIX II

## ESTIMATE OF THE TUBE SIDE HEAT TRANSFER COEFFICIENT

The Dittus-Boelter Equation was used to estimate $h_f$ as a function of $\overline{V}_{ST}^{0.8}$. The equation is given in reference (9) for fluids being heated as:

$$\frac{hD}{k} = 0.023 \left(\frac{DG}{\mu}\right)^{0.8} \left(\frac{\mu C_p}{k}\right)^{0.4}$$

where $h = h_f$, $G = \overline{V}_{ST}\,\rho$

For all the tests the inlet water temperatures to the heat exchanger ranged from 52 °F to 68 °F and outlet water ranged from 92 °F to 174 °F. The physical properties(8) were therefore taken at the average of the two extremes or 72 °F and 121 °F.

| Average Water Temp. (°F) | 72 | 121 |
|---|---|---|
| k (BTU/hr. ft. °F) | 0.355 | 0.369 |
| $\mu$ (lb./ft. hr.) | 2.31 | 1.32 |
| $C_p$ (BTU/lb. °F) | 1.00 | 1.00 |
| D (ft.) | 0.0437 | 0.0437 |
| $\rho$ (lb./cu. ft.) | 62.4 | 62.4 |

At 72 °F

$$h = 0.023\frac{k}{D}\left(\frac{\rho \overline{V}_{ST} D}{\mu}\right)^{0.8}\left(\frac{\mu C_p}{k}\right)^{0.4}$$

$$= 0.023\frac{.355}{.0437}(791)(2.12)\overline{V}_{ST}^{0.8}$$

$$= 319\ \overline{V}_{ST}^{0.8}\ \text{BTU/hr. sq. ft. °F}$$

and $B = 1.0/319 = 0.00313$

At 121 °F

$$h = 0.194\ (1250)(1.67)\ \overline{V}_{ST}^{0.8}$$

$$= 406\ \overline{V}_{ST}^{0.8}\ \text{BTU/hr. sq. ft. °F}$$

and $B = 1.0/406 = 0.00247$

## APPENDIX III

## COST ESTIMATE

An estimate of the capital and operating costs of a "water blow" pulsation unit has been done. The costs have been calculated for two flows of water i.e., 10 and 1,000 cfm. The following assumptions were made:

i) the required $U_{PU}/U_{ST} = 1.4$ with a DPV = 4.0;

ii) air requirements will be 4.0 scf air per cu. ft. water;

iii) maximum pressure in the surge volumes will be 10 psig.;

iv) pulsation frequency (F) = 30 cycles/min.;

v) air at 70 psig is used for pulsation.

The cost estimating technique of Guthrie(11) was used:

### A) For 10 cfm of Water

Calculation of surge volume sizes.

The liquid surge volume ($V_W$) required can be calculated from the equation:

$$V_W = DPV \times \overline{V} / \pi \times F = 0.212 \text{ cu. ft.}$$

The total surge volume ($V_T$) can be obtained from the two equations:

$$V_T = V_A + V_W \qquad (8)$$

and $$P_o V_T^{1.4} = P_A V_A^{1.4} \qquad (9)$$

where $V_A$ = surge volume occupied, only air.

$P_o$ = initial surge volume pressure = 14.7 psia.

$P_A$ = final surge volume pressure = 25.7 psia.

The solution of equations (8) and (9) yields a value of:

$V_T$ = 2.1 cu. ft.

Calculation of compressor requirements.

The flow of air required is 4.0 x 10 = 40 scfm.

Using equation (9) the flow of compressed air at 84.7 psia ($P_2$) will be

$V_1$ = 11.4 cfm

The adiabatic horsepower can be calculated from equation (8) (10):

$$\text{Horsepower} = \frac{144\ k}{33{,}000\ (k-1)}\ P_1V_1 \left[\left(\frac{P_2}{P_1}\right)^{\frac{k-1}{k}} - 1\right] \qquad (10)$$

where k = ratio of specific heat of the vapor, $C_p/C_v$, and $P_1 = P_o$.

Assuming the compressor is 80% efficient

Horse power = 2.10

## EQUIPMENT COSTS:

### Pressure Vessels: - two - 2.1 cu. ft. each.

(Carbon steel, 50 psig., escalation at 6%/year)

Base cost - \$500 x 2 = \$ 1,000

Expected cost (mid 1970) - \$1000 x $(1.06)^2$ = \$1,220

Base Module Factor - 4.34

Base Module Cost - \$1,220 x 4.34 = \$5,300

### Air Compressor:

From a direct quotation (10 cfm compressor -100 psig) = \$ 480

Field Installation (M and L) \$480 x 1.60 = \$768

Norm indirects at 29% - \$768 x 0.29 = 222

Base Module Cost \$ 990

Total Base Module Cost \$5300 + \$990 = \$6,290

Contingencies at 15% of \$6290 = 945

Capital Cost = \$7,235

## OPERATING COSTS:

Assume i) Maintenance at 4% of capital cost.
ii) Power available at \$10.00/1,000 KWH.

Power - 2.10 x 24 x 365 x \$10.00x 0.746/1,000 = \$137/year

Maintenance - \$7,235 x 0.04 = 289/year

Total \$ 426/year

Total Cost per cfm flow of water per year
(Assume straight line depreciation at 10% of capital cost)

(\$7,235 x 0.1 +\$426) /10 = \$125.00/cfm of water per year

B) For 1,000 cfm of water

Calculation similar to (A) above given the following:

Liquid surge volume size $V_W$ = 42.4 cu. ft.

Total surge volume size $V_T$ = 207 cu. ft.

Flow of compressed air $V_1$ = 920 cfm

Horsepower required = 168

EQUIPMENT COSTS:

Pressure Vessels:

(carbon steel, 50 psig., escalation at 6%/year)

Base module cost (mid 1970) = $39,000

Air Compressor:

Unit cost - $2,900/cfm

(920 cfm, size exponent - 0.28, linear factor $F_L = 7.0$)

Expected equipment cost (mid 1970) $2900 x 7.0 x $(1.06)^2$ = $22,800

Field Installation (M & L) $22,800 x 1.6 = $36,500

Norm Indirects at 29% - $36,500 x .29 = 10,600

Base Module Cost $ 47,100

Total Base Module Cost - $39,000 + $47,100 = $ 86,100

Contingencies at 15% of $86,100 = 12,900

Capital Cost = $ 99,000

OPERATING COSTS:

| | |
|---|---|
| Power | $ 10,980/year |
| Maintenance | 3,960/year |
| Total | $ 14,940/year |

Total cost per cfm flow of water per year
(assume straight line depreciation at 10% of capital cost)

($99,000 x 0.1 + $14,940) /1,000 = $24.94 of water per year