NASA CR-135339

SUPERCRITICAL OXYGEN HEAT TRANSFER

by

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AEROJET LIQUID ROCKET COMPANY
Sacramento, California

prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

November 1977

CONTRACT NAS 3-20384

NASA Lewis Research Center
Cleveland, Ohio
H. G. Price, Project Manager

(NASA-CR-135339) SUPERCRITICAL OXYGEN HEAT TRANSFER Final Report (Aerojet Liquid Rocket Co.) 95 p HC A05/MF A01 CSCL 20D

N78-17342

Unclas
G3/34 05358

1. Report No. NASA	2. Government Accession No.	3. Recipient's Catalog No.

4. Title and Subtitle Supercritical Oxygen Heat Transfer Investigation	5. Report Date 6. Performing Organization Code
7. Author(s) R. G. Spencer and D. C. Rousar	8. Performing Organization Report No.
9. Performing Organization Name and Address Aerojet Liquid Rocket Company Sacramento, California	10. Work Unit No. 11. Contract or Grant No. NAS 3 20384
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D.C. 20546	13. Type of Report and Period Covered Final Report 14. Sponsoring Agency Code 9521

15. Supplementary Notes

Project Manager, H. G. Price, NASA Lewis Research Center, Cleveland, Ohio

16. Abstract

Heat transfer to supercritical oxygen was experimentally measured in electrically heated tubes. Experimental data were obtained for pressures ranging from 17 to 34.5 MPa (2460 to 5000 psia), and heat fluxes from 2 x 10^6 to 90 x 10^6 W/m^2 (1.2 to 55 Btu/(in.^{2} sec)). Bulk temperatures ranged from 96 to 217 K (173 to 391 R). Experimental data obtained by other investigators were added to this to increase the range of pressure down to 2 MPa (290 psia) and increase the range of bulk temperature up to 566 K (1019 R). From this compilation of experimental data a correlating equation was developed which predicts over 95% of the experimental data within ± 30%.

17. Key Words (Suggested by Author(s)) Rengenerative Cooling Heat Transfer Oxygen High Pressure	18. Distribution Statement Unclassified - Unlimited

19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 101	22. Price*

TABLE OF CONTENTS

Appendices

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES (cont.)

I. SUMMARY

Heat transfer to supercritical oxygen was experimentally measured in electrically heated tubes. Experimental data was obtained for pressures ranging from 17 to 34.5 MPa (2460 to 5000 psia), and heat fluxes from 2×10^6 to 90×10^6 W/m^2 (1.2 to 55 Btu/in.^{2}-sec). Bulk temperatures ranged from 96 to 217 K (173 to 391 R). Experimental data obtained by other investigators were added to this to increase the range of pressure down to 2 MPa (290 psia) and increase the range of bulk temperature up to 566 K (1019 R). From this compilation of experimental data the following correlation was developed:

$$Nu_b = Nu_{ref}\left(\frac{\rho_b}{\rho_w}\right)^{-1/2}\left(\frac{k_b}{k_w}\right)^{1/2}\left(\frac{\overline{Cp}}{Cp_b}\right)^{2/3}\left(\frac{P}{P_{cr}}\right)^{-1/5}\left(1+\frac{2}{\ell/d}\right)$$

in which:

Nu_{ref} = $.0025\, Re_b\, Pr_b^{.4}$
Cp = constant pressure specific heat
$\overline{Cp}$ = integrated average specific heat from T_w to T_b
d = inside tube diameter
k = thermal conductivity
ℓ = length from start of heated tube to temperature measurement station
Nu = Nusselt Number
P = local static pressure
Pr = Prandtl Number
Re = Reynolds Number
ρ = density

Subscripts:

b = evaluated at bulk temperature
cr = critical property
w = evaluated at wall temperature

Over 95% of the heat transfer measurements used to develop the correlation are predicted within ± 30% by the above equation.

II. INTRODUCTION

Recent proposals for a single-stage-to-orbit vehicle as a second generation space shuttle have created an interest in high pressure oxygen as a coolant for regenerative thrust chambers. This is because versions of the single-stage-to-orbit concept utilize engines burning two fuels (dense hydrocarbons, and hydrogen) fired sequentially in a single thrust chamber with oxygen as a common oxidizer (Ref. 1). In addition, recent studies have shown that cooling high pressure LOx/Hydrocarbon engines with hydrocarbon fuels is impractical because of the high velocities necessary to prevent coking (Ref. 2). Using oxygen as the coolant avoids this problem and also results in a simpler system. The feasibility of such a concept depends on the capability of oxygen to provide sufficient cooling.

Until recently, little information has been available on the heat transfer characteristics of high pressure oxygen. Powell obtained data at 7 MPa (1000 psia) which is far below the proposed engine operating pressures of 20 to 50 MPa (3000 to 7000 psia) (Ref. 3).

More recently data were obtained in the range of 24 to 35 MPa (3500 to 5000 psia) in an Aerojet IR&D investigation by Rousar and Miller (Ref. 4). This investigation is a continuation of the work by Rousar and Miller. The range of conditions has been increased over the previous work and the number of heat transfer measurements has been tripled. During this investigation the heat transfer characteristics of supercritical oxygen were measured over the following range of conditions:

Pressure	17 to 34.5 MPa (2500 to 5000 psia)
Bulk Temperature	96 to 217 K (173 to 391 R)
Wall Temperature	122 to 952 K (220 to 1714 R)
Heat Flux	2×10^6 to 90×10^6 Watt/m^2 (1.2 to 55 Btu/in.^{2}-sec)
Reynold's Number	1.5×10^5 to 3.2×10^6

III. EXPERIMENTAL APPARATUS

A. HIGH PRESSURE HEAT TRANSFER LOOP

All tests were conducted on Aerojet's 38 MPa (5500 psi) blowdown heat transfer loop shown schematically in Figure 1. The principal components of the loop were the 70 MPa (10,000 psi) nitrogen pressurization system, the oxygen feed system, the preheater, the test section apparatus, and the flow control valve. Electric power for the test section was provided by a 225 KW, 70 VDC power supply. The preheater was powered by two 50 KW 15 VDC supplies. The power supplies were operated from a 480 volt, 3-phase ac line source.

The feed system consisted of a .2 m^3 (50 gal), 38 MPa (5500 psi) rated, type 321 stainless steel, jacketed pressure vessel (run tank) for oxygen storage and pressurization; a 70 MPa (10,000 psi) pressure-reducing regulator, a tank safety valve, and various other valves for filling, draining and venting; and an overpressure relief valve used in conjunction with a burst disc to protect the vessel from excess pressure. For the low inlet temperature tests the run tank jacket was filled with LN_2. For all other tests the jacket was evacuated.

The preheater and test section apparatus are shown in Figure 2. Both were enclosed in 12.7 mm (1/2 in.) thick aluminum boxes. The test section enclosure was covered with an acrylic window and purged with dry nitrogen to prevent frost buildup. This allowed the test section to be monitored continuously with a closed circuit television during the test. Electrical taps brazed to the preheater coil provided four parallel current paths. Insulation requirements were minimized by maintaining the inlet and outlet at ground potential. The preheater was used only for the high inlet temperature tests. For all other tests the preheater was removed and the flowmeters installed in its enclosure, as shown in Figure 3.

The test section was clamped into electrical connections that were cantilever-mounted in the test section enclosure. The upper connection was supported with flexures to permit axial movement of the heated test section tube due to thermal expansion. To insure free axial movement a tension force of 150 N (35 lbf) was applied to the outlet end of the test section. The inlet of the test section was maintained at ground polarity and the outlet mixer incorporated electrical insulation which isolated the test section from downstream plumbing.

Flow control was accomplished using a 12.7 mm (1/2 in.) valve, operated by an electric motor actuator. After flowing through the flow control valve the oxygen was vented to atmosphere.

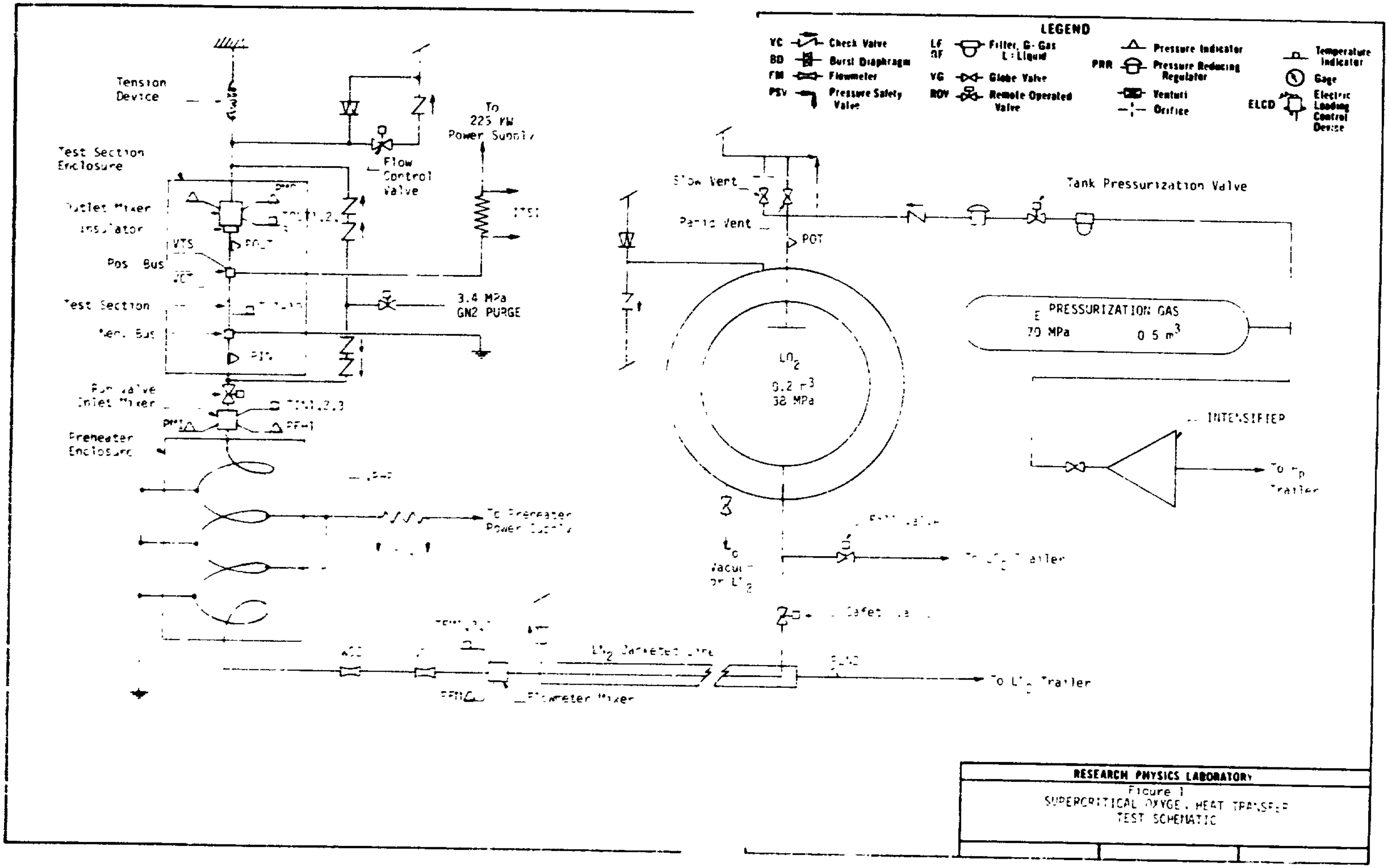

Figure 1. Supercritical Oxygen Heat Transfer Test Schematic

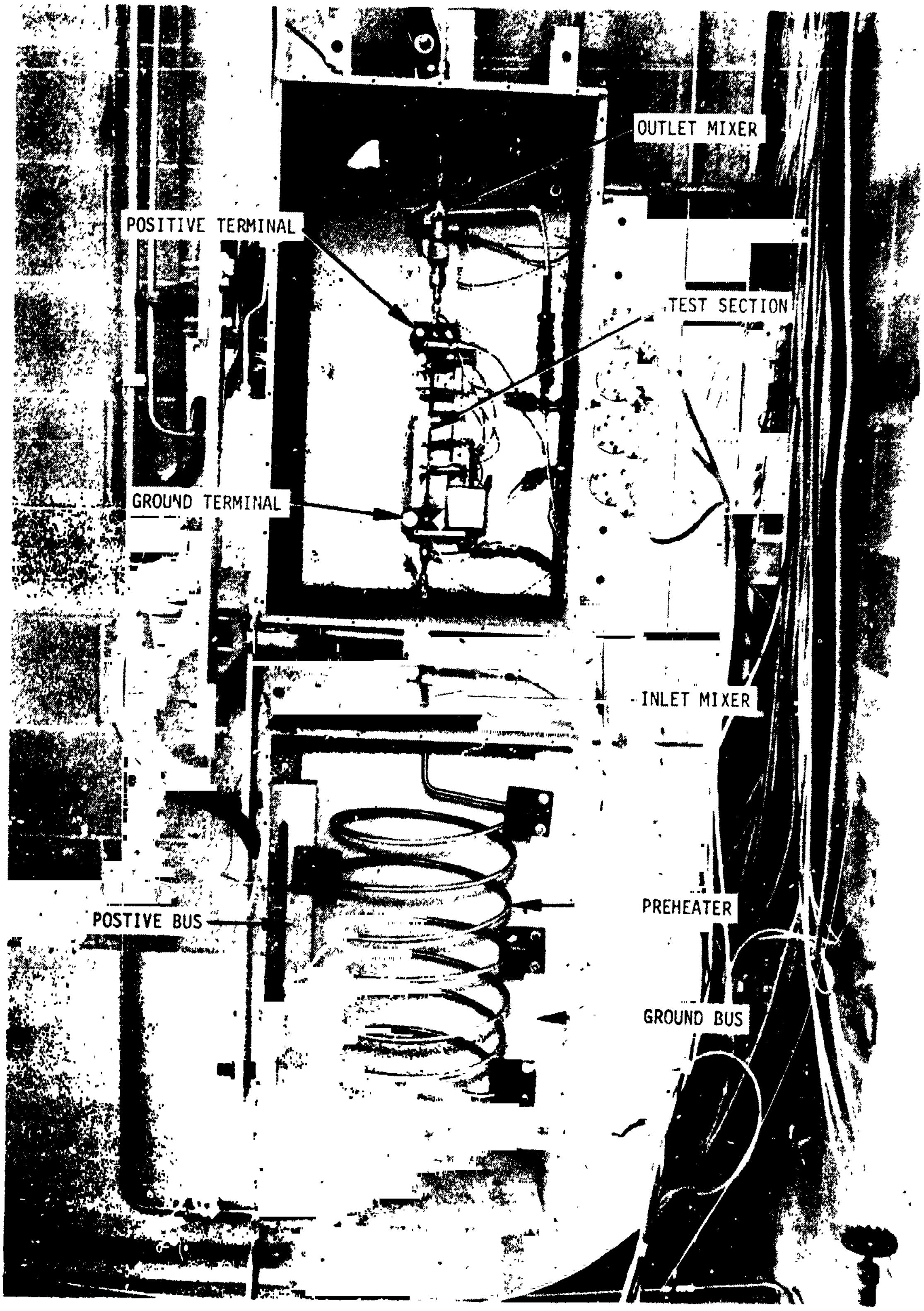

Figure 2. Test Setup With Preheater

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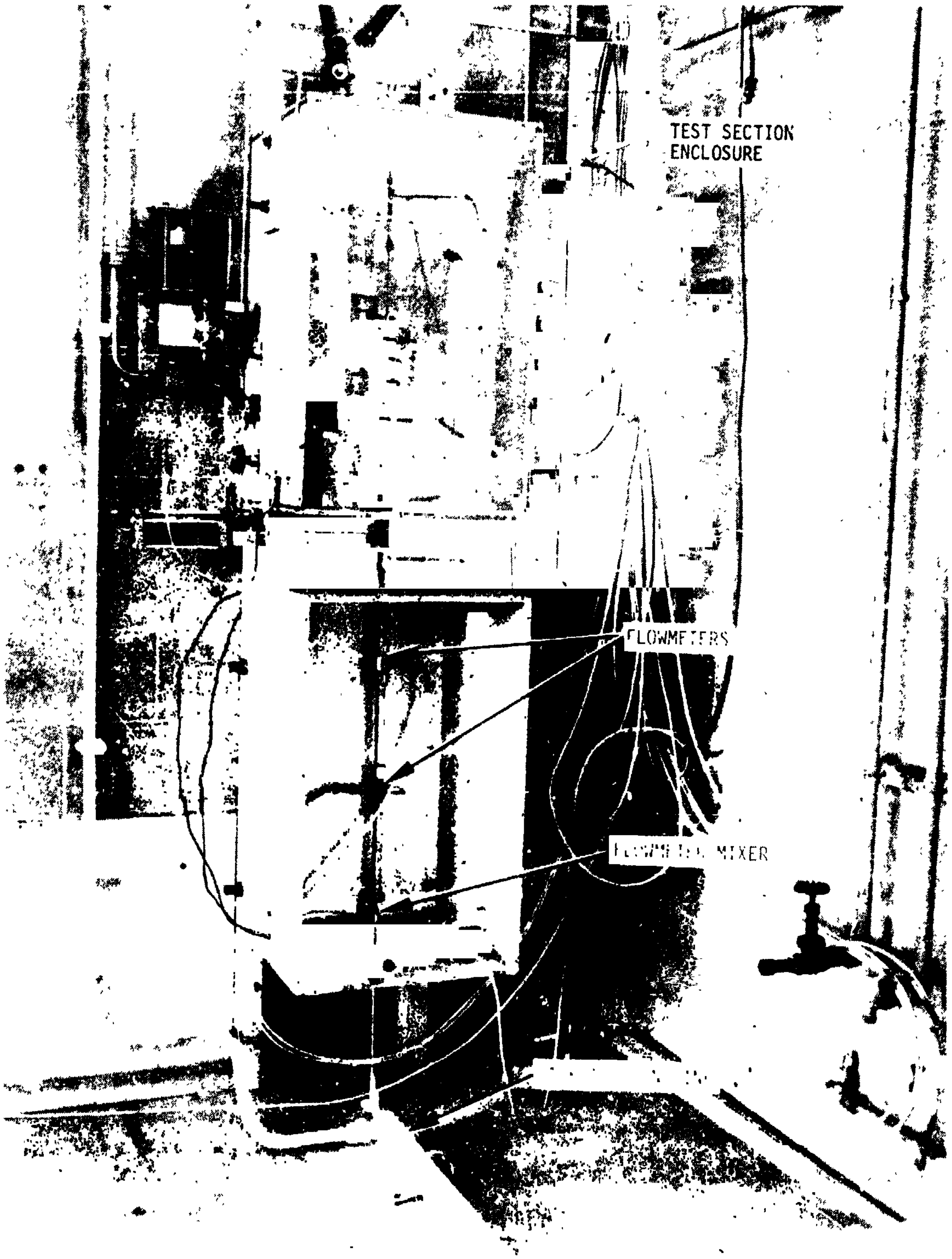


Figure 3. Test Setup Without Preheater

III, Experimental Apparatus (cont.)

B. TEST SECTIONS

Test sections were fabricated from Monel K-500 and Inconel 625 tubing with 3.18 and 4.76 mm (1/8 and 3/16 in.) OD and .38 mm (.015 in.) wall thickness. The dimensions and material of each test section are listed in Table I.

The heated lengths of the test sections were formed by silver brazing two pre-drilled cylindrical copper electrodes onto the tubing. These copper cylinders were fitted into the copper bus-bar clamps mounted in the test section enclosure. Figure 4 shows an installed test section. Pressure taps, located upstream and downstream of the test section electrodes, were fabricated by positioning a modified Swagelok union with Teflon ferrules over a .79 mm (.031 in.) diameter drilled hole. Before installation the union was drilled through at a wrenching flat and a 3.18 mm (1/8 in.) OD stainless steel tube was welded over the hole.

C. INTRUMENTATION

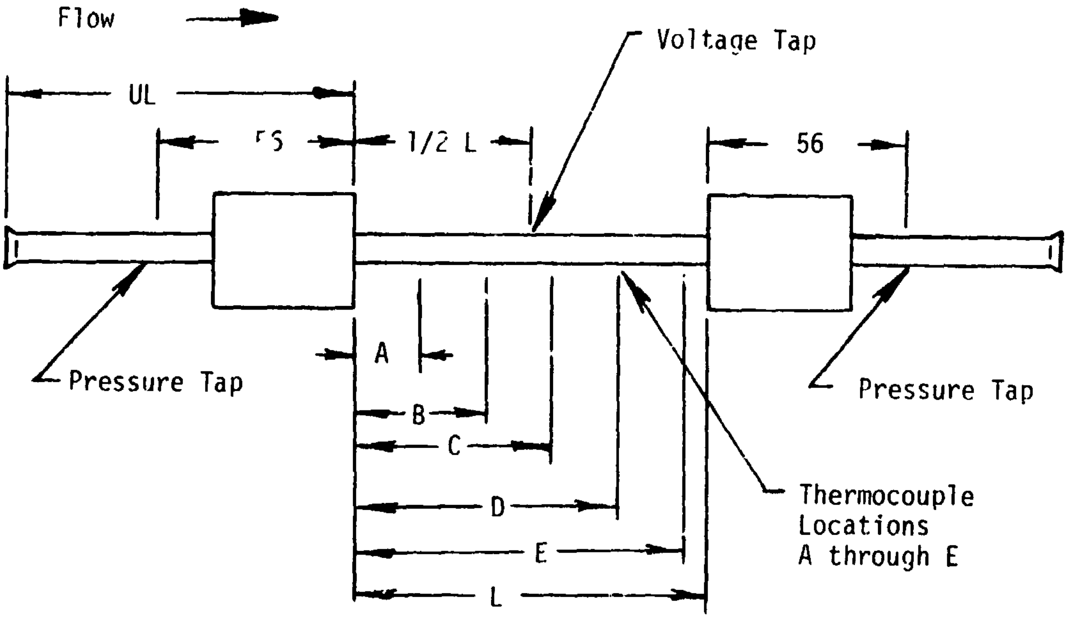
Each test section tube was instrumented with from eight to ten chromel alumel thermocouples for measuring outer wall temperature, and two voltage taps. The thermocouples were fabricated from 40 gauge (.08 mm dia) premium grade chromel and alumel wire and were installed in pairs (180° apart) at even increments of ℓ/d along the tube axis. The thermocouples were installed as shown in Figure 5. The junctions were formed by welding the two thermocouple wires together in a loop around the test section. The junction was then pulled up against the tube with a leaf spring. To prevent voltage from the tube interfering with the thermocouple readings, the thermocouples were electrically insulated from the tube with a thin strip of mica.

Because the thermocouples were not directly attached to the heated tube the measured temperature was somewhat lower than the actual wall temperature. To determine the magnitude of this difference a thermocouple calibration test was conducted. For this calibration a special test section was fabricated with both 3.18 and 4.76 mm (1/8 and 3/16 in.) diameter tubes as shown in Figure 6. Installed on each diameter were six electrically insulated thermocouples and two reference thermocouples which were welded directly to the tube wall. Three of the insulated thermocouples were covered with a ceramic coating to minimize convective heat loss.

The special test section was installed in the test section box as if it were an actual heat transfer test. The section was then heated with alternating electric current in 110 K (200 R) steps and data were sampled with the laboratory analog to digital converter. The data were sampled over a ten second period to average out any effects of the alternating current on the welded-on thermocouples.

TABLE I

TEST SECTION DIMENSIONS



Test NO.	Tube OD	Wall	Mat'l	UL	L	A	B	C	D	E
-102	3.18	0.38	Monel K-500	100.1	150.9	24.4	72.7	96.5	120.5	144.8
-103	4.76	0.38	Monel K-500	143.4	76.7	20.1	39.8	50.1	60.1	70.4
-105	4.76	0.38	Monel K-500	142.3	76.8	19.3	39.9	49.6	59.6	69.0
-106	4.76	0.38	Monel K-500	142.1	76.4	19.9	40.1	49.9	59.9	70.1
-107 & -108	3.18	0.38	Monel K-500	101.6	76.6	23.9	36.4	47.9	60.5	72.8
-109	3.18	0.38	Monel K-500	77.3	51.6	11.9	24.0	35.9	47.4	-
-110	3.18	0.38	Inconel 625	78.1	50.9	11.5	24.1	35.9	48.9	-
-111	3.18	0.38	Inconel 625	78.2	51.0	12.0	24.7	36.4	49.5	-
-112 & -113	3.18	0.38	Inconel 625	78.0	152.3	48.5	72.7	96.6	120.8	145.3
-114	4.76	0.38	Monel K-500	113.1	51.9	10.0	20.3	30.3	40.4	-
-115	4.76	0.38	Monel K-500	112.2	77.3	20.0	39.9	50.1	60.0	70.0
-116	4.76	0.38	Monel K-500	112.1	102.4	20.0	40.3	60.1	80.3	100.1
-117	4.76	0.38	Monel K-500	142.2	89.3	19.9	39.6	58.8	69.0	77.5
-118	4.76	0.38	Monel K-500	142.2	254.0	81.5	119.5	160.8	201.5	240.3

All Dimensions in mm

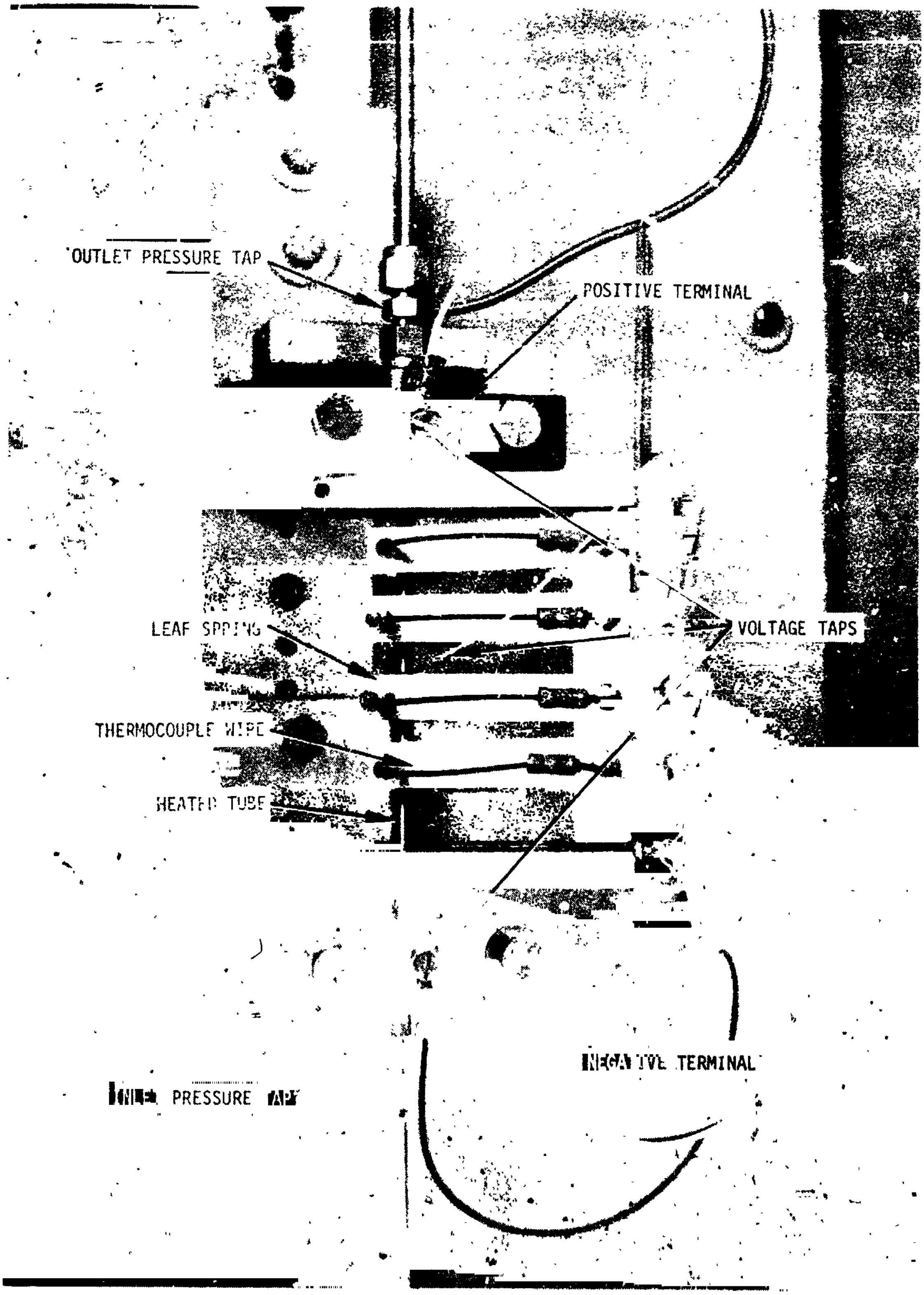


Figure 4. Test Section Installation

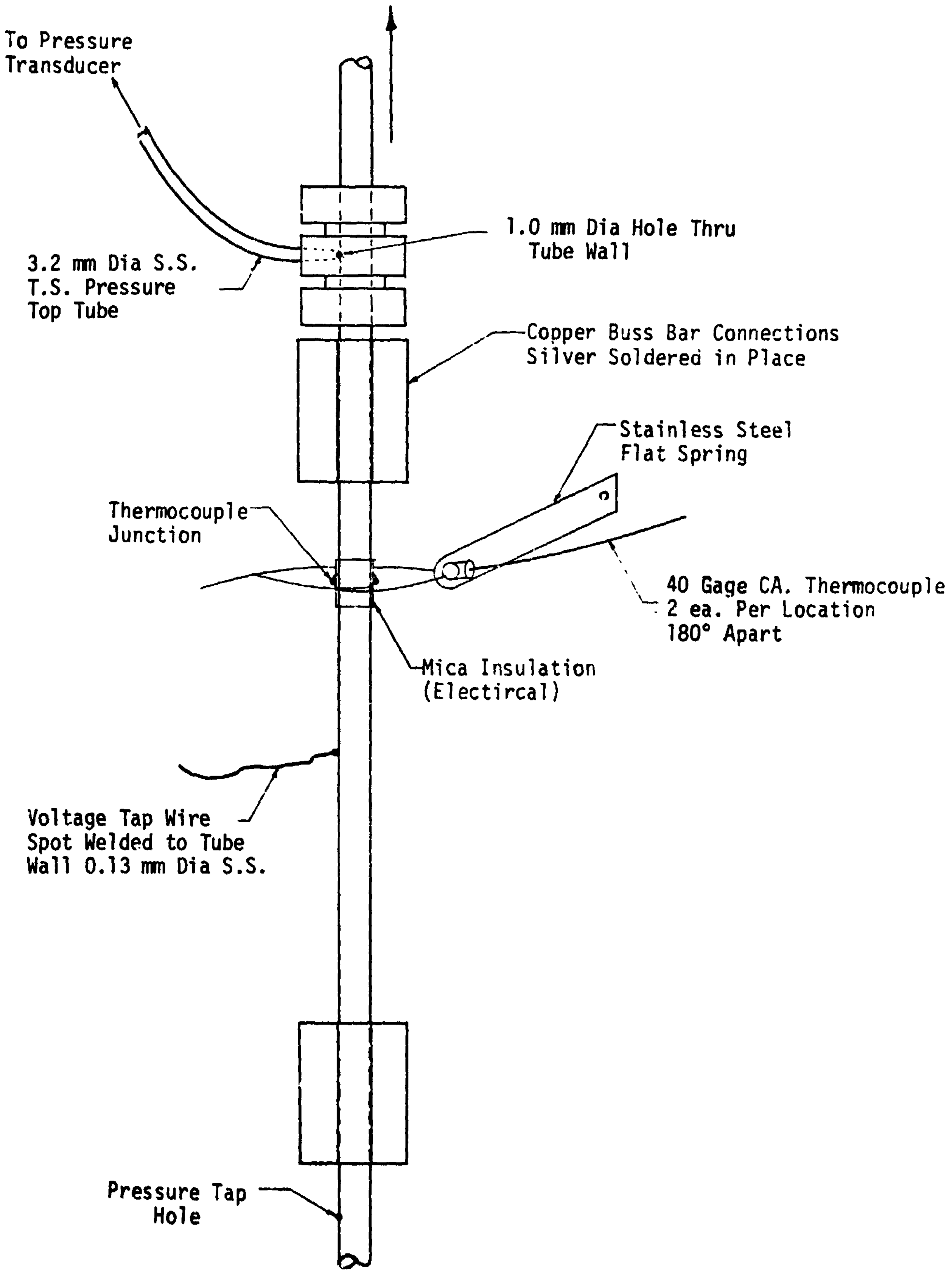
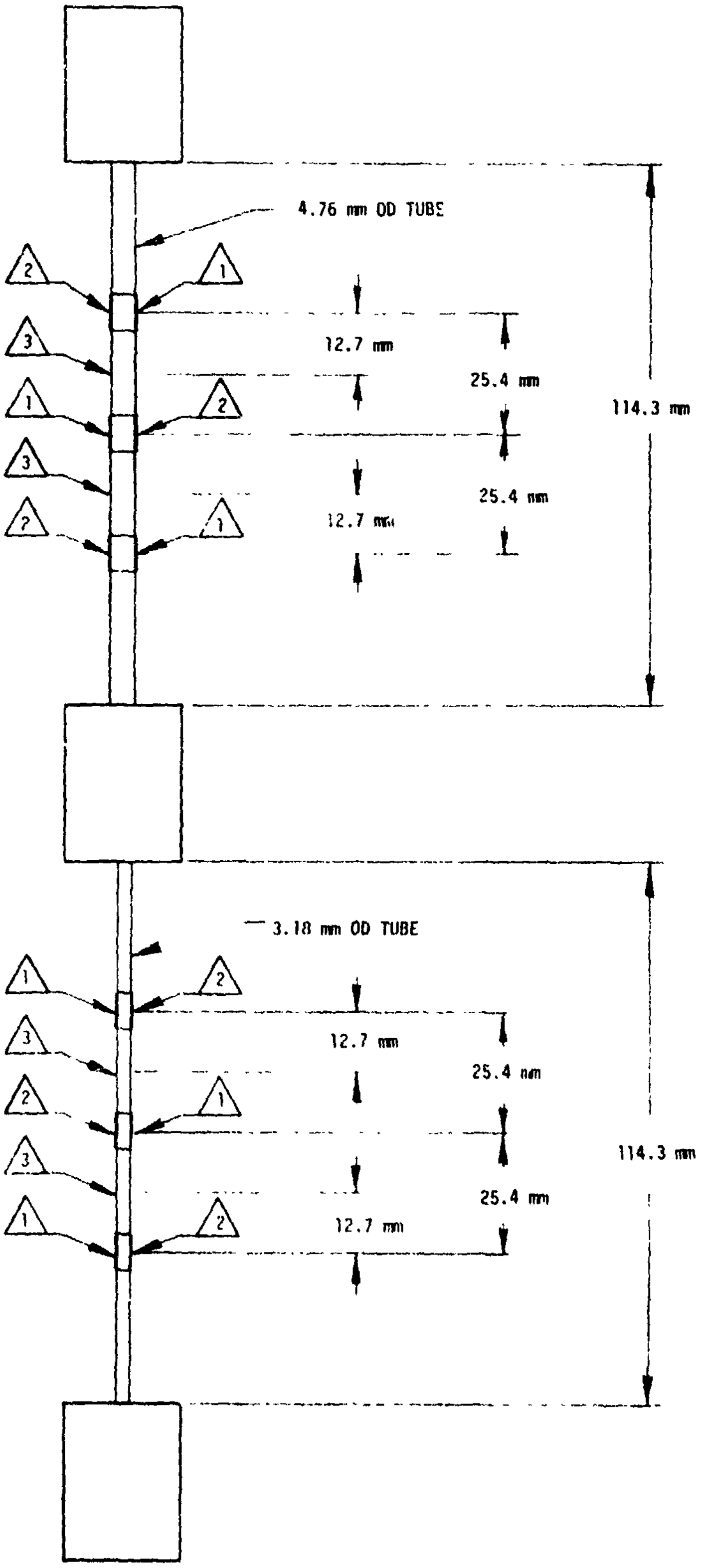


Figure 5. Heat Transfer Test Section



NOTES:

1. Spring loaded, electrically insulated thermocouple.
2. Spring loaded, electrically insulated thermocouple, with ceramic insulation over junction.
3. Thermocouple welded to tube.

Figure 6. Test Section for Thermocouple Calibration

III, C, Instrumentation (cont.)

The results did not indicate any significant difference variations from side to side, top to bottom or for coated or uncoated thermocouples. There was an indication that the ceramic coating caused some data scatter, therefore the ceramic coating was not used for the heat transfer tests. A significant difference between 3.18 mm (1/8 in.) tubes and 4.76 mm (3/16 in.) tubes was indicated. Temperature correction equations were developed from the test results for both 3.18 and 4.76 mm (1/8 and 3/16 in.) dia tubes using the data for uncoated thermocouples and a least squares curve fit routine. The test data and the calculated correction equation are shown in Figures 7 and 8.

Additional instrumentation included current shunts for the test section and preheater power supplies, voltage taps on the test section positive and negative busses and at the center of test section, strain gauge pressure transducers connected to the test section inlet and outlet pressure taps and to each mixing section.

Propellant mixing sections were positioned upstream and downstream of the test section, and upstream of the flowmeters. One platinum resistance temperature transducer (RTT), and two immersion-type 1.6 mm (1/16 in.) OD copper constantan thermocouples were installed in each mixer. The test section inlet and outlet mixers also contained high frequency piezoelectric pressure transducers.

The instrumentation system used for this investigation is calibrated traceable to the National Bureau of Standards. The expected measurement accuracy is as follows:

Strain Gauge Pressure Transducer	± .06 MPa (10 psi)
Piezoelectric Pressure Transducer	± .34 MPa (50 psi)
Flowmeter	± .005 Kg/sec (.01 lbm/sec)
Current	± 10 A
Voltage	± .2 V
Resistance Temperature Transducer	± .28 K (.5 R)
Copper-Constantan Thermocouple (Bulk Temp.)	± 1.1 K (2 R)
Chromel-Alumel Thermocouple (Wall Temp.)	± 2.8 (5 R)

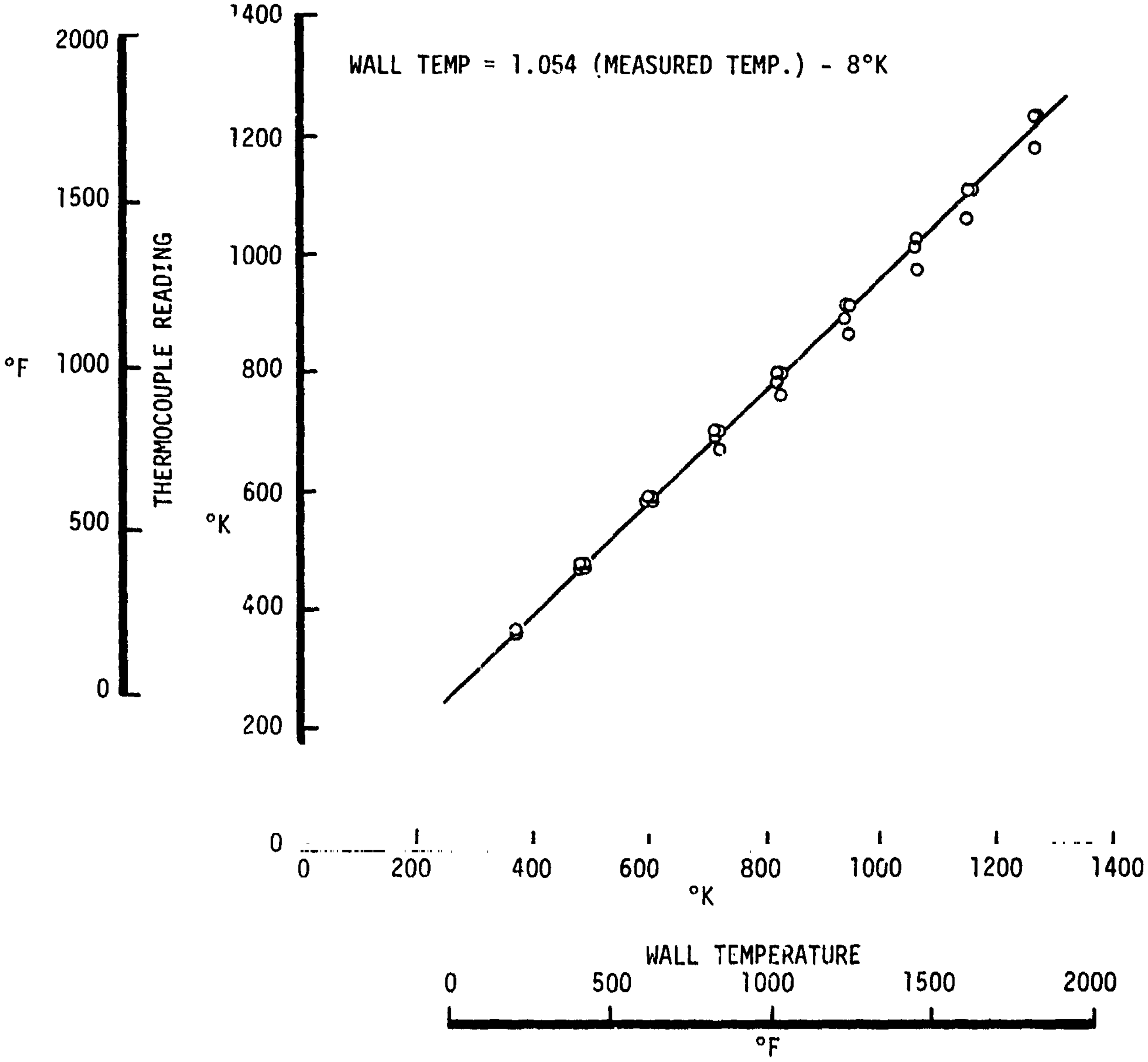


Figure 7. Wall Temperature Calibration for 3.18 mm (1/8 in.) OD Tubes

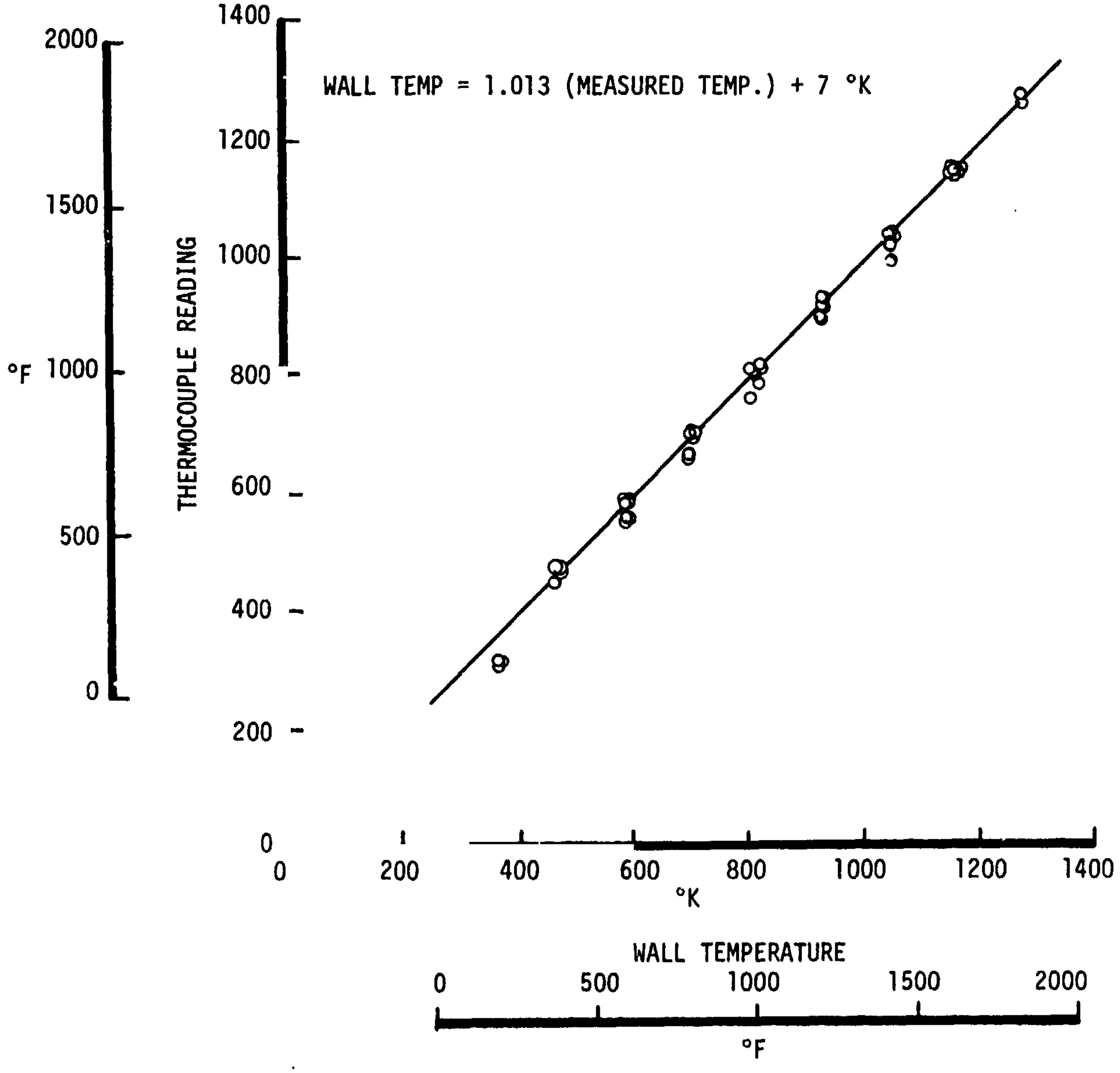


Figure 8. Wall Temperature Calibration for 4.76 mm (3/16 in.) OD Tubes

IV. TEST PROCEDURE

The following basic test procedure was used to conduct the heat transfer tests:

a. Final instrumentation calibrations were obtained.

b. The jacketed run tank was filled with liquid oxygen.

c. The flow of liquid nitrogen through the cooling jacket of the LO_2 run line was initiated and left on throughout the test.

d. The flow control valve was closed and the run valve and tank safety valve opened.

e. The entire system was then pressurized to the desired pressure and data recorded on magnetic tape.

f. The flow control valve position was adjusted until the desired inlet pressure and flow rate were obtained, and a second data point recorded.

g. For the high inlet temperature tests the preheater was adjusted to provide the desired inlet temperature and data were recorded.

h. The initial test heat flux level was achieved by applying a predetermined DC voltage across the test section tube.

i. When the test section had achieved thermal steady state, all pertinent data were recorded on magnetic tape. Test section wall temperatures were viewed on visual gauges to insure thermally steady conditions.

j. The next predetermined voltage was then applied to the test section and steady state data were again recorded. Tank pressure and the flow control valve were adjusted prior to each data point to maintain desired inlet pressure and flow rate.

k. Step j was repeated until the oxygen supply was depleted or until test section failure occurred.

V. DATA REDUCTION AND ANALYSIS

All data were recorded on magnetic tape and processed after completion of each test run. The data processing was done in several steps. The first step was to adjust the measured data based on calibration information. The second step was to calculate the inner wall temperature using a SINDA heat transfer program (Ref. 5), and to calculate fluid property parameters. The final step was to generate a heat transfer correlation using a multiple regression technique.

In the first step the true wall temperatures were calculated using the equations described in Section III.C. of this report; the mass flow measurements were corrected for changes in fluid density based on measured temperature and pressure at the inlet to the flowmeters, and the pressures were corrected for inlet and outlet length. As shown in Table I the inlet and outlet pressure taps are located some distance from the actual heated portion of the tube. To account for this and also any differences in the inlet and outlet pressure transducers the pressure readings were adjusted as follows: as described in Section IV data were recorded with full pressure on the test section and no flow (nf). These data were used to adjust the outlet pressure reading equal to the inlet pressure reading. Data were also recorded with full flow and no heat (nh). These data were used to determine the pressure drop in the tube. The true inlet and outlet pressure are then calculated as follows:

$$\Delta P_{nh} = \left[(P_{in})_{nh} - (P_{out})_{nh} \frac{P_{in\ nf}}{P_{out\ nf}} \right] \frac{56\ \text{mm}}{L + 112\ \text{mm}} \qquad (1)$$

$$\text{True } P_{in} = P_{in} - \Delta P_{nh} \left(\frac{\dot{m}^2/\rho_{in}}{\dot{m}^2_{nh}/\rho_{in\ nh}} \right) \qquad (2)$$

$$\text{True } P_{out} = P_{out} \left(\frac{P_{in\ nf}}{P_{out\ nf}} \right) + \Delta P_{nh} \left(\frac{\dot{m}^2/\rho_{out}}{\dot{m}^2_{nh}/\rho_{in\ nh}} \right) \qquad (3)$$

The second step in data reduction is to calculate the inner wall temperature and fluid properties. The inner wall temperatures were calculated using the SINDA computer program. This computer program assumed the tube wall was divided into ten radial nodes. Using an iterative technique the inside wall temperature was determined from the electrical heat input, outside wall temperature, and the thermal conductivity of the tube wall as a function of temperature.

After the inner wall temperatures were determined, the fluid property ratios and dimensionless parameters used in data correlation were calculated and punched on computer cards. A sample printout is shown in Table II. Oxygen properties used came from NBS subroutines for temperatures up to 333 K (600 R). Above 333 K density and specific heat were obtained from Russian Data (Ref. 6), and conductivity and viscosity were interpolated from an Aerojet Publication on Cryogenic Properties by P. J. Petrozzi and P. H. Davidson. A tabulation of these properties is given in Appendix A.

The final step in data analysis was the actual data correlation. This was accomplished with a multiple linear regression computer program which, using the method of least squares, calculated the coefficients to an equation of the following form:

$$\ln Y = \ln A + B \ln X_1 + C \ln X_2 + D \ln X_3 + \ldots \qquad (4)$$

Where Y is the dependent variable and X_1, X_2, X_3, etc. are the independent variables. A, B, C, D, etc. are calculated by the regression program.

TABLE II

1 of 3

SINDA OUTPUT

```
*******************************************************************************
                       DATA REDUCTION COMPUTER PROGRAM
                                     FOR
                      ELECTRICALLY HEATED TUBE TEST DATA
*******************************************************************************
        OVERALL PARAMETERS
*******************************************************************************
        TUBE MATERIAL IS K500 MONEL
 TUBE INSIDE DIAMETER=      .15750    INCHES              .40005-02 METERS
 TUBE OUTSIDE DIAMETER=     .18750    INCHES              .47625-02 METERS
 NUMBER OF TEST SECTIONS=        5                                5
 NUMBER OF DATA POINTS=          2                                2



*******************************************************************************
        DATA POINT   1        118-004
*******************************************************************************


 COOLANT FLOW RATE=          .67700    LB/SEC              .30708     KG/SEC
 COOLANT MASS FLUX=          34.75     LB/SQ IN-SEC        24431      KG/SQ M-SEC
 INLET MIXER PRESSURE=       3353.0    PSIA                .23118+08  PASCALS
 INLET PRESSURE=             3078.0    PSIA                .21222+08  PASCALS
 OUTLET PRESSURE=            3023.0    PSIA                .20843+08  PASCALS
 OUTLET MIXER PRESSURE=      3008.0    PSIA                .20739+08  PASCALS
 INLET TEMPERATURE=         -186.90    F                  -121.61     C
 OUTLET TEMPERATURE=        -102.20    F                  -74.556     C
 INLET VELOCITY=             89.597    FT/SEC              27.309     M/SEC
 OUTLET VELOCITY=            133.21    FT/SEC              40.603     M/SEC

 CURRENT=                    986.00    AMPS                986.00     AMPS
 VOLTAGE DROP=               28.930    VOLTS               28.930     VOLTS
 HEATED LENGTH=              10.000    INCHES              .25400     METERS

 ENERGY BALANCE=             .19538-01                     .19538-01



*******************************************************************************
        DATA POINT   2       118-005
*******************************************************************************


 COOLANT FLOW RATE=          .63500    LB/SEC              .28803     KG/SEC
 COOLANT MASS FLUX=          32.59     LB/SQ IN-SEC        22915      KG/SQ M-SEC
 INLET MIXER PRESSURE=       3386.0    PSIA                .23346+08  PASCALS
 INLET PRESSURE=             3131.0    PSIA                .21587+08  PASCALS
 OUTLET PRESSURE=            3085.0    PSIA                .21270+08  PASCALS
 OUTLET MIXER PRESSURE=      3052.0    PSIA                .21043+08  PASCALS
 INLET TEMPERATURE=         -169.10    F                  -111.72     C
 OUTLET TEMPERATURE=        -63.500    F                  -53.056     C
 INLET VELOCITY=             89.339    FT/SEC              27.231     M/SEC
 OUTLET VELOCITY=            152.61    FT/SEC              46.516     M/SEC

 CURRENT=                    1056.0    AMPS                1056.0     AMPS
 VOLTAGE DROP=               31.950    VOLTS               31.950     VOLTS
 HEATED LENGTH=              10.000    INCHES              .25400     METERS

 ENERGY BALANCE=             .24180-01                     .24180-01
```

TABLE II (cont.)

TEST SECTION - LOCAL TEST PARAMETERS

DATA POINT 1 118-004

ST	AXIAL POS (INCHES)	TWO(TEST) (F)	INNER TMP (F)	Q/A(TEST) (B/SI-SEC)	Q/A(CALC) (B/SI-SEC)	HT COEFF (B/SI-SEC-F)
1	.321+01	.302+03	.152+03	.547+01	.547+01	.176-01
2	.470+01	.341+03	.196+03	.547+01	.547+01	.160-01
3	.633+01	.392+03	.252+03	.547+01	.547+01	.142-01
4	.794+01	.404+03	.265+03	.547+01	.547+01	.142-01
5	.946+01	.412+03	.274+03	.547+01	.547+01	.144-01

ST	AXIAL POS (METERS)	TWO(TEST) (C)	INNER TMP (C)	Q/A(TEST) (W/SQ M)	Q/A(CALC) (W/SQ M)	HT COEFF (W/SQ M-C)
1	.815-01	.150+03	.667+02	.894+07	.894+07	.516+05
2	.119+00	.172+03	.909+02	.894+07	.894+07	.470+05
3	.161+00	.200+03	.122+03	.894+07	.894+07	.418+05
4	.202+00	.207+03	.129+03	.894+07	.894+07	.418+05
5	.240+00	.211+03	.134+03	.894+07	.894+07	.423+05

ST	VELOCITY (FPS)	PRESSURE (PSIA)	BULK TMP (F)	L/ID	VOLT DROP (VOLTS)	LENGTH OF SECT (INCHES)
1	.993+02	.306+04	-.160+03	.251+02	.114+02	.395+01
2	.105+03	.305+04	-.147+03	.350+02	.451+01	.156+01
3	.112+03	.304+04	-.133+03	.453+02	.469+01	.162+01
4	.121+03	.303+04	-.120+03	.552+02	.453+01	.157+01
5	.130+03	.303+04	-.107+03	.635+02	.376+01	.130+01

ST	VELOCITY (M/S)	PRESSURE (PASCAL)	BULK TMP (C)	L/ID	VOLT DROP (VOLTS)	LENGTH OF SECT (METERS)
1	.303+02	.211+08	-.107+03	.251+02	.114+02	.100+00
2	.320+02	.210+08	-.995+02	.350+02	.451+01	.396-01
3	.342+02	.210+08	-.918+02	.453+02	.469+01	.411-01
4	.368+02	.209+08	-.842+02	.552+02	.453+01	.398-01
5	.395+02	.209+08	-.771+02	.635+02	.376+01	.330-01

ST	NUSSELT (BULK)	PRANDTL (BULK)	NU/PR**.4 (BULK)	REYNOLDS (BULK)	TI/TB
1	.251+04	.162+01	.208+04	.138+07	.204+01
2	.246+04	.166+01	.201+04	.149+07	.210+01
3	.236+04	.168+01	.192+04	.162+07	.218+01
4	.253+04	.167+01	.206+04	.177+07	.213+01
5	.271+04	.164+01	.223+04	.191+07	.208+01

ST	NUSSELT (FILM)	PRANDTL (FILM)	NU/PR**.4 (FILM)	REYNOLDS (FILM)	RE(G)
1	.446+04	.116+01	.421+04	.124+07	.269+07
2	.420+04	.108+01	.408+04	.122+07	.278+07
3	.384+04	.999+00	.384+04	.120+07	.285+07
4	.386+04	.972+00	.391+04	.124+07	.287+07
5	.392+04	.949+00	.400+04	.130+07	.288+07

TABLE II (cont.)

ST	NUSSELT (WALL)	PRANDTL (WALL)	NU/PR**.4 (WALL)	REYNOLDS (WALL)	RE(G)
1	.479+04	.908+00	.498+04	.851+06	.286+07
2	.442+04	.915+00	.458+04	.816+06	.281+07
3	.387+04	.883+00	.406+04	.770+06	.278+07
4	.386+04	.877+00	.407+04	.805+06	.277+07
5	.389+04	.875+00	.411+04	.851+06	.277+07

ST	NUSSELT (AVG)	PRANDTL (AVG)	NU/PR**.4 (AVG)	REYNOLDS (AVG)	RE(G)
1	.401+04	.123+01	.369+04	.125+07	.236+07
2	.381+04	.118+01	.357+04	.126+07	.248+07
3	.352+04	.112+01	.337+04	.126+07	.258+07
4	.360+04	.109+01	.348+04	.131+07	.264+07
5	.370+04	.107+01	.360+04	.137+07	.268+07

CARD No.	ST	RHOB/RHOI	MUB/MUI	CONB/CONI	CPBAR/CPB
705	1	.337+01	.207+01	.191+01	.828+00
706	2	.345+01	.189+01	.179+01	.771+00
707	3	.360+01	.171+01	.164+01	.713+00
708	4	.344+01	.157+01	.153+01	.689+00
709	5	.325+01	.145+01	.144+01	.677+00

ST	RHOF/RHOI	MUF/MUI	CONF/CONI	CPBAR/CPF
1	.155+01	.106+01	.107+01	.873+00
2	.151+01	.101+01	.105+01	.893+00
3	.151+01	.973+00	.101+01	.920+00
4	.149+01	.965+00	.999+00	.935+00
5	.147+01	.960+00	.993+00	.951+00

VI. RESULTS AND DISCUSSION

A. TESTING

A total of 16 heat transfer tests were conducted resulting in over 450 individual measurements of heat transfer characteristics. A summary of test conditions is given in Table III.

Because one of the principal goals of this investigation was to obtain data at high pressures and heat fluxes, several of the test sections were heated to failure. One typical failure mode started with the development of a hot spot near the outlet end of the tube. The tube would yield at this point and the hot spot would migrate upstream and increase in intensity as the heat flux was increased. The hottest point on the tube appeared to be between the portion of the tube that had yielded and the portion that had not (the point where the diameter increased). When ultimate failure occurred the hot spot would be somewhere near the center of the test section. Figures 9 through 12 show the condition of the tubes after completion of the testing.

Wall temperature readings used in data correlation were obtained only from the portion of the test section that had not yielded. Although operating above the heat flux where yielding first occurred required eliminating some of the wall temperature readings, it allowed heat flux levels to be reached that would have been otherwise unobtainable.

Because the monel tubes yielded at high temperatures, an alternate material, Inconel 625, which retains more of its strength at elevated temperatures, was substituted on tests -109 through -113. The Inconel, however, has a lower thermal conductivity than monel and therefore had a higher outside wall temperature for a given heat flux. The higher wall temperatures caused the wall thermocouples to fail which prevented the high strength properties of the material from being utilized.

To insure rapid response, the wall thermocouples were fabricated from very small diameter wire. This small wire was very delicate and the manner in which the thermocouples were installed (see Figure 5) put a tensile load on it. The wire was not strong enough to withstand this load at temperatures above 1000 K (1800 R), and one or more of the thermocouples would commonly fail during a test run. To insure that only accurate data was used to develop a heat transfer correlation, the wall temperature readings were continuously recorded on an oscillograph. After each test run the oscillograph record was examined, and any thermocouple that was not reading properly at any heat flux level would not be used in developing a correlation.

In a similar investigation using supercritical hydrogen, Hendricks observed flow oscillations at certain operating conditions (see Ref. 7). To detect this phenomenon high frequency pressure trans-

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TABLE III

TEST SUMMARY

TABLE III

TEST SUMMARY

Test No.	Card No. No.	Card No. thru No.	Material	Tube OD mm	Wall mm	Length mm	Heat Flux W/mm² Min.	Heat Flux W/mm² Max.	Pressure MPa Min.	Pressure MPa Max.	Mass Flux Mg/m² sec	Bulk Temp. K Min.	Bulk Temp. K Max.	Wall Temp. K Min.	Wall Temp. K Max.	Energy Balance Min.	Energy Balance Max.	Comments
-101	--	--	Monel	3.18	0.38	150.9												Test aborted, Low flow
-102	213	242	Monel	3.18	0.38	150.9	16.2	45.5	21.6	25.4	80	108	164	154	637	0.03	0.10	Leak in enclosures; Tube burned out No high freq. data
-103	243	261	Monel	4.76	0.38	76.7	14.3	28.4	30.6	31.4	42	106	129	260	950	-0.02	0.01	Pressurization system not working properly; Tube burned out; No high frequency data
-104	--	--	Monel	4.76	0.38	76.8												Test aborted, line voltage spike tripped auto shutdown device.
-105	262	286	Monel	4.76	0.38	76.8	19.4	44.9	26.4	27.2	68	107	134	202	779	-0.12	-0.01	
-106	287	316	Monel	4.76	0.38	76.4	25.7	47.0	27.2	27.9	65	104	128	245	802	0.00	0.03	Only 2 thermocouples intact at end of test.
-107	317	356	Monel	3.18	0.38	76.6	6.0	22.9	20.4	25.3	103	106	130	132	209	-0.34	-0.08	Outlet temperature exceeded range of RTT.
-108	357	386	Monel	3.18	0.38	76.6	30.0	77.3	17.3	20.0	115	109	145	183	952	-0.06	0.17	Outlet temperature exceeded range of RTT.
-109	387	423	Monel	3.18	0.38	51.6	32.5	90.0	22.[illegible]	24.5	109	108	141	190	864	-0.19	0.04	Possible leak.
-110	424	453	Inconel	3.13	0.38	50.9	23.4	57.2	33.1	34.0	71	108	144	241	929	-0.03	0.02	Possible leak.
-111	454	465	Inconel	3.18	0.38	51.0	43.6	65.5	16.6	19.6	122	107	133	188	514	-0.05	0.01	Thermocouples failed; flow control valve wide open.
-112	466	550	Inconel	3.18	0.38	152.3	1.9	18.9	27.0	33.8	66	103	150	122	325	-0.79	-0.01	
-113	551	610	Inconel	3.18	0.38	152.3	19.0	40.6	31.1	33.3	67	118	191	258	927	-0.03	-0.01	Continuation of Test 112.
-114	611	614	Monel	4.76	0.38	51.9	32.0	32.0	21.7	22.2	82	110	119	271	328	-0.04	-0.04	
-115	615	634	Monel	4.76	0.38	77.3	25.4	42.8	25.0	28.1	66	96	113	245	507	0.05	0.11	Low temp. test, possilbe leak
-116	635	664	Monel	4.76	0.38	102.4	17.7	35.2	32.8	34.6	49	99	138	242	720	0.04	0.07	Low temp. test.
-117	565	704	Monel	4.76	0.38	89.3	8.8	20.4	31.0	34.6	30	144	173	239	898	-0.04	-0.01	High temp. test, high power supply ripple
-118	705	714	Monel	4.76	0.38	254.0	8.9	10.6	20.9	21.5	24	166	217	340	642	0.02	0.02	High temp. test, high power supply ripple.

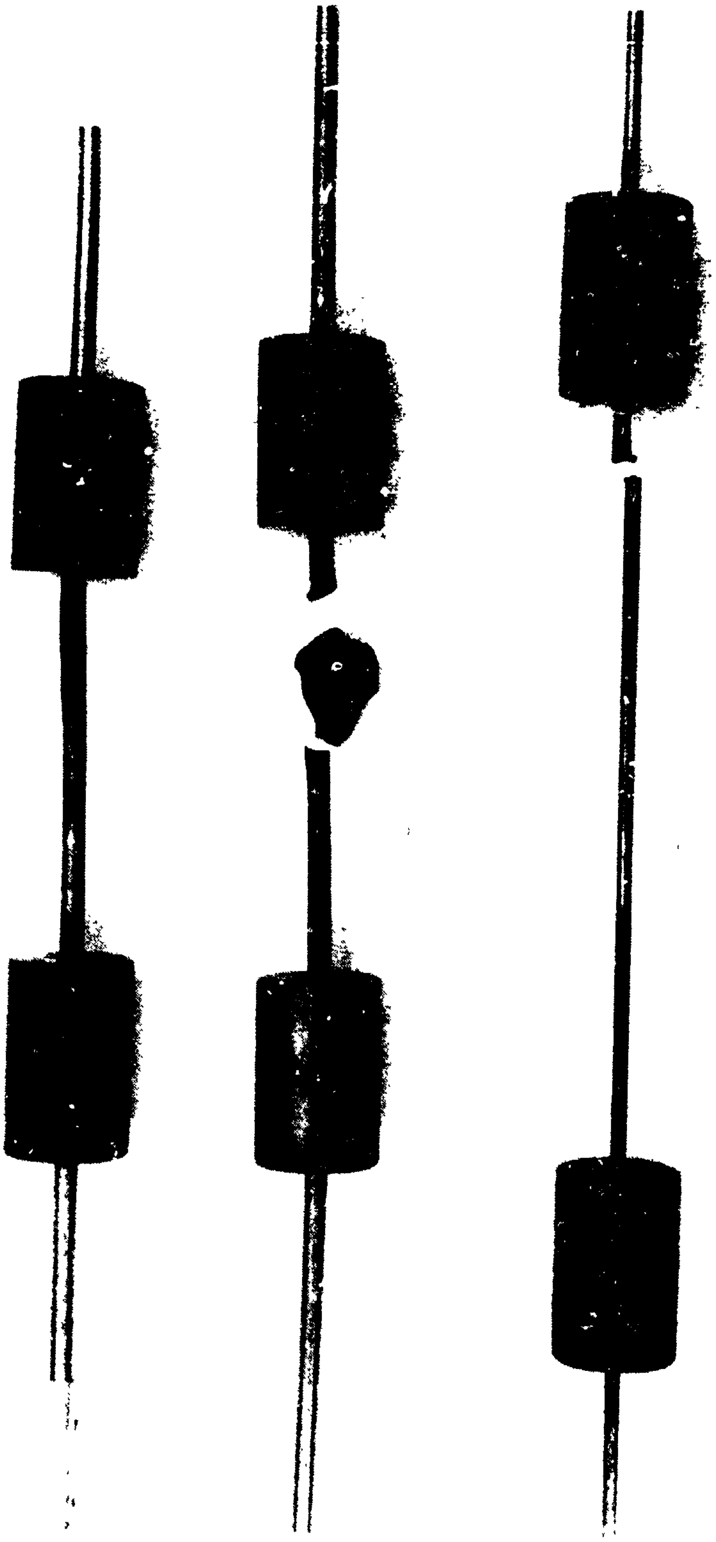

Figure 9. Test Section Tubes, Post Test

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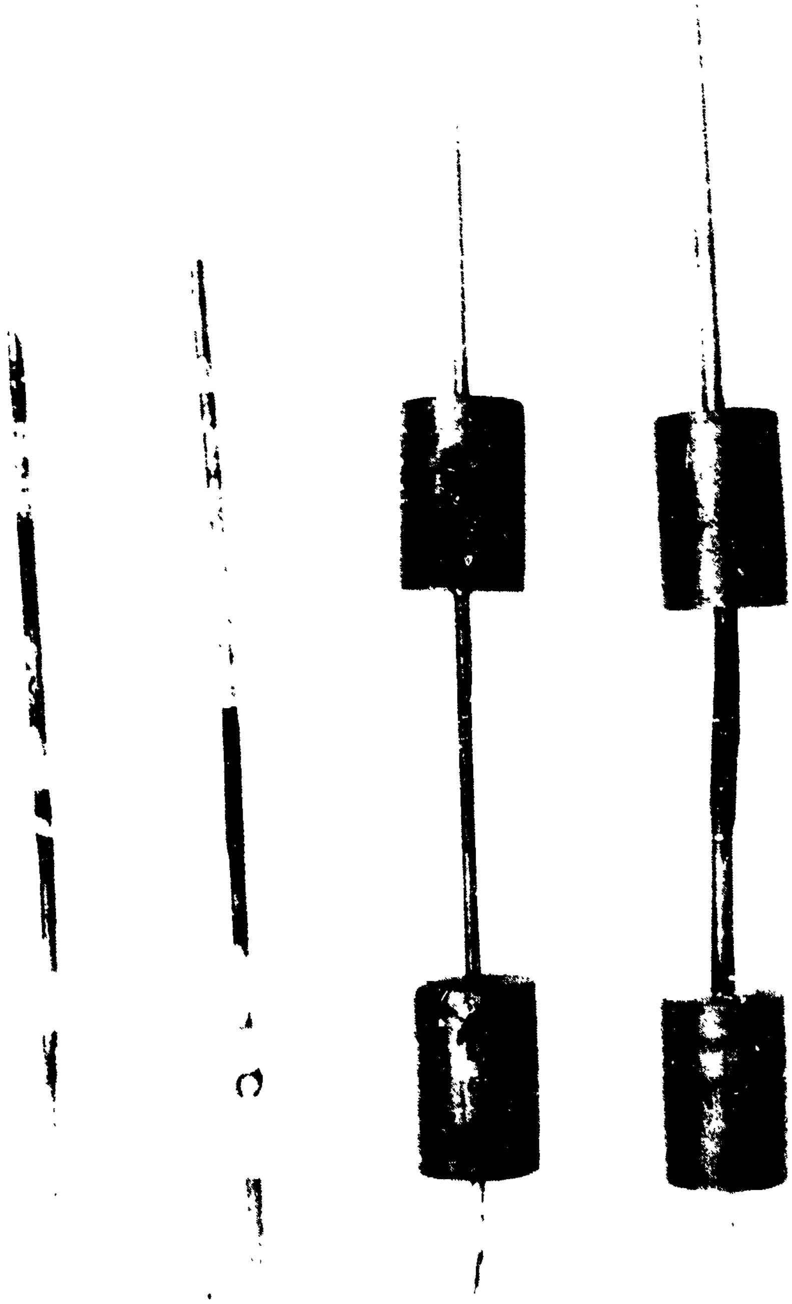

Figure 10. Test Section Tubes, Post Test

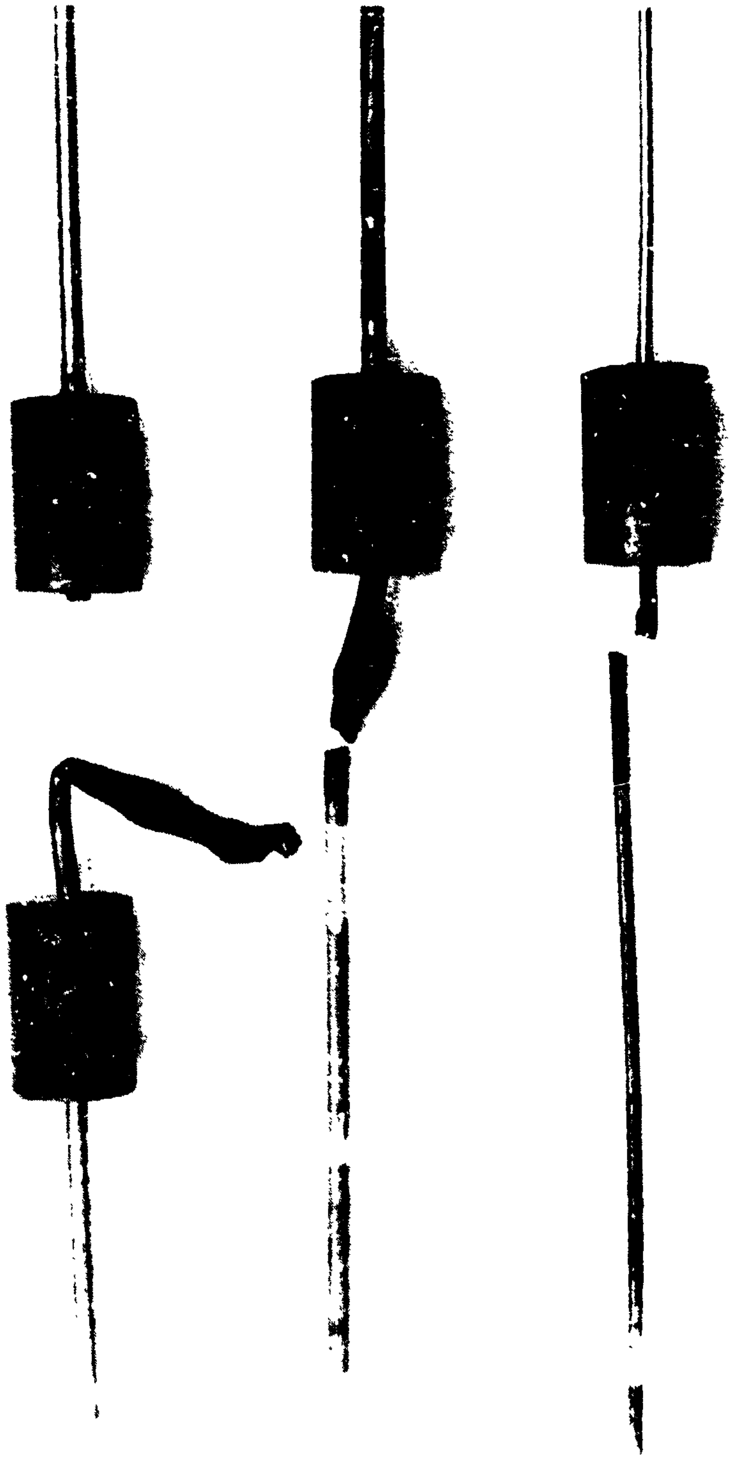

Figure 11. Test Section Tubes, Post Test

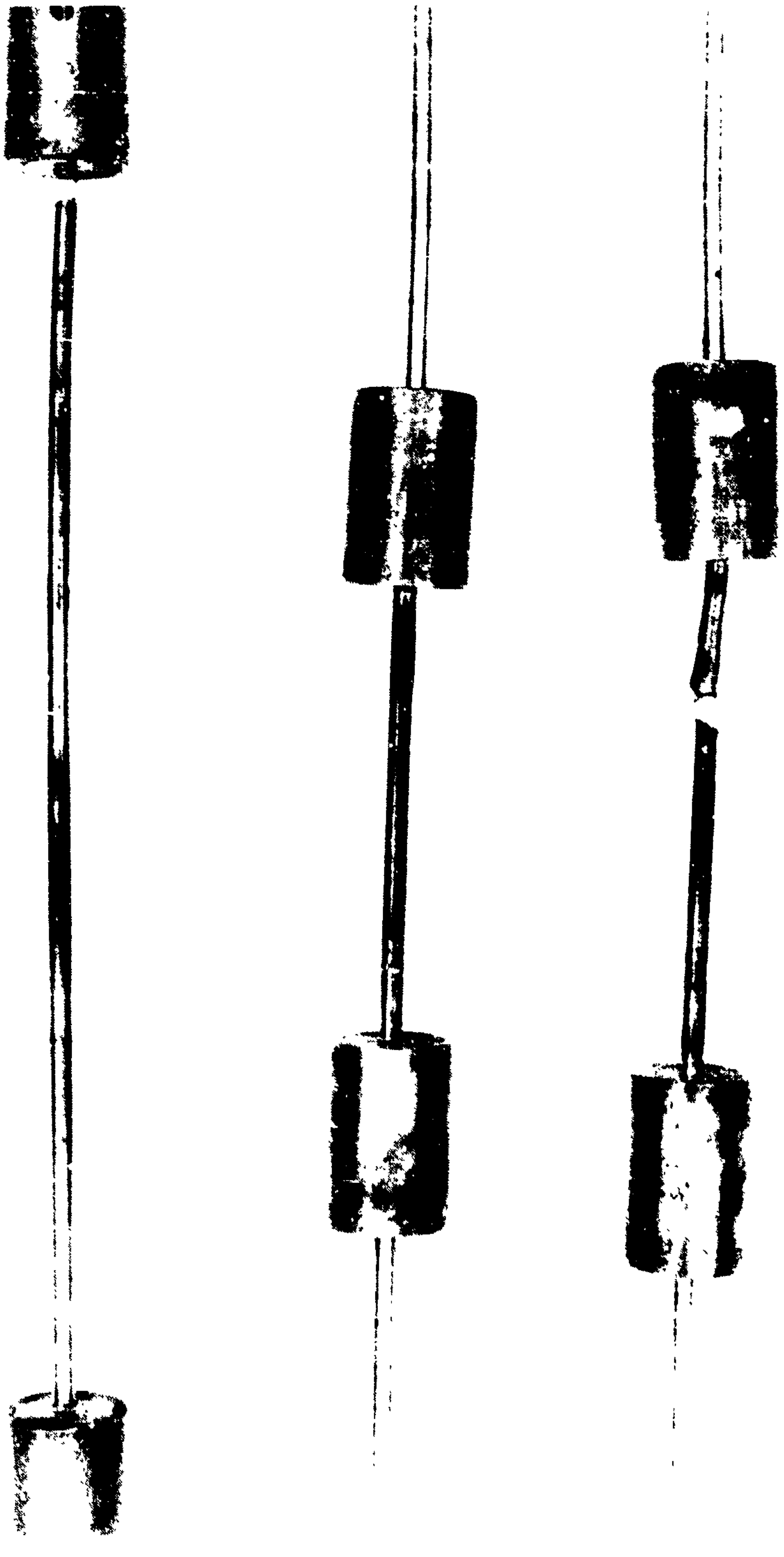

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Figure 12. Test Section Tubes, Post Test

ducers were installed in the inlet and outlet mixing sections. During this investigation no oscillations were observed except on the first test attempt when a fitting with a very small bore was inadvertently installed between the outlet of the test section and the outlet mixer. This resulted in choked flow and pressure fluctuations of 3.3 MPa (480 psi) peak to peak were observed at the outlet mixer. After the fitting was bored out to match the inside diameter of the heated tube, no flow oscillations were ever observed in any of the oxygen heat transfer tests.

Figure 13 shows the range of pressure and heat flux for this investigation. The maximum pressure was limited to 34.5 MPa (5000 psia) by facility tankage pressure ratings. The maximum heat flux obtained was 90 x 10^{-6} w/m^2 (55 Btu/in.^{2}-sec).

B. DATA CORRELATION

To develop a heat transfer correlation an equation of the following form was assumed:

$$Nu = Nu_{ref} \left(\frac{\mu}{\mu_w}\right)^c \left(\frac{k}{k_w}\right)^d \left(\frac{\rho}{\rho_w}\right)^e \left(\frac{\bar{C}_p}{C_p}\right)^f \qquad (5)$$

where:

$$Nu_{ref} = K\ Re_b^{\ a}\ Pr_b^{\ b'},\ \text{or},\ = K\ Re_f^{\ a}\ Pr_f^{\ b'} \qquad (6)$$

Using the multiple regression computer program described in Section V, 26 different correlations were developed before reaching the recommended one. The intermediate correlations are listed in Table IV, and the logic of moving from one to the next is shown schematically in Figure 14.

Initially, correlations were generated for both bulk and film properties and for Reynold's Number exponents of 0.80 and 0.95 (the Prandtl number exponent was fixed at 0.4 in all cases). Using a Reynold's Number exponent of .8 results in a heat transfer equation which approaches the classical Dittus-Boltier correlation as the bulk temperature approaches the wall temperature. An exponent of .95 will result in an equation which approaches the correlation developed by Hines (Ref. 8). Of the above correlations the bulk property correlation with a Reynold's Number exponent of .95 best grouped the data (Case 1). The factors $(P/P_{cr})^g$ and $(1 + \frac{2}{\ell/d})$ were then added to Equation (5) and the grouping of the data was further improved (Case 7). In Case 7, it was discovered that the factors $(\mu_b/\mu_w)^c$ and $(\bar{C}p/Cp_b)^f$ had weak partial correlation coefficients. These factors were

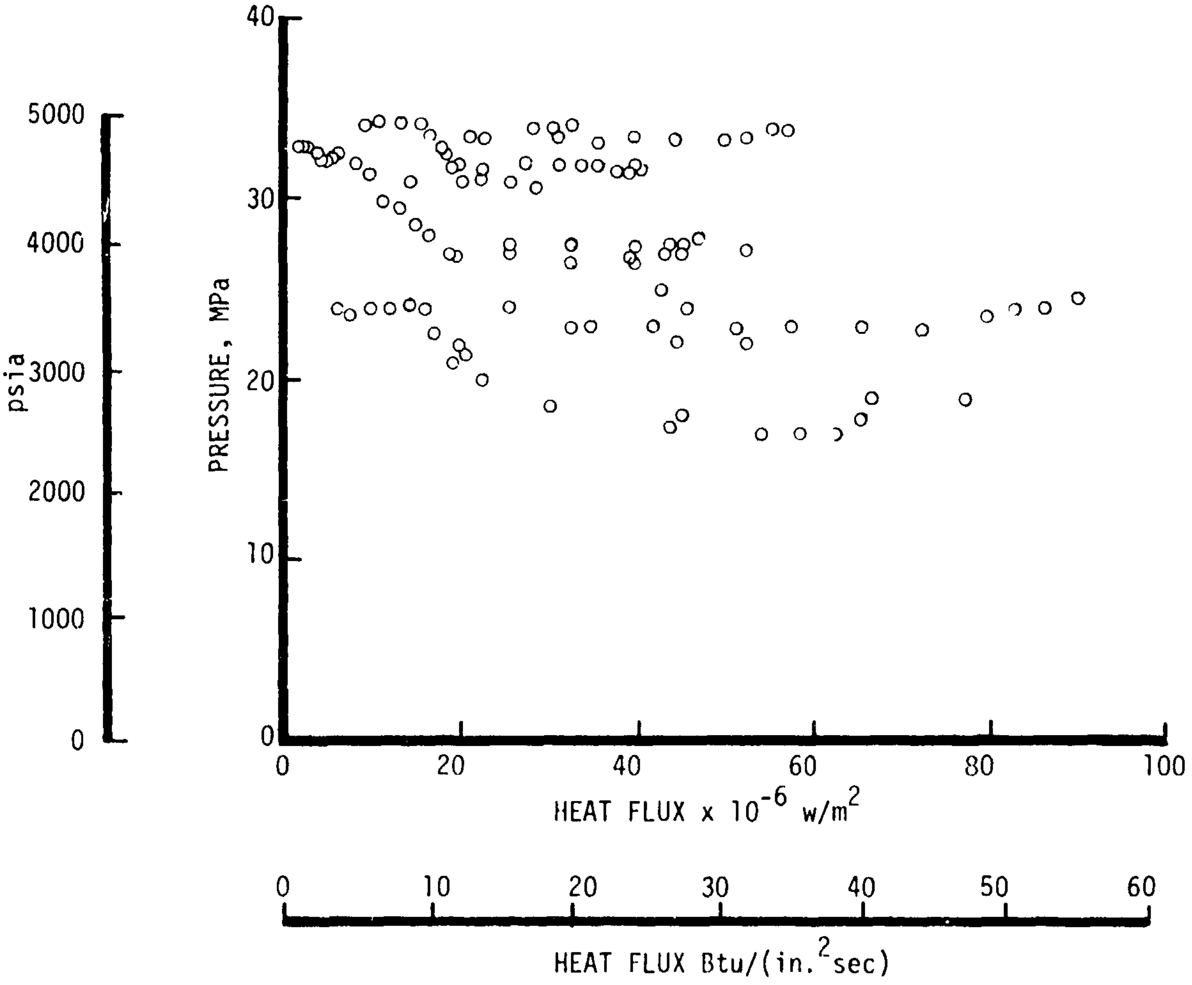

Figure 13. Range of Pressure and Heat Flux Tested

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TABLE IV

HEAT TRANSFER CORRELATIONS

$$Nu = K\,Re^{a}\,Pr^{b'}\left(\frac{\mu}{\mu_w}\right)^{c}\left(\frac{\rho}{\rho_w}\right)^{d}\left(\frac{k}{k_w}\right)^{e}\left(\frac{\overline{Cp}}{Cp}\right)^{f}\left(\frac{P}{P_{cr}}\right)^{g}\left(1+\frac{2}{\ell/d}\right)^{h}$$

Case	Data Base	Properties	K	a	b'	c	d	e	f	g	h	Std.Dev.	Range of Residules	% of Data Within ± 30%	Comments
0	Powell's + IR&D	Bulk	.02528	95	.4	-.568	1.216	-.746	.514	-1.060	0			85	Correlation Developed by Rousar & Miller
1	Contract	Bulk	.00338	.95	4	-.312	224	.245	1.271	0	0	.167	0.99	92.4	Modified Hines Correlation
2	Contract	Bulk	00286	.90	.4	-.178	.045	.320	[illegible]	0	0	.185	1.06	90.4	Modified Dittus-Boelter Correlation
3	Contract	Bulk	.00348	95	.4	-.309	-.022	.388	1.354	0	1	.151	0.99	94.1	#1 With /d Term Added
4	Contract	Bulk	.00295	.80	.4	-.175	-.201	.464	1.815	0	1	.170	1.04	91.3	#2 With /d Term Added
5	Contract	Bulk	.00894	.95	.4	-.609	.386	.365	-.024	-.533	0	.137	.83	96.8	#1 With Pressure Term Added
6	Contract	Bulk	09582	80	.4	-.546	246	.470	1.268	-.722	0	.142	.88	96.4	#2 With Pressure Term Added
7	Contract	Bulk	.00885	.95	.4	-.594	133	504	.109	-.560	1	.120	.94	97.2	#1 With Pressure and /d Terms
8	Contract	Bulk	.09499	80	4	-.531	-.007	.609	.260	-.700	1	.125	.89	97.5	#2 With Pressure and /d Terms
9	All	Bulk	.00513	.95	.4	-.515	-.142	.693	.639	-.203	1	.167	1.11	93.4	#7 With All Data
10	All	Bulk	04358	.80	.4	-.494	-.456	1.040	.756	-.183	1	.207	1.21	88.0	#8 With All Data
11	Contract	Film	.00334	95	4	-.348	-1.252	2.430	.171	0	0	.239	1.00	92.4	#1 Using Film Properties
12	Contract	Film	.02815	.80	.4	-.001	-1.546	2.670	2.687	0	0	.194	1.04	89.2	#2 Using Film Properties
13	All	Bulk	.00509	.95	.4	-.511	0	.542	.617	-.209	1	.167	1.13	93.0	#9 Without Viscosity Term
14	All	Bulk	.00404	.95	.4	-.414	-2.940	.660	.874	0	1	.187	1.33	91.4	#9 Without Pressure Term
15	All	Bulk	.00550	95	.4	-.502	.180	.406	.647	-.238	0	.183	1.17	91.8	#9 Without ℓ/d Term
16	All	Bulk	00568	.95	.4	-.661	003	.659	0	-.266	1	.184	1.80	92.0	#9 Without Specific Heat Term
17	Contract	Bulk	.00902	.95	.4	-.619	1.355	.531	0	-.572	1	.120	0.93	97.5	#16 With Contract Data Only
18	Contract	Bulk	.00887	.95	4	-.601	0	.660	.128	-.547	1	.121	.94	97.5	#13 With Contract Data Only
19	Powell's	Bulk	.00542	.95	.4	-.586	1.203	-.736	.521	.010	0	.185	.82	90.1	Correlation with Powell's Data Only
20	All	Bulk	.00568	95	.4	-.561	0	.673	0	-.265	1	.184	1.80	92.3	#9 Without Viscosity & Specific Heat Terms
21	Contract	Bulk	00905	.95	.4	-.633	0	.694	0	-.561	1	121	.94	97.5	#20 With Contract Data Only
22	All	Bulk	.00482	.95	.4	-.476	0	.529	.662	-.205	1	.145	1.11	95.8	#13 With IR&D Tests -104 & -105 Removed
23	All	Bulk	.00905	95	4	-.640	0	.671	0	-.267	1	.168	1.81	93.9	#20 With IR&D Tests -104 & -105 Removed
24	All	Bulk	.00159	1.03	.4	-.493	0	.531	.623	-.208	1	.138	1.07	96.6	#22 With Reynolds Number Exponent Floating
25	Powell's	Bulk	.00567	.93	.4	-.431	0	.426	.699	-.183	1	.152	.88	97.5	#24 With Powell's Data Only
26	All	Bulk	.00243	1	.4	-.486	0	.530	.638	-.207	1	.139	1.08	96.1	#22 With Reynolds Number Exponent ≡ 1
26A	All	Bulk	.0025	1	.4	-1/2	0	1/2	2/3	-1/5	1			96	Recommended Correlation

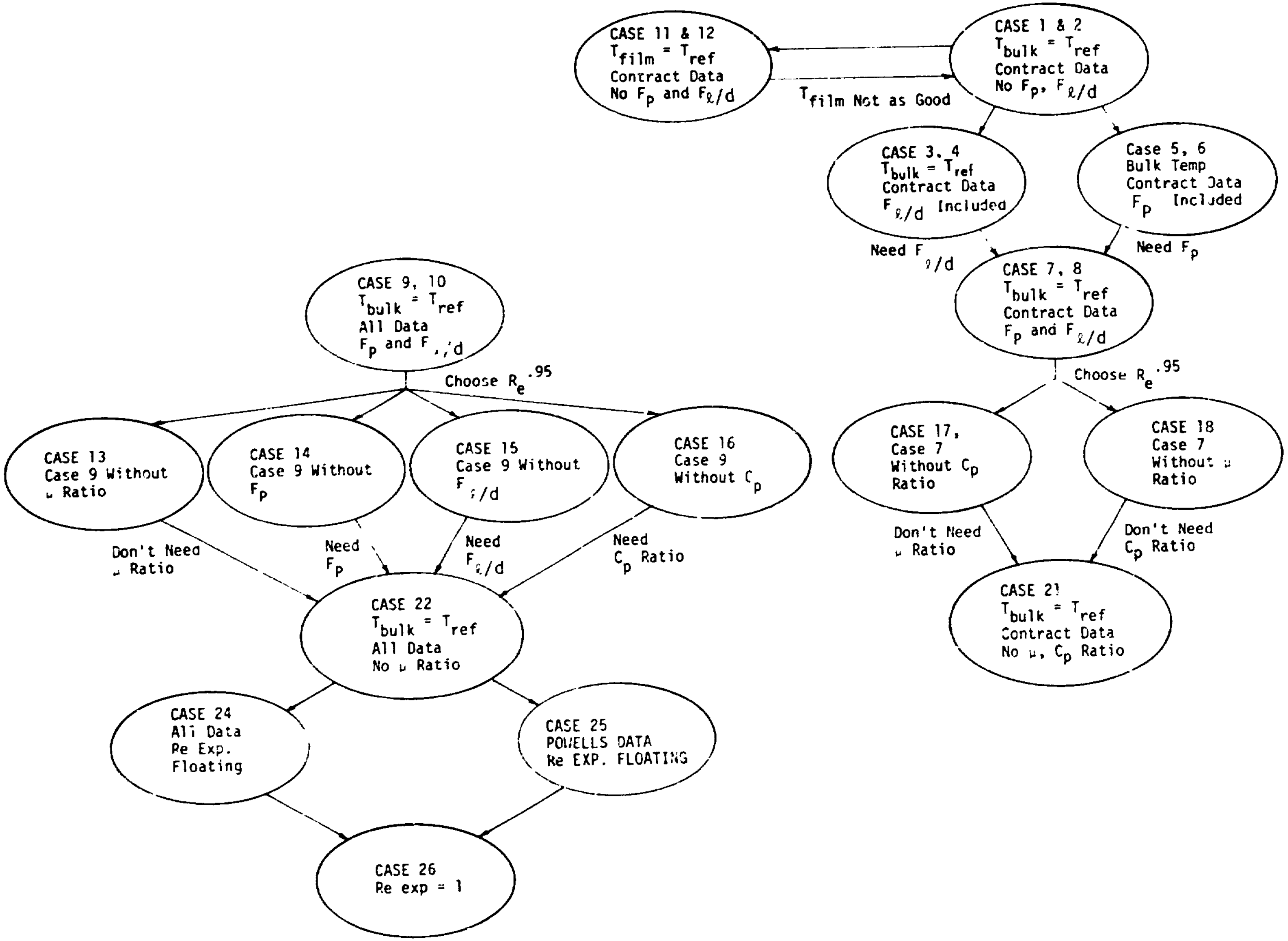


Figure 14. Correlation Development Logic

removed from the equation and the equation shown in Figure 15 was generated (Case 21). With this equation 97.5% of the data obtained during this investigation fell within ± 30% of the prediction. This is considerably better than the previous correlation which grouped only 85% of the previous data within this range (Ref. 4). Figure 16 shows the data from this investigation plotted against the previous correlation.

The data base was then expanded by adding Powell's low pressure data (Ref. 3) and some of the previous Aerojet data (Ref. 4). In the previous Aerojet IR&D investigation, the pressure measurements were not corrected for inlet and outlet length. This resulted in significant errors on two of the tests, where the fluid velocity was high. These two tests (HT-14-104 and HT-14-105) were, therefore, excluded from the data used to develop the heat transfer correlation. The correlation obtain (Figure 17) grouped over 95% of the data points within ± 30% of the predicted value. It was found that the $(\bar{C}p/Cp_b)^f$ term was statistically significant when the low pressure data were included, consequently this term was included for correlating the high and low pressure data together. The $(\mu_b/\mu_w)^c$ term was again found to have a low correlation coefficient and, as a result, was not included. At this time, the Reynold's Number exponent was also investigated. Using Powell's data only, the best fit was obtained with a Reynold's number exponent of 0.93 (Case 25); using all the data the best fit occurred with a Reynold's number exponent of 1.03 (Case 24). Other investigations with a variety of fluids have indicated that a Reynold's Number coefficient near unity might provide a more accurate heat transfer correlation than the value of .8 which is normally used (see Ref. 8 through 10). A Reynold's Number exponent of unity was chosen for the final correlation because it provided a good fit to the data, and also because it simplified the correlation equation. The recommended correlation (Case 26 with rounded exponents) is:

$$Nu = .0025\ Re_b\ Pr_b^{.4} \left(\frac{\rho_b}{\rho_w}\right)^{-1/2} \left(\frac{k_b}{k_w}\right)^{1/2} \left(\frac{\bar{C}p}{Cp_b}\right)^{2/3} \left(\frac{P}{P_{cr}}\right)^{-1/5} \left(1 + \frac{2}{\ell/d}\right) \quad (7)$$

The test data is plotted against this correlation in Figure 18. Although this correlation has been simplified by expressing the exponents as simple fractions, it still predicts over 95% of the test data within ± 30%. Table V lists the range of variables used to develop Equation 7.

The heat transfer trends predicted by the recommended correlation are shown graphically in Figure 19. As can be seen from this figure, for a fixed wall temperature, near the critical temperature and the critical pressure the heat transfer coefficient is a local minimum but at higher pressures the coefficient is a local maximum. Powell's data indicates this general trend although there is considerable data scatter near the critical temperature (Figures 20 and 21). This may indicate that near the critical point the heat transfer coefficient is changing rapidly and is difficult to accurately measure. At higher pressures (Figures 22 through 25) the data is more tightly grouped.

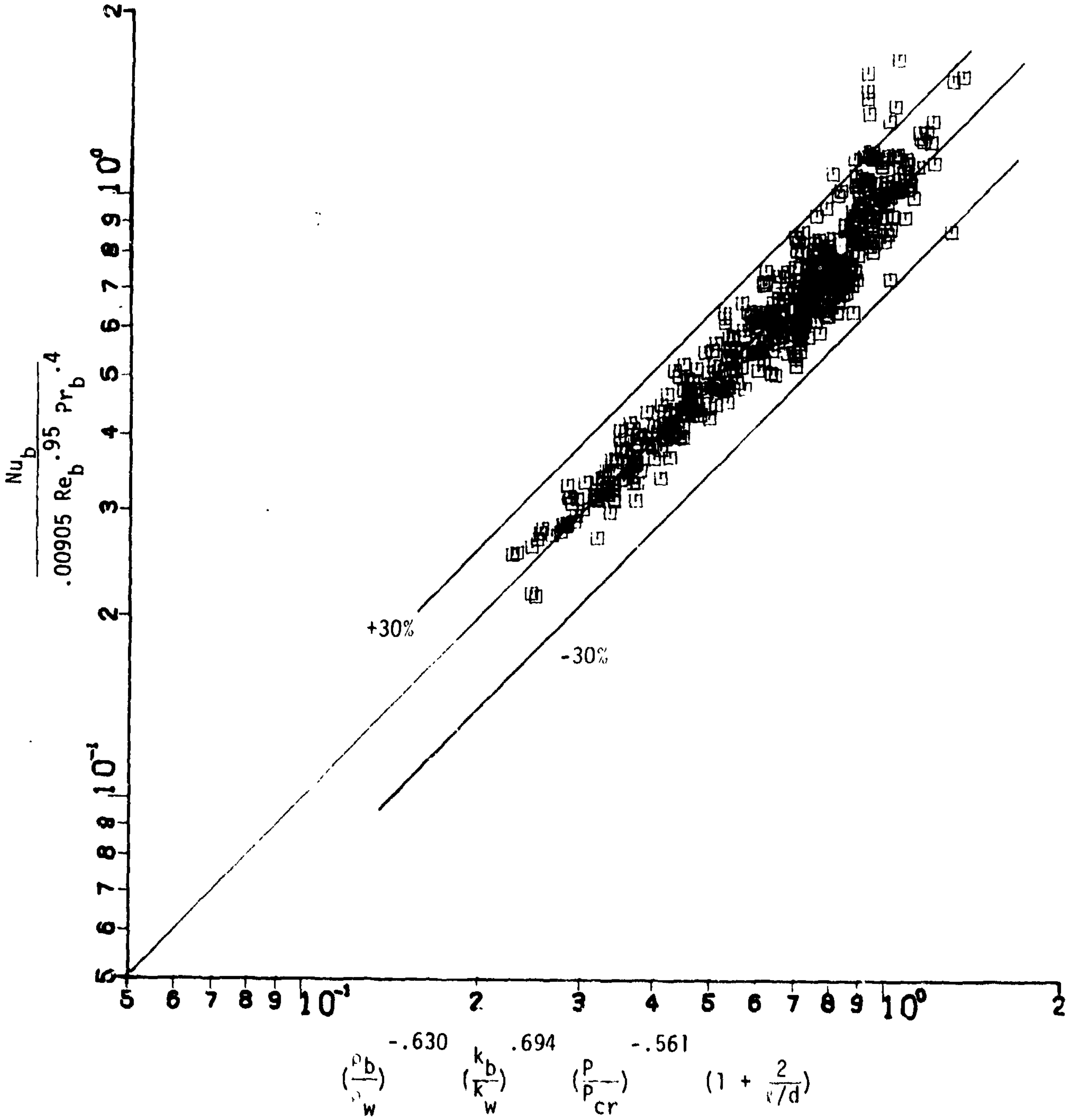
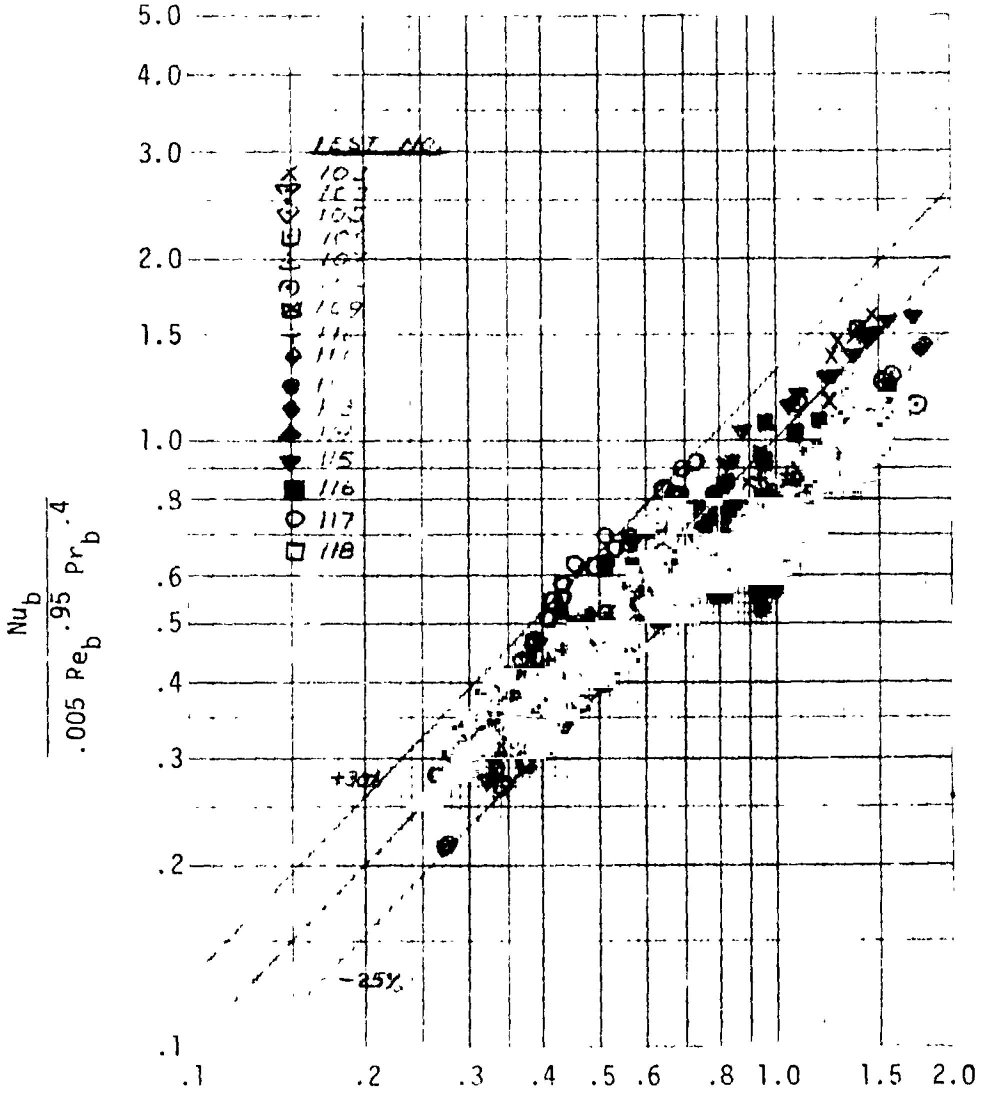


Figure 15. Modified Hines Correlation (Case 21)



$$1.085 \left(\frac{\mu_b}{\mu_w}\right)^{1.216} \left(\frac{k_b}{k_w}\right)^{-.746} \left(\frac{\rho_b}{\rho_w}\right)^{-.588} \left(\frac{\bar{C}_p}{C_{p_b}}\right)^{.514} \left[4.66\left(\frac{P_b}{P_{cr}}\right)^{-1.06}\right] \quad P_b > 3120 \text{ psia}$$

Figure 16. Test Results Compared to Previous Heat Transfer Correlation

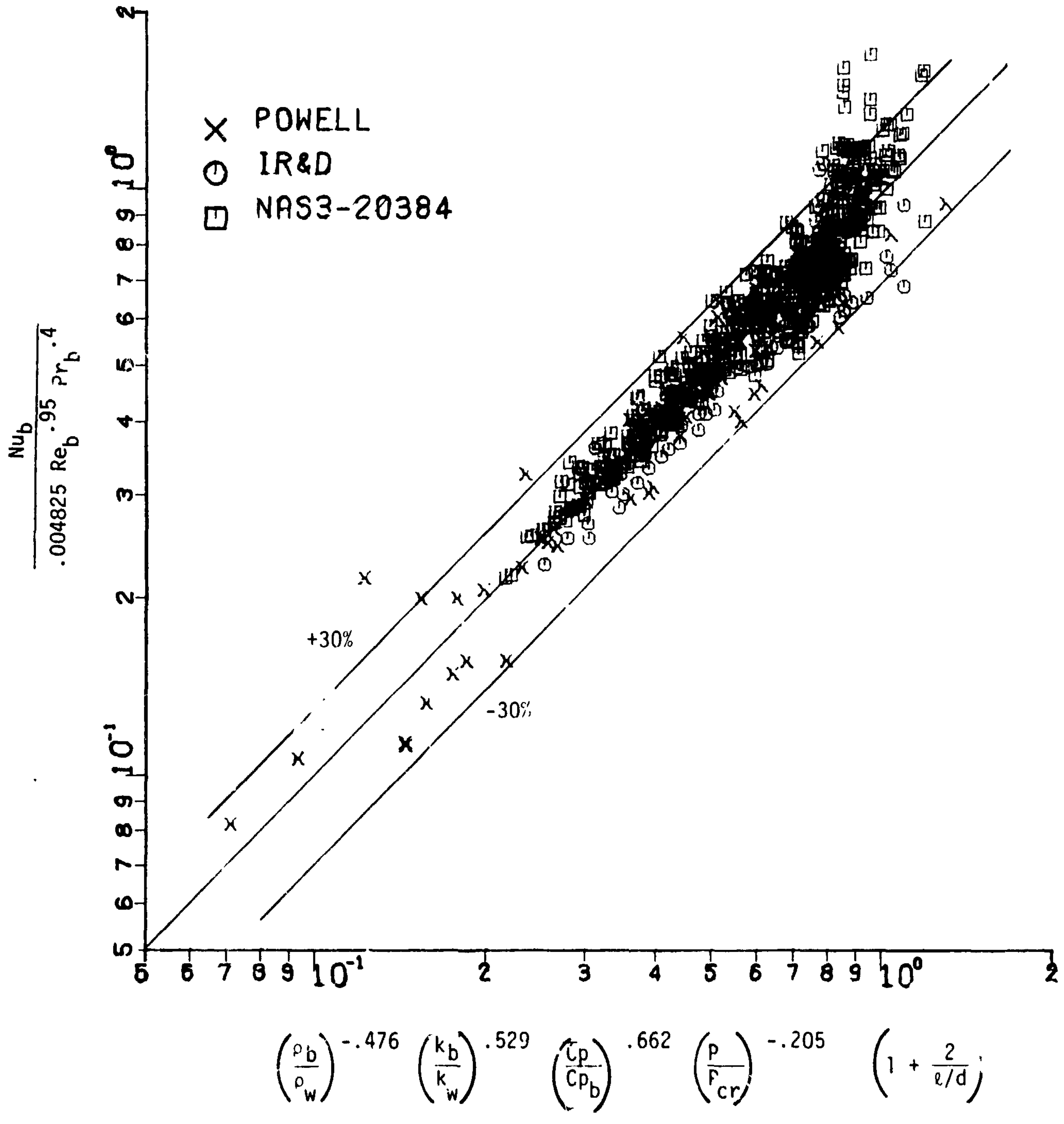


Figure 17. Modified Hines Correlation for Data from Various Souces (Case 22)

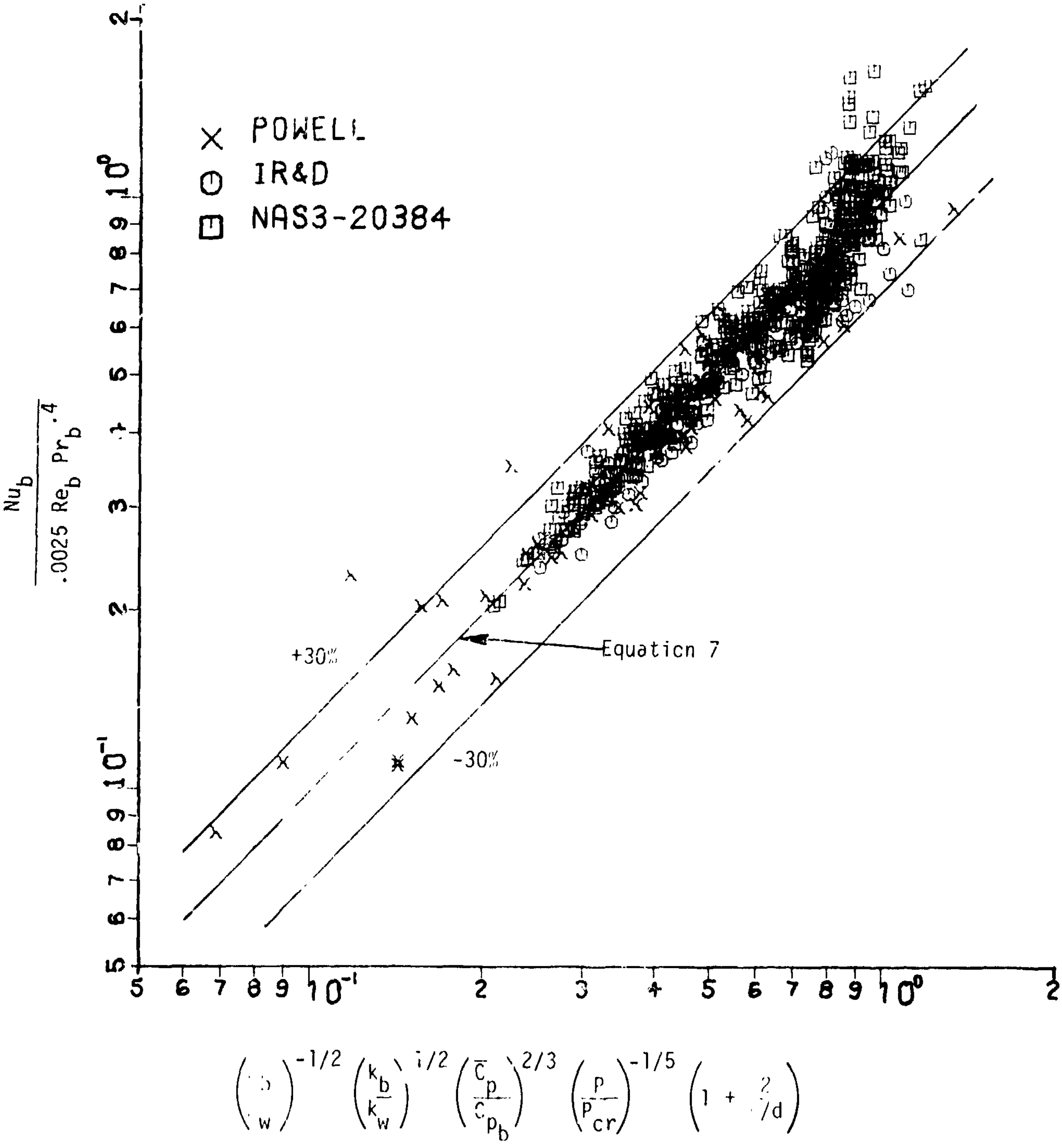


Figure 18. Recommended Correlation (Case 26A)

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TABLE V

RANGE OF VARIABLES

	Max.	Min.	Unit
P	34.56 (5013)	1.75 (254)	MPa (psia)
Tb	566 (1019)	96 (124)	Deg K (°R)
Tw	1000 (1800)	122 (220)	Deg K (°R)
Dia	5.59 (.220)	2.41 (.095)	mm (in.)
ℓ/d	204	3.6	
Nu	9635	193	
Pr	3.35	.75	
Re	3.32×10^6	$.15 \times 10^6$	
ϕ	90.0×10^6 (55)	$.3 \times 10^6$ (.2)	Watt/m^2 (Btu/in.^{2}sec)
ρV	122.8×10^3 (25.2×10^3)	2.1×10^3 (430)	Kg/sec/m^2 (lbm/ft^{2}sec)
$\frac{\rho_b}{\rho_w}$	24.9	1.1	
$\frac{\mu_b}{\mu_w}$	5.32	.44	
$\frac{k_b}{k_w}$	4.05	.40	
$\frac{C_p}{C_{pb}}$	1.18	.23	

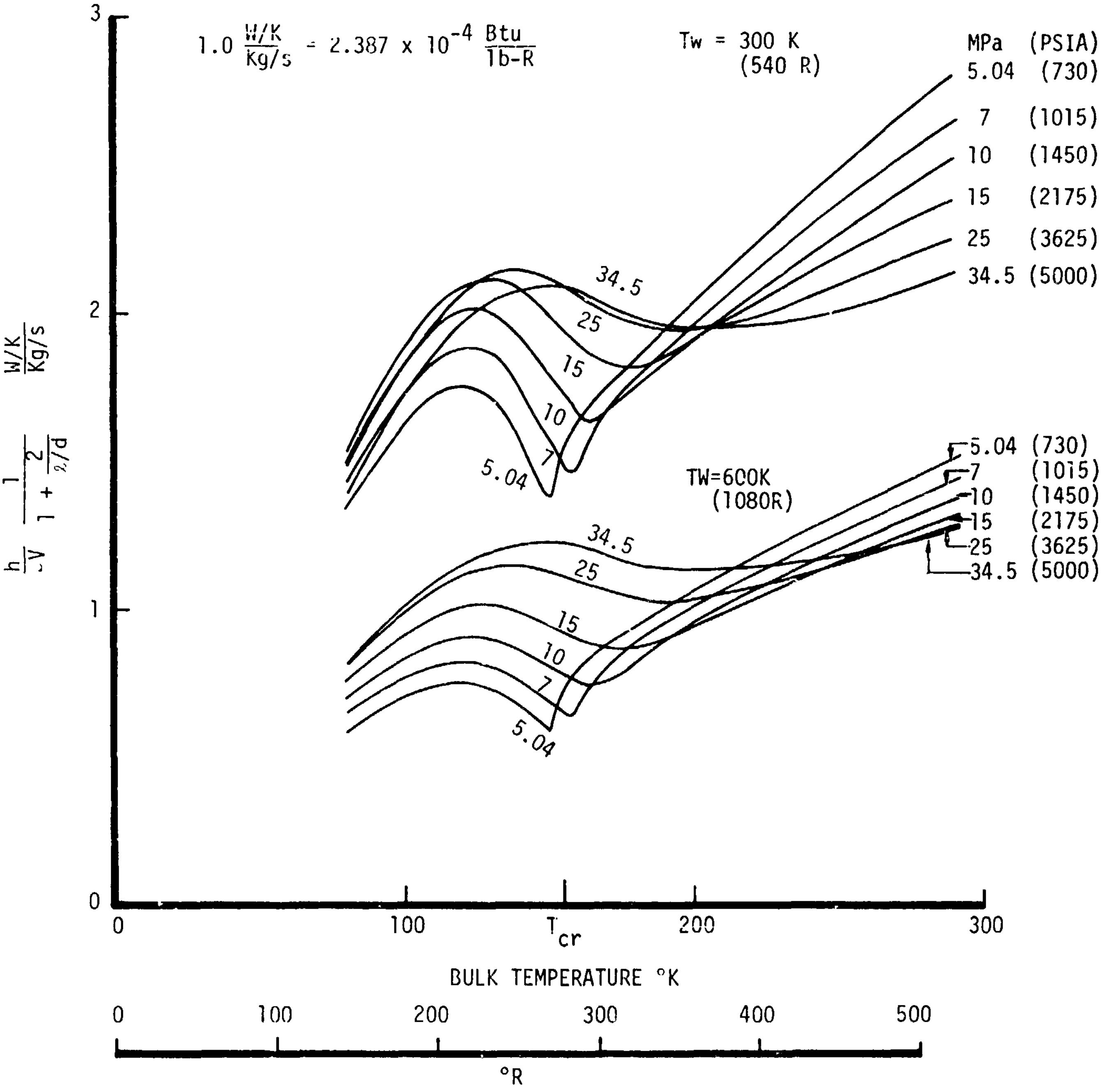

Figure 19. Predicted Heat Transfer Trends

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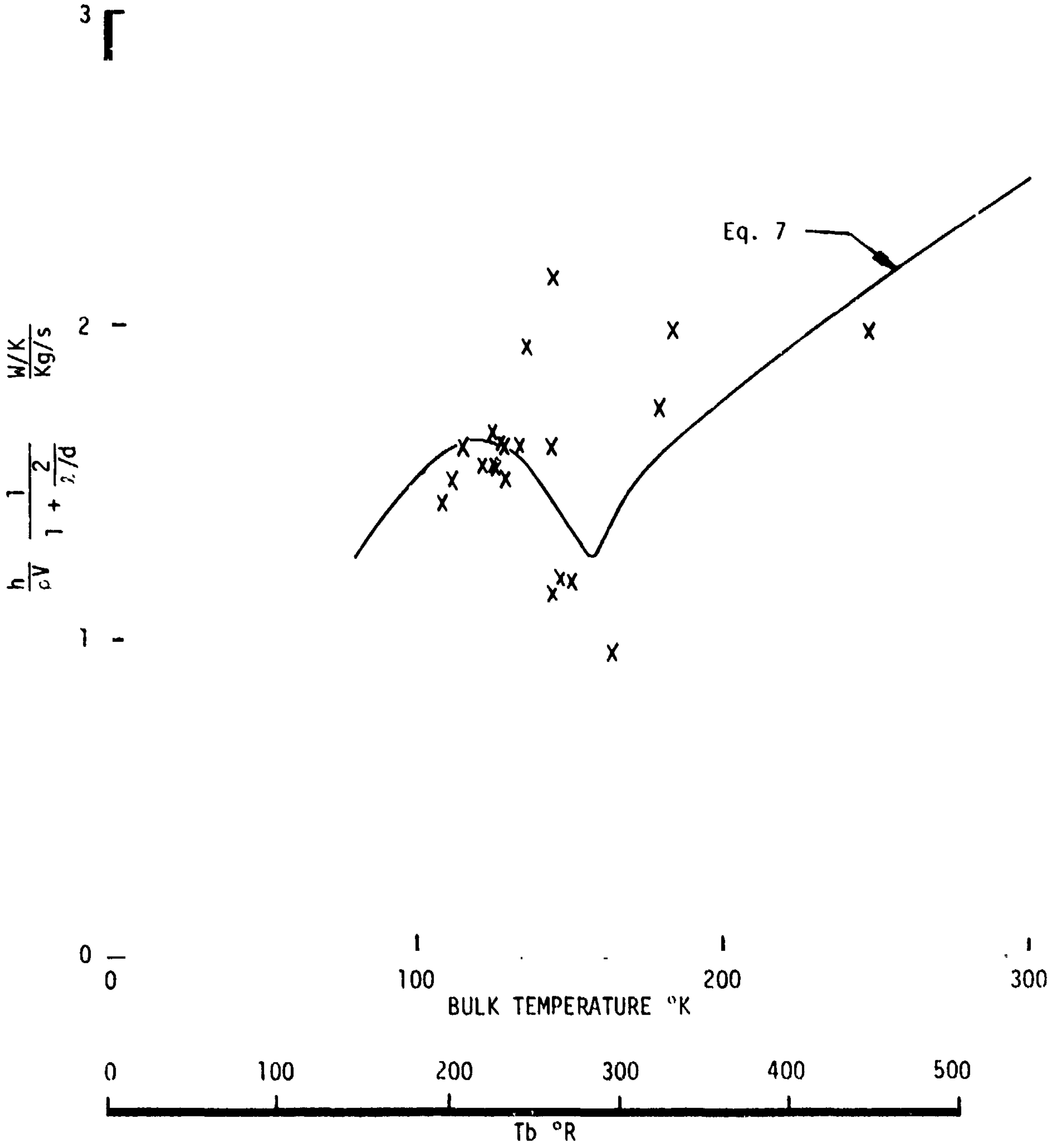

Figure 20. Measured and Predicted Heat Transfer Trends,
P = 7 MPa (1015 psia), Tw = 333K (600R)

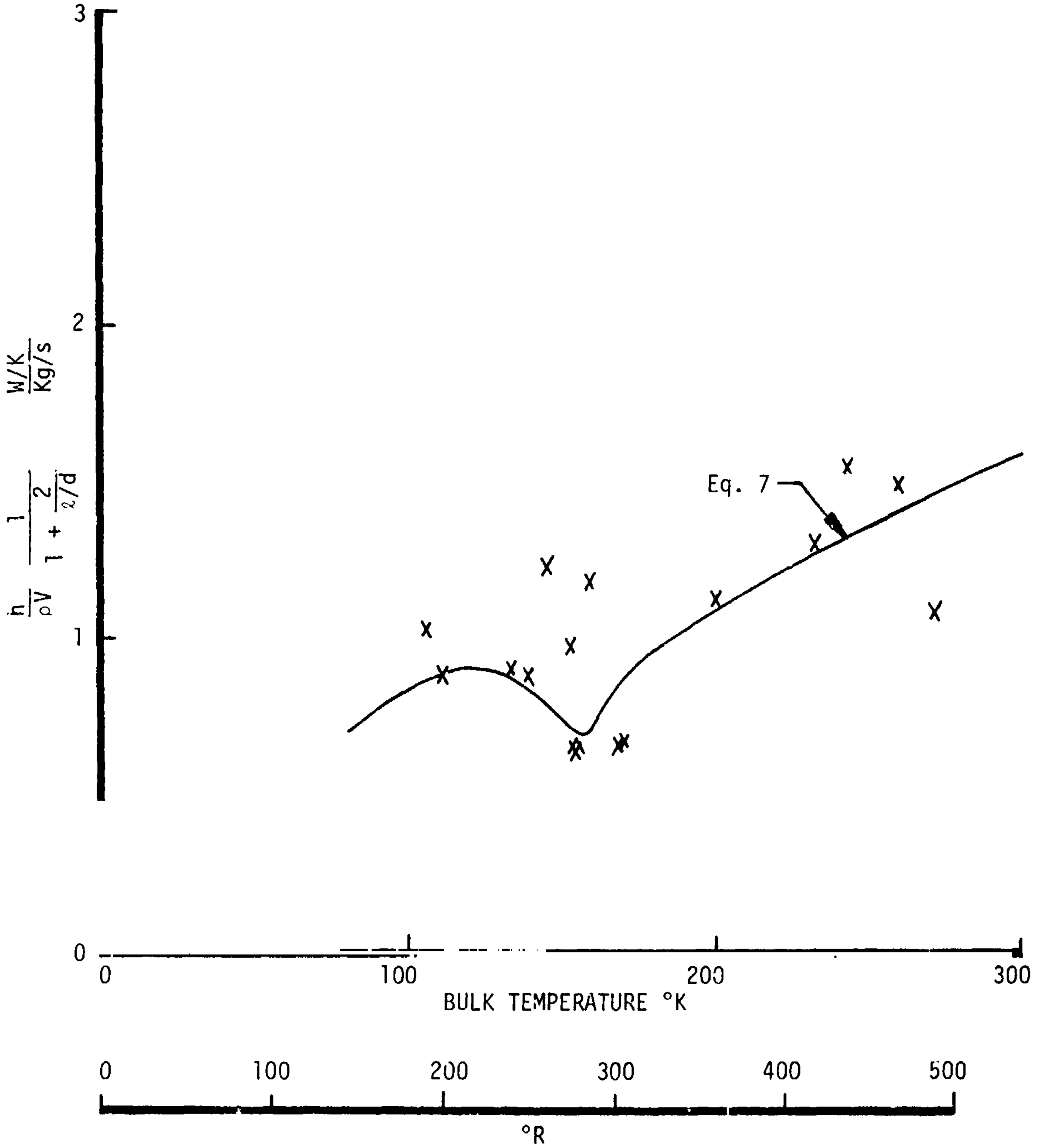

Figure 21. Trends, P = 7 MPa (1015 psia), Tw - 556K (1000R)

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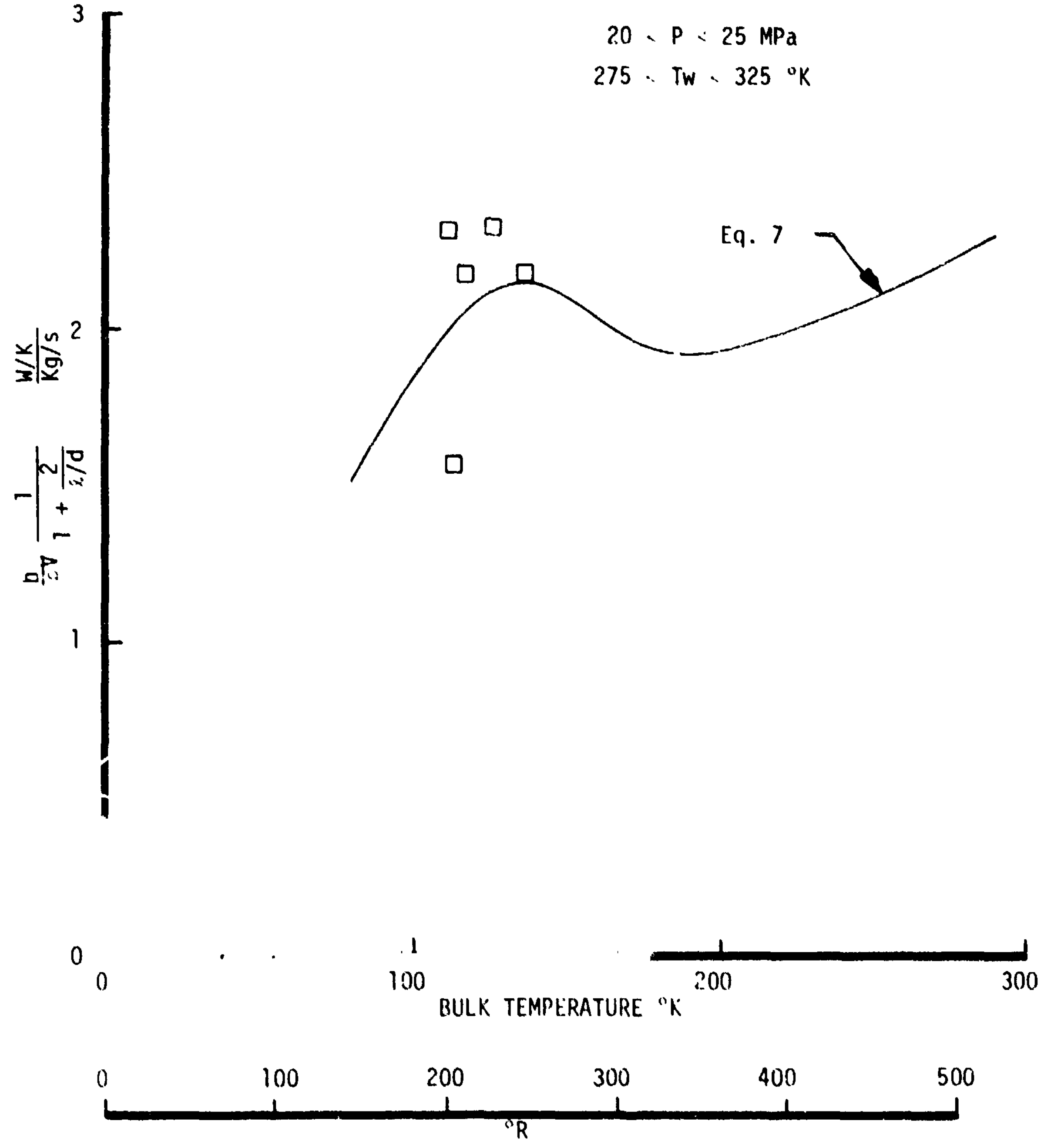

Figure 22. Trends, P ≈ 22.5 MPa (3250 psia), Tw ≈ 300K (540R)

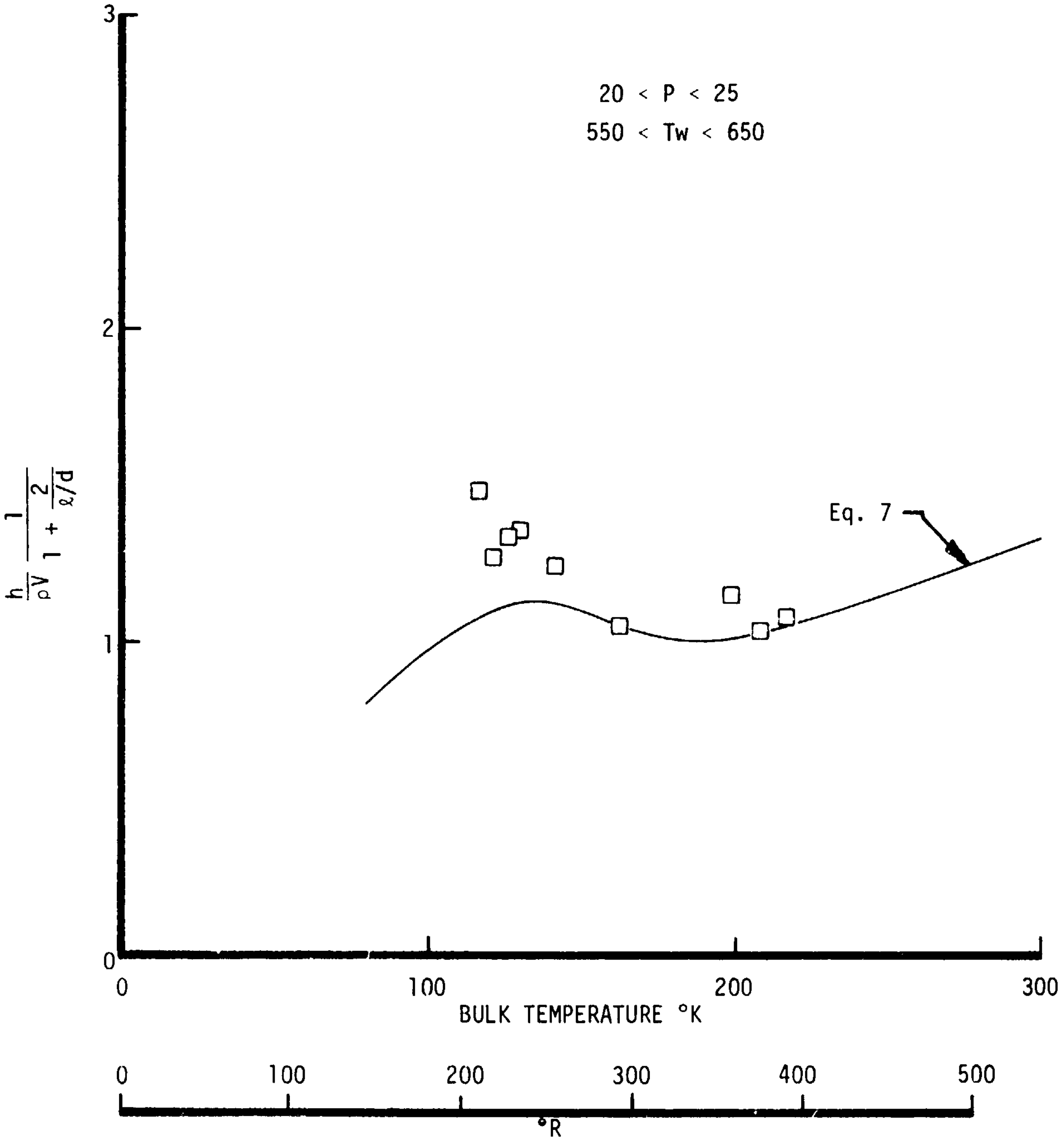

Figure 23. Trends, P ≃ 22.5 MPa (3250 psia), Tw ≃ 600K (1080R)

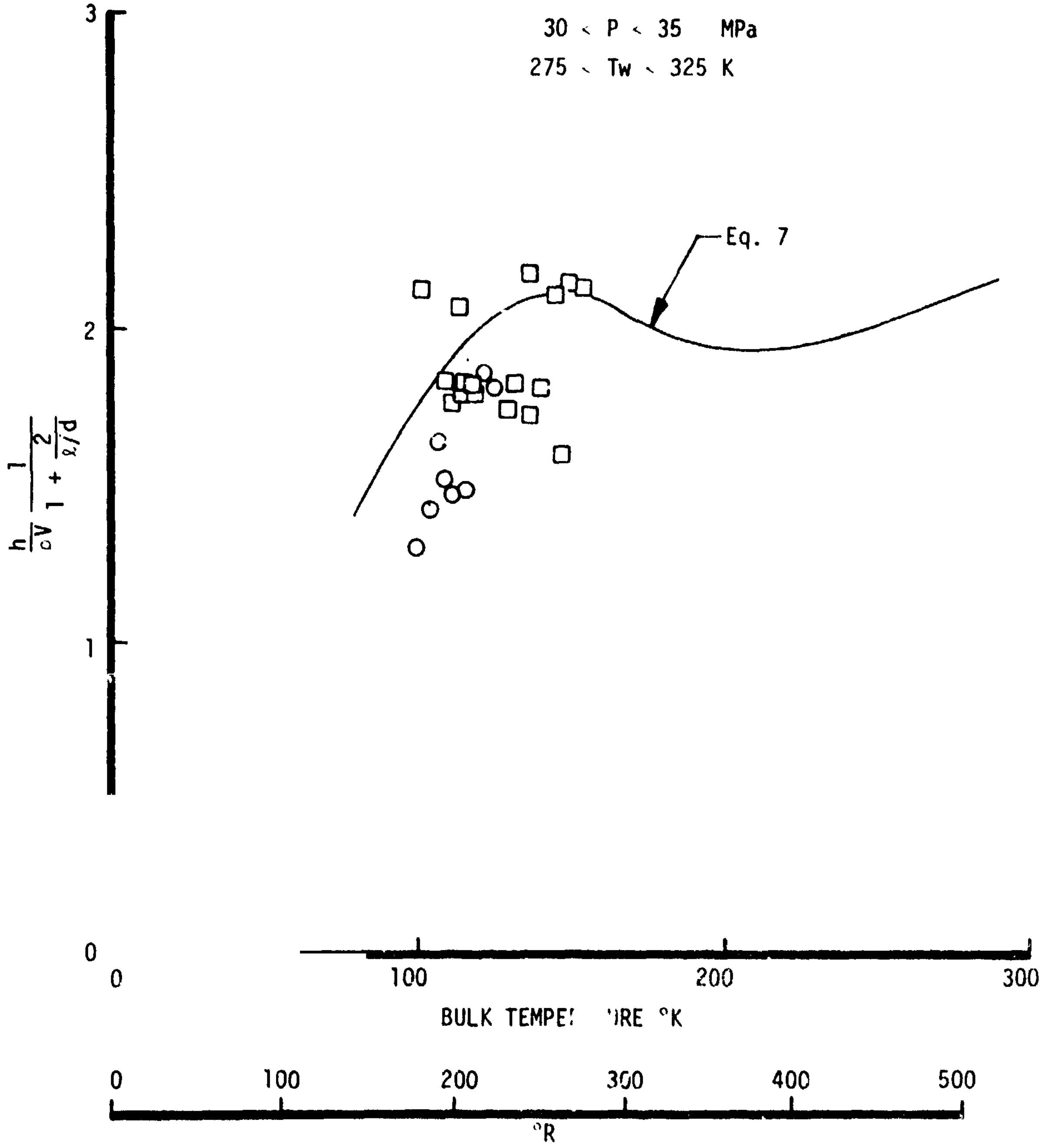

Figure 24. Trends, P ≃ 32.5 MPa (4700 psia), Tw ≃ 300K (540K)

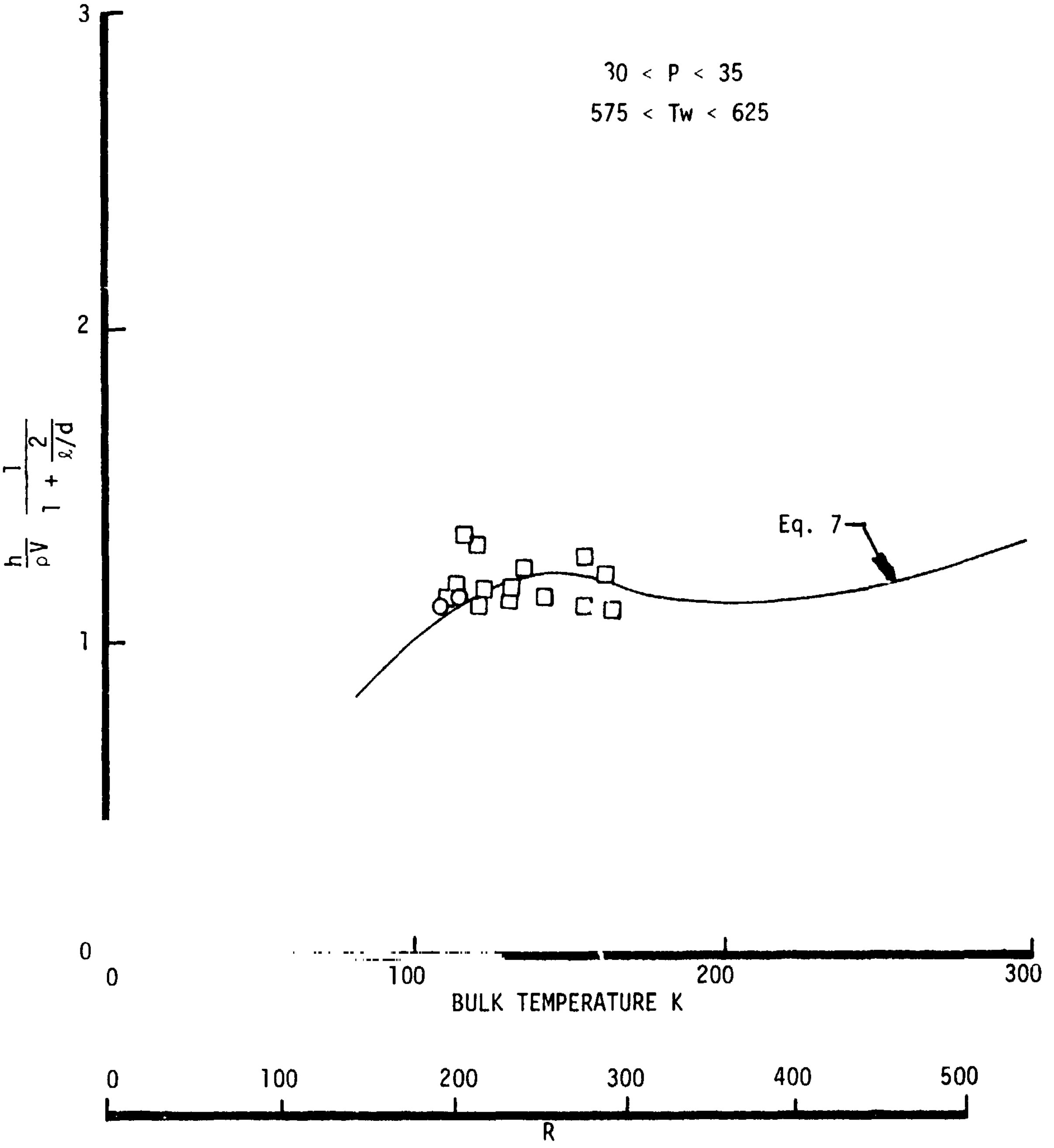

Figure 25. Trends, P $\simeq$ 32.5 MPa (4700 psia), Tw $\simeq$ 600K (1080R)

VI, B, Data Correlation (cont.)

Since test hardware may have been designed using the correlation recommended in Reference 4, a comparison of the new correlation (Equation 7) and the old one was made (Figure 26). The two correlations are virtually the same at 6.9 MPa (1000 psia), but differ at higher pressures. At 20.7 MPa (3000 psia) and a bulk temperature of 200 K (360 R), the new correlation predicts a heat transfer coefficient 27% lower than the Reference 4 correlation, at 34.5 MPa (5000 psia); Equation (7) predicts a coefficient 17% higher. This is within the ± 30% accuracy estimate for the correlations. The predicted trends in heat transfer coefficient as bulk temperature is reduced are different for the two correlations, however. The new correlation predicts a rapid drop in the heat transfer coefficient below 100 K (180 R), while the old correlation predicts a rise. Insufficient data is available in this region to determine the proper trend, and more testing is required.

Figure 27 shows the variation in heat transfer coefficient with pressure. As the pressure is increased, the heat transfer coefficient appears to be approaching a constant, for a constant wall temperature, and bulk temperatures removed from the critical temperature. On this basis, some extrapolation to higher pressures may be jusitifed.

Recently, heat transfer to nitrogen has been measured by R. C. Hendricks at NASA's Lewis Research Center (Ref. 11). Henricks suggested various parameters which might be used to correlate his nitrogen data with the oxygen data obtained by Powell (Ref. 3), and the Aerojet IR&D data (Ref. 4). To determine if Equation 7 could be used to predict heat transfer to nitrogen as well as oxygen, Henrick's nitrogen data were plotted against the correlation in Figure 28. The nitrogen data fell about 40% lower than the oxygen data. That is, the actual heat transfer coefficient for nitrogen is 40% lower than Equation 7 predicts. It may be possible to develop a generalized heat transfer correlation with the methods used to generate Equation 7. The viscosity term which was not significant when correlating oxygen data alone may be necessary when correlating data from other fluids. Other terms such as those suggested by Hendricks may also be required. Nitrogen data from other sources (Ref. 12 and 13), as well as data for other fluids, should be examined along with the oxygen data and Hendrick's nitrogen data, with a goal of developing a generalized heat transfer correlation.

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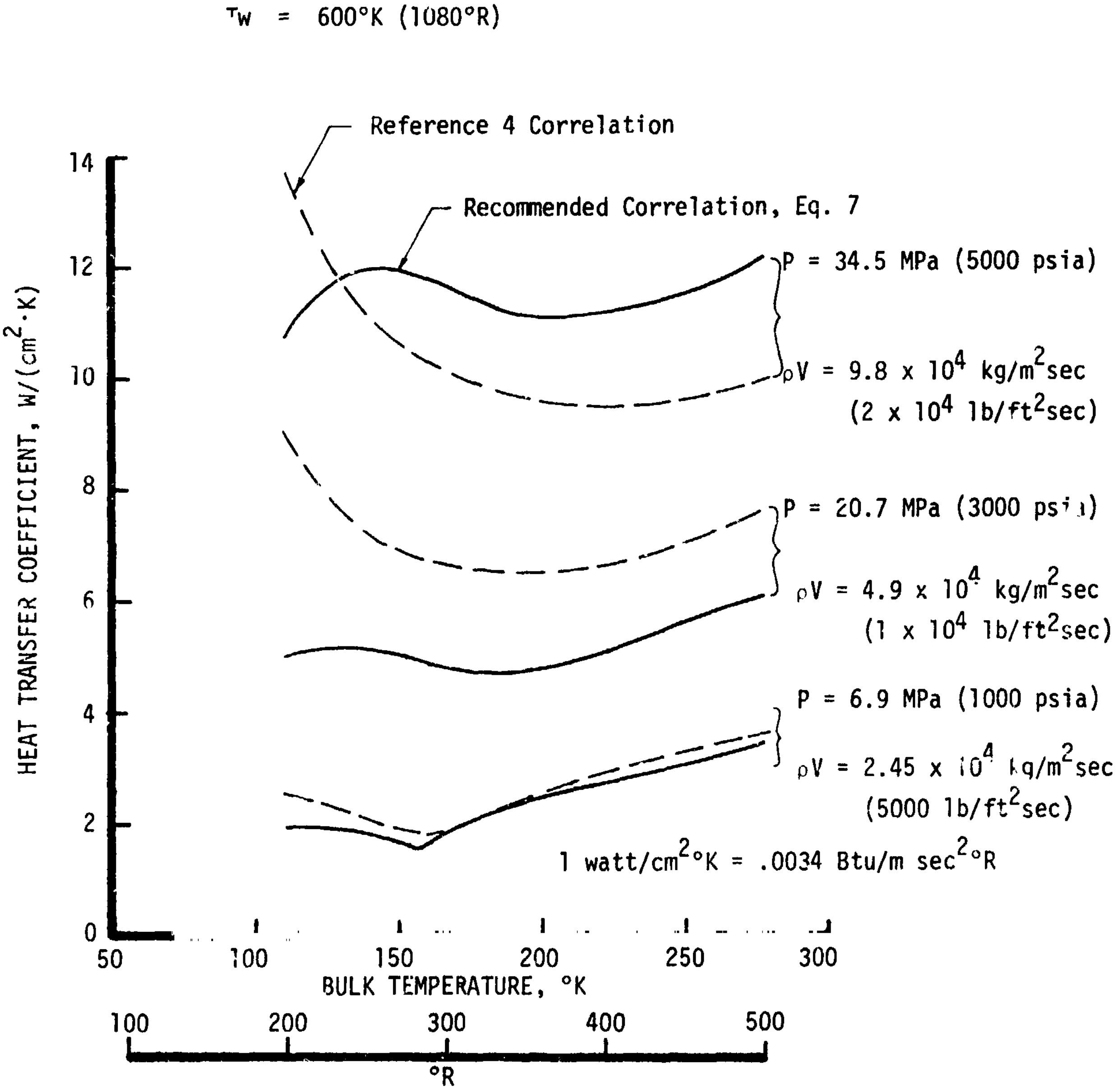

Figure 26. Comparison of the Recommended Correlation to the Correlation of Reference 4

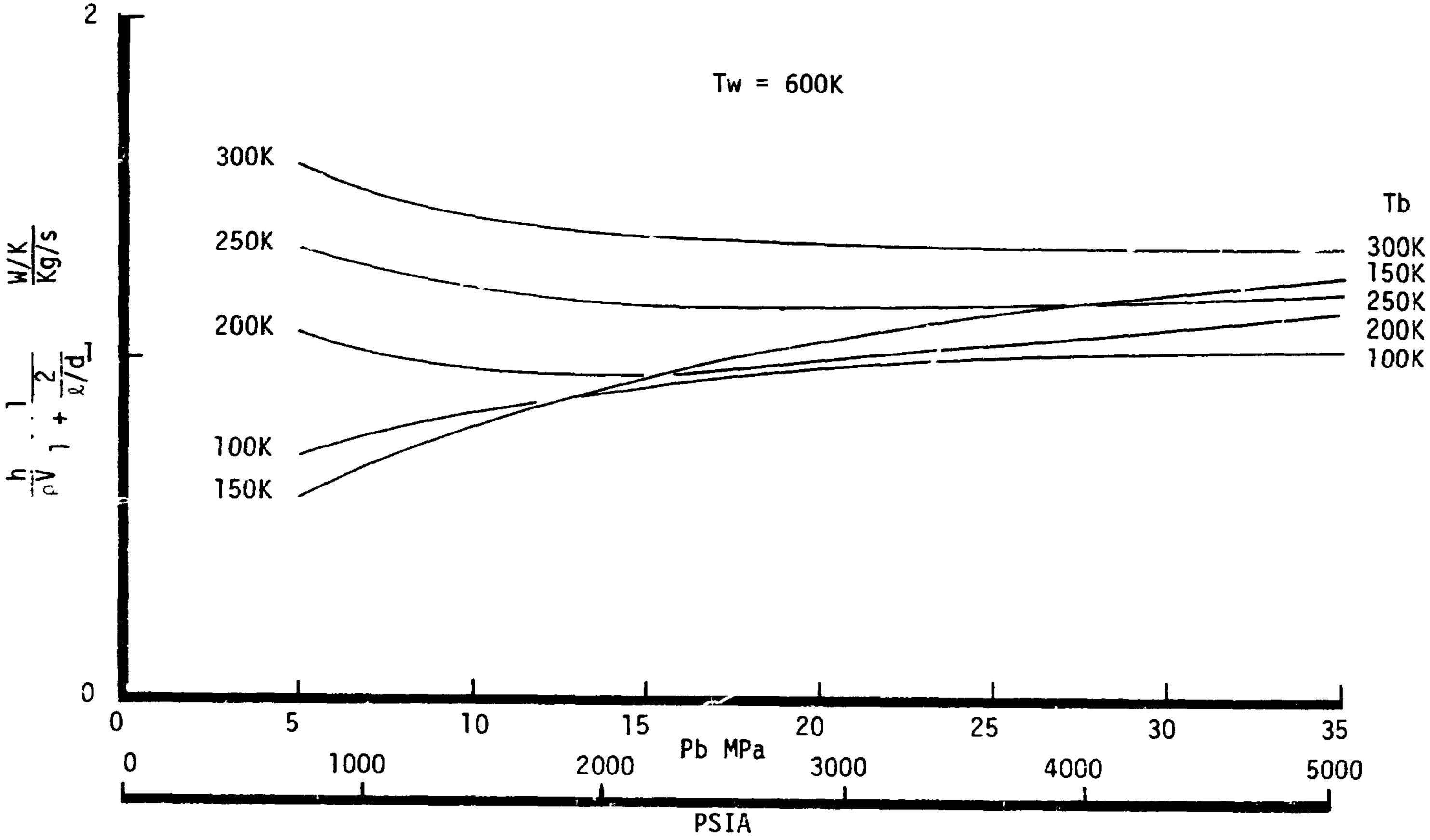

Figure 27. Predicted Heat Transfer Coefficient Variation with Pressure

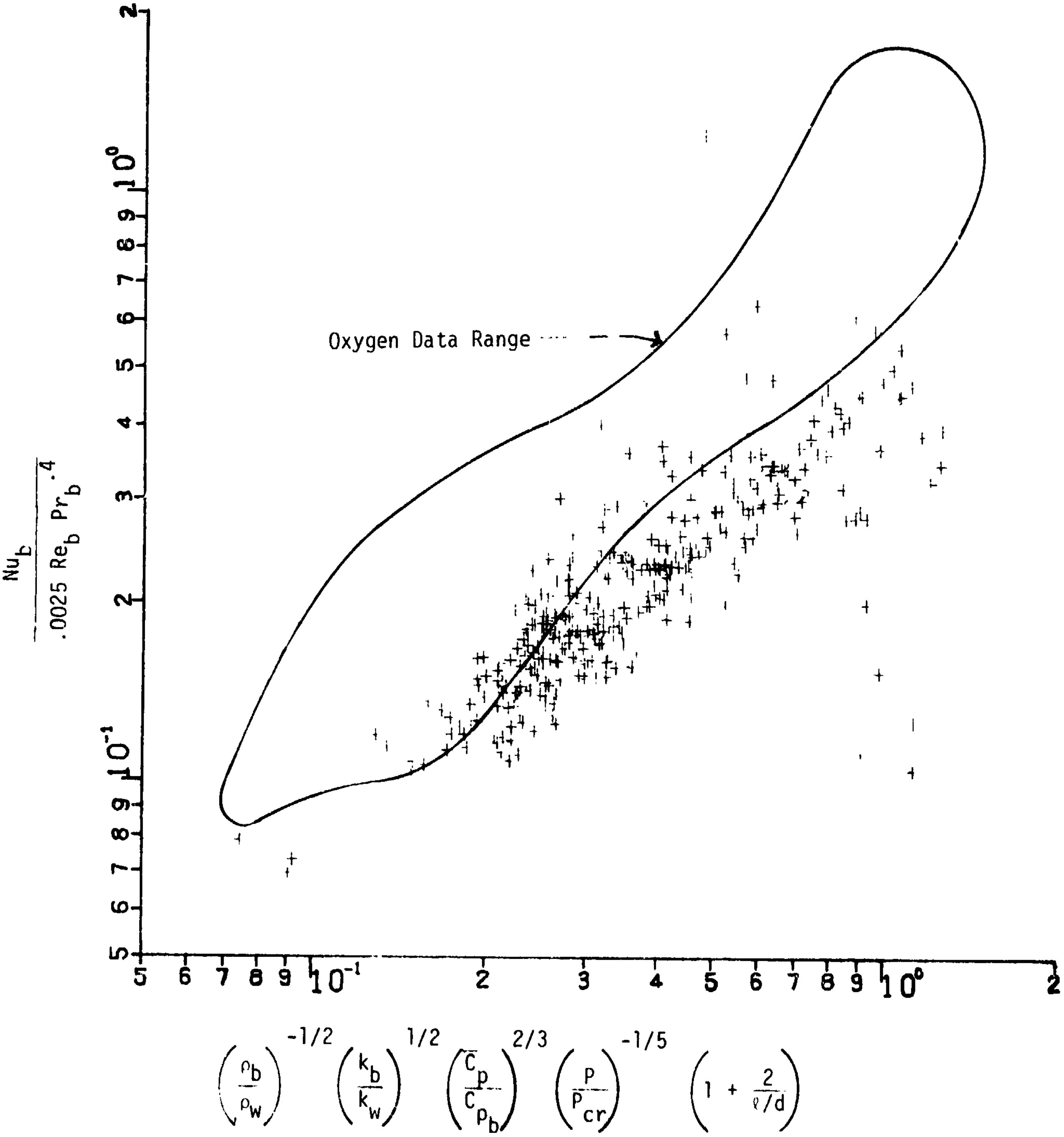

Figure 28. Comparison of Nitrogen Data of Ref. 11 with the Correlation Recommended for Oxygen

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VII. CONCLUSIONS AND RECOMMENDATIONS

Heat transfer to supercritical oxygen was experimentally measured in electrically heated tubes. The experimental data obtained during this investigation was combined with data obtained by others and used to develop a heat transfer correlation for supercritical pressures, and temperatures above 100 K (180 R). The results of this investigation indicate the following:

1. Supercritical oxygen heat transfer data can be correlated with an equation of the following form:

$$Nu_b = Nu_{ref} \left(\frac{\rho_b}{\rho_w}\right)^a \left(\frac{k_b}{k_w}\right)^b \left(\frac{\bar{Cp}}{Cp_b}\right)^c \left(\frac{P}{P_{cr}}\right)^d \left(1 + \frac{2}{\ell/d}\right)$$

We recommend the following equation

$$Nu_b = Nu_{ref} \left(\frac{\rho_b}{\rho_w}\right)^{-1/2} \left(\frac{k_b}{k_w}\right)^{1/2} \left(\frac{\bar{Cp}}{Cp_b}\right)^{2/3} \left(\frac{P}{P_{cr}}\right)^{-1/5} \left(1 + \frac{2}{\ell/d}\right)$$

in which:

Nu_{ref} = $.0025\, Re_b Pr_b^{.4}$

Cp = constant pressure specific heat

$\bar{Cp}$ = integrated average specific heat from T_w to T_b

d = inside tube diameter

ℓ = length from start of heated tube to temperature measurement station

Nu = Nusselt Number

P = local static pressure

Pr = Prandtl Number

Re = Reynolds Number

ρ = density

ϕ = heat flux

Subscripts:

b = evaluated at bulk temperature

cr = critical property

w = evaluated at wall temperature

The recommended correlation applies for the following range of conditions:

P = 5.04 to 35 MPa (730 to 5000 psia)

T_b = 100 to 500 K (180 to 900 R)

T_w = 125 to 1000 K (225 to 1800 R)

ϕ = $.3 \times 10^6$ to 90×10^6 w/m^2 (.2 to 55 $Btu/in.^2$-sec)

ℓ/d = 4 to 200

2. Heat transfer to supercritical oxygen can be more accurately predicted with bulk properties than with film properties.

3. A Reynold's Number exponent of unity in the above equation provides a better fit to the experimental data than does an exponent of .8 which is normally used in correlation equations.

4. More tests at temperatures below 100 K (180 R) are required, as the recommended correlation predicts a rapid drop in heat transfer coefficient below 100 K, and there is insufficient data in this range to substantiate this prediction.

5. Additional tests at pressures above 34.5 MPa (5000 psi) are necessary to meet the requirements of proposed high pressure rocket engines (Ref. 2).

6. Further investigation of nitrogen data, and data for other supercritical fluids, should be done with a goal of developing a generalized correlation.

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APPENDIX A

PROPERTIES OF OXYGEN

52

The properties of oxygen used in data reduction are listed in Table VI. Below 333 K (600 R) the properties were calculated using NBS subroutines. Above 333 K (600 R) density, specific heat, and enthalpy were obtained from Russian Data (Ref. 6), conductivity and viscosity were interpolated from an Aerojet publication on cryogenic properties by P. J. Petrozzi and P. H. Davidson.

TABLE VI

PROPERTIES OF OXYGEN

TEMPERATURE		PRESSURE		DENSITY		ENTHALPY		CP		THERMAL CONDUCTIVITY		VISCOSITY	
K	R	M PA	LB / SQ IN	LB / C FT	G / CC	BTU / LB	J / KG E-3	BTU / LB·R	J / KG·K E-3	BTU / FT·S·R	W / M·K E-6	LB / FT·S E+6	KG / M·S E+6
100.	180.	5.00	725.	68.8	5.36	-49.	-114.	.41	1.70	295.	1.84	108.	160.
120.	216.	5.00	725.	62.0	4.82	-34.	-79.	.43	1.82	239.	1.49	69.	103.
140.	252.	5.00	725.	52.7	4.10	-17.	-39.	.55	2.32	179.	1.11	50.	74.
160.	288.	5.00	725.	12.9	1.00	38.	88.	.73	3.04	69.	.43	14.	21.
180.	324.	5.00	725.	8.7	.68	55.	127.	.36	1.50	55.	.34	13.	20.
200.	360.	5.00	725.	7.1	.55	66.	154.	.30	1.24	54.	.34	13.	20.
220.	396.	5.00	725.	6.1	.48	76.	178.	.27	1.13	55.	.34	14.	20.
240.	432.	5.00	725.	5.4	.42	86.	200.	.26	1.07	56.	.35	14.	21.
260.	468.	5.00	725.	4.9	.38	95.	221.	.25	1.04	58.	.36	15.	22.
280.	504.	5.00	725.	4.5	.35	104.	241.	.24	1.01	60.	.36	15.	23.
300.	540.	5.00	725.	4.1	.32	112.	261.	.24	1.00	63.	.39	16.	24.
320.	576.	5.00	725.	3.8	.30	121.	281.	.24	.99	65.	.41	17.	25.
340.	612.	5.00	725.	3.6	.28	128.	298.	.24	.99	70.	.44	18.	26.
360.	648.	5.00	725.	3.4	.26	137.	318.	.23	.98	73.	.45	18.	27.
380.	684.	5.00	725.	3.2	.25	145.	338.	.23	.98	76.	.47	19.	28.
400.	720.	5.00	725.	3.0	.23	154.	356.	.23	.98	78.	.49	19.	29.
420.	756.	5.00	725.	2.9	.22	162.	378.	.23	.98	80.	.50	20.	30.
440.	792.	5.00	725.	2.7	.21	171.	398.	.23	.98	83.	.52	20.	30.
460.	828.	5.00	725.	2.6	.20	179.	417.	.24	.99	86.	.53	21.	31.
480.	864.	5.00	725.	2.5	.19	188.	437.	.24	.99	88.	.55	21.	32.
500.	900.	5.00	725.	2.4	.18	197.	457.	.24	1.00	91.	.57	22.	33.
520.	936.	5.00	725.	2.3	.18	205.	478.	.24	1.00	93.	.58	23.	33.
540.	972.	5.00	725.	2.2	.17	214.	498.	.24	1.01	95.	.59	23.	34.
560.	1008.	5.00	725.	2.1	.17	223.	518.	.24	1.01	98.	.61	24.	35.
580.	1044.	5.00	725.	2.1	.16	231.	539.	.24	1.02	100.	.62	24.	36.
600.	1080.	5.00	725.	2.0	.15	240.	559.	.24	1.02	102.	.64	25.	36.
620.	1116.	5.00	725.	1.9	.15	249.	580.	.24	1.02	105.	.65	25.	37.
640.	1152.	5.00	725.	1.9	.14	258.	600.	.25	1.03	107.	.67	25.	38.
660.	1188.	5.00	725.	1.8	.14	267.	621.	.25	1.03	109.	.68	26.	39.
680.	1224.	5.00	725.	1.7	.14	276.	642.	.25	1.04	111.	.69	26.	39.
700.	1260.	5.00	725.	1.7	.13	285.	663.	.25	1.04	113.	.71	27.	40.
720.	1296.	5.00	725.	1.7	.13	294.	684.	.25	1.05	115.	.72	27.	41.
740.	1332.	5.00	725.	1.6	.13	303.	705.	.25	1.05	118.	.73	28.	42.
760.	1368.	5.00	725.	1.6	.12	312.	726.	.25	1.06	120.	.75	28.	42.
780.	1404.	5.00	725.	1.5	.12	321.	747.	.25	1.06	122.	.76	29.	43.
800.	1440.	5.00	725.	1.5	.12	330.	768.	.25	1.06	125.	.78	29.	44.
820.	1476.	5.00	725.	1.5	.11	339.	790.	.25	1.07	127.	.79	30.	44.
840.	1512.	5.00	725.	1.4	.11	348.	811.	.26	1.07	129.	.81	30.	45.
860.	1548.	5.00	725.	1.4	.11	358.	833.	.26	1.08	132.	.82	31.	46.
880.	1584.	5.00	725.	1.3	.10	367.	854.	.26	1.08	134.	.84	31.	47.
900.	1620.	5.00	725.	1.3	.10	376.	876.	.26	1.08	136.	.85	32.	47.
920.	1656.	5.00	725.	1.3	.10	386.	898.	.26	1.08	138.	.86	32.	48.
940.	1692.	5.00	725.	1.3	.10	395.	919.	.26	1.09	141.	.88	33.	49.
960.	1728.	5.00	725.	1.2	.10	404.	941.	.26	1.09	143.	.89	33.	50.
980.	1764.	5.00	725.	1.2	.09	414.	963.	.26	1.09	145.	.90	34.	51.
1000.	1800.	5.00	725.	1.2	.09	423.	985.	.26	1.09	147.	.92	35.	51.

TABLE VI (cont.)

TEMPERATURE		PRESSURE		DENSITY		ENTHALPY		CP		THERMAL CONDUCTIVITY		VISCOSIT	
K	R	M PA	LB/SQ IN	LB/C FT	G/CC	BTU/LB	J/KG E-3	BTU/LB•R	J/KG•K E-3	BTU/FT•HR	W/M•K E-6	LB/FT•S E+6	KG/M•S E+6
100.	180.	10.00	1450.	69.6	5.42	-48.	-112.	.40	1.67	302.	1.88	115.	171.
120.	216.	10.00	1450.	63.3	4.93	-33.	-78.	.42	1.74	250.	1.56	74.	111.
140.	252.	10.00	1450.	55.6	4.33	-18.	-41.	.47	1.97	197.	1.23	55.	81.
160.	288.	10.00	1450.	44.6	3.47	2.	4.	.65	2.71	145.	.90	39.	59.
180.	324.	10.00	1450.	26.3	2.04	30.	71.	.79	3.31	103.	.64	23.	35.
200.	360.	10.00	1450.	17.3	1.34	52.	120.	.45	1.89	78.	.49	19.	28.
220.	396.	10.00	1450.	13.7	1.07	66.	153.	.35	1.46	71.	.45	18.	26.
240.	432.	10.00	1450.	11.6	.91	77.	180.	.31	1.28	69.	.43	17.	26.
260.	468.	10.00	1450.	10.2	.80	88.	205.	.28	1.18	69.	.43	17.	26.
280.	504.	10.00	1450.	9.2	.72	98.	228.	.27	1.12	70.	.43	18.	26.
300.	540.	10.00	1450.	8.4	.65	107.	250.	.26	1.08	71.	.44	18.	27.
320.	576.	10.00	1450.	7.7	.60	116.	271.	.25	1.05	73.	.45	18.	27.
340.	612.	10.00	1450.	7.2	.56	126.	293.	.25	1.04	74.	.46	19.	28.
360.	648.	10.00	1450.	6.8	.53	135.	314.	.25	1.03	76.	.47	19.	29.
380.	684.	10.00	1450.	6.4	.50	144.	334.	.24	1.02	78.	.49	20.	29.
400.	720.	10.00	1450.	6.0	.46	152.	355.	.24	1.01	80.	.50	20.	30.
420.	756.	10.00	1450.	5.7	.44	161.	375.	.24	1.01	83.	.52	21.	31.
440.	792.	10.00	1450.	5.4	.42	170.	395.	.24	1.01	85.	.53	21.	31.
460.	828.	10.00	1450.	5.1	.40	178.	415.	.24	1.01	88.	.55	22.	32.
480.	864.	10.00	1450.	4.9	.38	187.	436.	.24	1.01	90.	.56	22.	33.
500.	900.	10.00	1450.	4.7	.36	196.	456.	.24	1.02	93.	.58	23.	34.
520.	936.	10.00	1450.	4.5	.35	205.	476.	.24	1.02	95.	.59	23.	34.
540.	972.	10.00	1450.	4.4	.34	213.	497.	.24	1.02	97.	.61	24.	35.
560.	1008.	10.00	1450.	4.2	.33	222.	517.	.25	1.03	99.	.62	24.	36.
580.	1044.	10.00	1450.	4.0	.31	231.	538.	.25	1.03	102.	.63	25.	37.
600.	1080.	10.00	1450.	3.9	.30	240.	558.	.25	1.03	104.	.65	25.	37.
620.	1116.	10.00	1450.	3.8	.29	249.	579.	.25	1.04	106.	.66	26.	38.
640.	1152.	10.00	1450.	3.7	.28	258.	600.	.25	1.04	108.	.67	26.	39.
660.	1188.	10.00	1450.	3.5	.28	267.	621.	.25	1.05	110.	.69	26.	39.
680.	1224.	10.00	1450.	3.4	.27	276.	642.	.25	1.05	112.	.70	27.	40.
700.	1260.	10.00	1450.	3.3	.26	285.	662.	.25	1.05	114.	.71	27.	41.
720.	1296.	10.00	1450.	3.2	.25	294.	684.	.25	1.06	116.	.73	28.	42.
740.	1332.	10.00	1450.	3.2	.25	303.	705.	.25	1.06	119.	.74	28.	42.
760.	1368.	10.00	1450.	3.1	.24	312.	726.	.25	1.06	121.	.75	29.	43.
780.	1404.	10.00	1450.	3.0	.23	321.	747.	.25	1.07	123.	.77	29.	44.
800.	1440.	10.00	1450.	2.9	.23	330.	769.	.26	1.07	125.	.78	30.	44.
820.	1476.	10.00	1450.	2.9	.22	339.	790.	.26	1.07	127.	.79	30.	45.
840.	1512.	10.00	1450.	2.8	.22	349.	812.	.26	1.08	130.	.81	31.	46.
860.	1548.	10.00	1450.	2.7	.21	358.	833.	.26	1.08	132.	.82	31.	47.
880.	1584.	10.00	1450.	2.7	.21	367.	855.	.26	1.08	134.	.84	32.	47.
900.	1620.	10.00	1450.	2.6	.20	377.	877.	.26	1.09	137.	.85	32.	48.
920.	1656.	10.00	1450.	2.5	.20	386.	898.	.26	1.09	139.	.87	33.	49.
940.	1692.	10.00	1450.	2.5	.19	395.	920.	.26	1.09	141.	.88	33.	50.
960.	1728.	10.00	1450.	2.4	.19	405.	942.	.26	1.09	143.	.89	34.	50.
980.	1764.	10.00	1450.	2.4	.19	414.	964.	.26	1.10	145.	.90	34.	51.
1000.	1800.	10.00	1450.	2.3	.18	423.	986.	.26	1.10	147.	.92	35.	52.

TABLE VI (cont.)

TEMPERATURE		PRESSURE		DENSITY		ENTHALPY			CP	THERMAL CUNDUCTIVITY		VISCOS	
K	R	M PA	LB/SQ IN	LB/C FT	G/CC	BTU/LB	J/KG E-3	BTU/LB·R	J/KG·K E-3	BTU/FT·S·R	W/M·K E-6	LB/FT·S F+6	KG/M·S E+6
100.	180.	15.00	2176.	70.3	5.47	-47.	-109.	.39	1.65	309.	1.93	122.	182.
120.	216.	15.00	2176.	64.4	5.01	-33.	-76.	.40	1.69	259.	1.62	80.	118.
140.	252.	15.00	2176.	57.7	4.49	-17.	-41.	.43	1.82	211.	1.31	58.	87.
160.	288.	15.00	2176.	49.4	3.85	-1.	-2.	.50	2.08	165.	1.03	46.	68.
180.	324.	15.00	2176.	38.9	3.03	19.	43.	.58	2.43	130.	.81	34.	51.
200.	360.	15.00	2176.	28.5	2.22	39.	91.	.53	2.22	105.	.65	26.	38.
220.	396.	15.00	2176.	22.0	1.71	56.	130.	.42	1.75	90.	.56	22.	33.
240.	432.	15.00	2176.	18.3	1.42	70.	163.	.35	1.47	84.	.52	21.	31.
260.	468.	15.00	2176.	15.8	1.23	82.	190.	.31	1.32	81.	.50	20.	30.
280.	504.	15.00	2176.	14.0	1.09	93.	216.	.29	1.22	79.	.50	20.	30.
300.	540.	15.00	2176.	12.7	.99	103.	239.	.28	1.15	80.	.50	20.	30.
320.	576.	15.00	2176.	11.6	.90	112.	262.	.26	1.11	81.	.50	20.	30.
340.	612.	15.00	2176.	10.8	.64	123.	285.	.26	1.09	81.	.51	21.	31.
360.	648.	15.00	2176.	10.2	.79	132.	307.	.26	1.08	81.	.50	21.	31.
380.	684.	15.00	2176.	9.5	.74	141.	328.	.25	1.06	83.	.51	21.	32.
400.	720.	15.00	2176.	8.9	.69	150.	349.	.25	1.05	84.	.53	22.	32.
420.	756.	15.00	2176.	8.4	.66	159.	370.	.25	1.04	86.	.54	22.	33.
440.	792.	15.00	2176.	8.0	.62	168.	391.	.25	1.04	89.	.55	22.	33.
460.	828.	15.00	2176.	7.6	.59	177.	412.	.25	1.04	91.	.57	23.	34.
480.	864.	15.00	2176.	7.3	.57	186.	432.	.25	1.04	93.	.58	23.	35.
500.	900.	15.00	2176.	7.0	.54	195.	453.	.25	1.04	96.	.60	24.	35.
520.	936.	15.00	2176.	6.7	.52	204.	474.	.25	1.04	98.	.61	24.	36.
540.	972.	15.00	2176.	6.5	.50	212.	494.	.25	1.04	100.	.62	25.	37.
560.	1008.	15.00	2176.	6.2	.49	221.	515.	.25	1.04	102.	.64	25.	37.
580.	1044.	15.00	2176.	6.0	.47	230.	536.	.25	1.05	104.	.65	26.	38.
600.	1080.	15.00	2176.	5.6	.45	239.	557.	.25	1.05	106.	.66	26.	39.
620.	1116.	15.00	2176.	5.6	.44	248.	578.	.25	1.05	108.	.67	26.	39.
640.	1152.	15.00	2176.	5.4	.42	257.	599.	.25	1.05	110.	.69	27.	40.
660.	1188.	15.00	2176.	5.3	.41	266.	620.	.25	1.06	112.	.70	27.	41.
680.	1224.	15.00	2176.	5.1	.40	275.	641.	.25	1.06	114.	.71	28.	41.
700.	1260.	15.00	2176.	4.9	.38	284.	662.	.25	1.06	116.	.72	28.	42.
720.	1296.	15.00	2176.	4.8	.38	294.	684.	.25	1.06	118.	.73	29.	43.
740.	1332.	15.00	2176.	4.7	.37	303.	705.	.25	1.07	120.	.75	29.	43.
760.	1368.	15.00	2176.	4.6	.36	312.	727.	.26	1.07	122.	.76	30.	44.
780.	1404.	15.00	2176.	4.5	.35	321.	748.	.26	1.07	124.	.77	30.	45.
800.	1440.	15.00	2176.	4.4	.34	330.	769.	.26	1.08	126.	.79	31.	45.
820.	1476.	15.00	2176.	4.2	.33	340.	791.	.26	1.08	128.	.80	31.	46.
840.	1512.	15.00	2176.	4.1	.32	349.	813.	.26	1.08	130.	.81	32.	47.
860.	1548.	15.00	2176.	4.0	.31	358.	834.	.26	1.09	133.	.83	32.	48.
880.	1584.	15.00	2176.	3.9	.31	368.	856.	.26	1.09	135.	.84	33.	48.
900.	1620.	15.00	2176.	3.9	.30	377.	878.	.26	1.09	137.	.85	33.	49.
920.	1656.	15.00	2176.	3.8	.29	387.	900.	.26	1.09	139.	.87	33.	50.
940.	1692.	15.00	2176.	3.7	.29	396.	922.	.26	1.10	141.	.88	34.	51.
960.	1728.	15.00	2176.	3.6	.28	405.	944.	.26	1.10	143.	.89	34.	51.
980.	1764.	15.00	2176.	3.5	.28	415.	966.	.26	1.10	145.	.91	35.	52.
1000.	1800.	15.00	2176.	3.5	.27	424.	988.	.26	1.10	147.	.92	35.	53.

TABLE VI (cont.)

TEMPERATURE K	R	PRESSURE M PA	LB/SQ IN	DENSITY LB/C FT	G/CC	ENTHALPY BTU/LB	J/KG E-3	CP BTU/LB·R	J/KG·K E-3	THERMAL CONDUCTIVITY BTU/FT·S·R	W/M·K E-6	VISCOSITY LB/FT·S E+6	KG/M·S E+6
100.	180.	20.00	2901.	71.0	5.52	-46.	-106.	.39	1.63	315.	1.97	129.	193.
120.	216.	20.00	2901.	65.4	5.09	-32.	-74.	.39	1.65	268.	1.67	85.	126.
140.	252.	20.00	2901.	59.3	4.61	-17.	-40.	.41	1.73	222.	1.39	62.	92.
160.	288.	20.00	2901.	52.3	4.07	-2.	-4.	.45	1.87	180.	1.12	50.	75.
180.	324.	20.00	2901.	44.3	3.45	15.	35.	.48	2.02	146.	.91	40.	60.
200.	360.	20.00	2901.	36.1	2.81	33.	76.	.48	2.02	123.	.77	32.	48.
220.	396.	20.00	2901.	29.3	2.28	49.	114.	.43	1.81	107.	.67	27.	40.
240.	432.	20.00	2901.	24.4	1.90	64.	148.	.38	1.58	98.	.61	25.	37.
260.	468.	20.00	2901.	21.1	1.64	77.	178.	.34	1.41	92.	.58	23.	35.
280.	504.	20.00	2901.	18.7	1.45	88.	205.	.31	1.30	89.	.56	23.	34.
300.	540.	20.00	2901.	16.9	1.31	99.	230.	.29	1.21	88.	.55	22.	33.
320.	576.	20.00	2901.	15.4	1.20	109.	254.	.27	1.15	88.	.55	22.	33.
340.	612.	20.00	2901.	14.2	1.11	120.	279.	.27	1.14	88.	.55	23.	34.
360.	648.	20.00	2901.	13.3	1.04	130.	302.	.27	1.12	87.	.54	23.	34.
380.	684.	20.00	2901.	12.5	.97	139.	324.	.26	1.10	88.	.55	23.	34.
400.	720.	20.00	2901.	11.6	.90	148.	345.	.26	1.08	89.	.56	23.	35.
420.	756.	20.00	2901.	11.0	.86	157.	367.	.25	1.07	91.	.56	24.	35.
440.	792.	20.00	2901.	10.5	.82	167.	388.	.25	1.06	93.	.58	24.	36.
460.	828.	20.00	2901.	10.0	.78	176.	409.	.25	1.06	95.	.59	24.	36.
480.	864.	20.00	2901.	9.5	.74	185.	430.	.25	1.05	96.	.60	25.	37.
500.	900.	20.00	2901.	9.1	.71	194.	451.	.25	1.05	98.	.61	25.	37.
520.	936.	20.00	2901.	8.8	.68	203.	472.	.25	1.05	100.	.63	25.	38.
540.	972.	20.00	2901.	8.5	.66	212.	493.	.25	1.05	102.	.64	26.	38.
560.	1008.	20.00	2901.	8.2	.64	221.	514.	.25	1.05	104.	.65	26.	39.
580.	1044.	20.00	2901.	7.9	.61	230.	535.	.25	1.06	106.	.66	26.	39.
600.	1080.	20.00	2901.	7.5	.59	239.	556.	.25	1.06	108.	.67	27.	40.
620.	1116.	20.00	2901.	7.3	.57	248.	578.	.25	1.06	110.	.69	27.	40.
640.	1152.	20.00	2901.	7.1	.55	257.	599.	.25	1.06	112.	.70	28.	41.
660.	1188.	20.00	2901.	6.9	.54	266.	620.	.25	1.06	114.	.71	28.	42.
680.	1224.	20.00	2901.	6.7	.52	275.	641.	.25	1.07	115.	.72	28.	42.
700.	1260.	20.00	2901.	6.5	.50	285.	663.	.25	1.07	117.	.73	29.	43.
720.	1296.	20.00	2901.	6.3	.49	294.	684.	.25	1.07	119.	.74	29.	44.
740.	1332.	20.00	2901.	6.2	.48	303.	706.	.25	1.07	121.	.76	30.	44.
760.	1368.	20.00	2901.	6.0	.47	312.	727.	.25	1.07	123.	.77	30.	45.
780.	1404.	20.00	2901.	5.9	.46	322.	749.	.25	1.07	125.	.78	31.	46.
800.	1440.	20.00	2901.	5.7	.45	331.	770.	.25	1.06	127.	.79	31.	46.
820.	1476.	20.00	2901.	5.6	.43	340.	792.	.25	1.06	129.	.80	32.	47.
840.	1512.	20.00	2901.	5.4	.42	350.	814.	.25	1.06	131.	.82	32.	48.
860.	1548.	20.00	2901.	5.3	.41	359.	836.	.25	1.07	133.	.83	33.	48.
880.	1584.	20.00	2901.	5.2	.40	368.	857.	.26	1.08	135.	.84	33.	49.
900.	1620.	20.00	2901.	5.1	.39	378.	879.	.26	1.08	138.	.86	33.	50.
920.	1656.	20.00	2901.	5.0	.39	387.	901.	.26	1.09	140.	.87	34.	50.
940.	1692.	20.00	2901.	4.9	.38	397.	923.	.26	1.10	142.	.88	34.	51.
960.	1728.	20.00	2901.	4.8	.37	406.	945.	.26	1.10	144.	.90	35.	52.
980.	1764.	20.00	2901.	4.7	.36	416.	967.	.26	1.11	146.	.91	35.	52.
1000.	1800.	20.00	2901.	4.6	.36	425.	990.	.26	1.11	148.	.92	36.	53.

TABLE VI (cont.)

TEMPERATURE		PRESSURE		DENSITY		ENTHALPY		CP		THERMAL CONDUCTIVITY		VISCOSITY	
K	R	M PA	LB/SQ IN	LB/C FT	G/CC	BTU/LB	J/KG E-3	BTU/LB·R	J/KG·K E-3	BTU/FT·S·R	W/M·K E-6	LB/FT·S E+6	KG/M·S E+6
100.	180.	25.00	3626.	71.6	5.57	-44.	-104.	.39	1.61	321.	2.00	137.	204.
120.	216.	25.00	3626.	66.3	5.16	-31.	-71.	.39	1.62	276.	1.72	90.	134.
140.	252.	25.00	3626.	60.7	4.72	-16.	-38.	.40	1.68	232.	1.45	66.	98.
160.	288.	25.00	3626.	54.4	4.24	-2.	-4.	.42	1.76	193.	1.20	54.	80.
180.	324.	25.00	3626.	47.7	3.71	14.	32.	.44	1.83	160.	1.00	44.	66.
200.	360.	25.00	3626.	40.9	3.18	29.	69.	.44	1.84	137.	.86	37.	55.
220.	396.	25.00	3626.	34.6	2.69	45.	105.	.42	1.75	121.	.75	32.	47.
240.	432.	25.00	3626.	29.6	2.31	59.	138.	.38	1.60	110.	.68	28.	42.
260.	468.	25.00	3626.	25.8	2.01	73.	169.	.35	1.46	103.	.64	26.	39.
280.	504.	25.00	3626.	23.0	1.79	85.	197.	.32	1.35	99.	.62	25.	38.
300.	540.	25.00	3626.	20.7	1.61	96.	223.	.30	1.26	97.	.60	25.	37.
320.	576.	25.00	3626.	19.0	1.48	106.	247.	.28	1.19	96.	.60	24.	36.
340.	612.	25.00	3626.	17.4	1.36	118.	274.	.28	1.17	95.	.59	24.	36.
360.	648.	25.00	3626.	16.4	1.27	127.	297.	.27	1.15	94.	.58	25.	36.
380.	684.	25.00	3626.	15.3	1.19	137.	319.	.27	1.12	94.	.59	25.	37.
400.	720.	25.00	3626.	14.2	1.11	147.	342.	.26	1.10	95.	.59	25.	37.
420.	756.	25.00	3626.	13.5	1.05	156.	363.	.26	1.09	96.	.60	25.	37.
440.	792.	25.00	3626.	12.8	1.00	165.	385.	.26	1.08	98.	.61	25.	38.
460.	828.	25.00	3626.	12.2	.95	175.	407.	.26	1.08	99.	.62	26.	38.
480.	864.	25.00	3626.	11.7	.91	184.	428.	.26	1.07	101.	.63	26.	38.
500.	900.	25.00	3626.	11.2	.87	193.	449.	.25	1.07	102.	.64	26.	39.
520.	936.	25.00	3626.	10.8	.84	202.	471.	.25	1.07	104.	.65	27.	39.
540.	972.	25.00	3626.	10.4	.81	211.	492.	.25	1.07	106.	.66	27.	40.
560.	1008.	25.00	3626.	10.0	.78	221.	513.	.25	1.07	107.	.67	27.	41.
580.	1044.	25.00	3626.	9.7	.75	230.	535.	.25	1.07	109.	.68	28.	41.
600.	1080.	25.00	3626.	9.3	.72	239.	556.	.25	1.07	111.	.69	28.	41.
620.	1116.	25.00	3626.	9.0	.70	248.	577.	.25	1.07	112.	.70	28.	42.
640.	1152.	25.00	3626.	8.7	.68	257.	599.	.26	1.07	114.	.71	29.	43.
660.	1188.	25.00	3626.	8.5	.66	266.	620.	.26	1.07	116.	.72	29.	43.
680.	1224.	25.00	3626.	8.2	.64	276.	642.	.26	1.07	117.	.73	29.	44.
700.	1260.	25.00	3626.	8.0	.62	285.	663.	.26	1.08	119.	.74	30.	44.
720.	1296.	25.00	3626.	7.8	.60	294.	685.	.26	1.07	121.	.75	30.	45.
740.	1332.	25.00	3626.	7.6	.59	303.	706.	.26	1.07	123.	.76	31.	46.
760.	1368.	25.00	3626.	7.4	.58	313.	728.	.26	1.07	124.	.78	31.	46.
780.	1404.	25.00	3626.	7.2	.56	322.	750.	.25	1.07	126.	.79	31.	47.
800.	1440.	25.00	3626.	7.0	.55	331.	771.	.25	1.07	128.	.80	32.	47.
820.	1476.	25.00	3626.	6.9	.53	341.	793.	.25	1.06	130.	.81	32.	48.
840.	1512.	25.00	3626.	6.7	.52	350.	815.	.25	1.06	132.	.82	33.	49.
860.	1548.	25.00	3626.	6.5	.51	360.	837.	.25	1.07	134.	.84	33.	49.
880.	1584.	25.00	3626.	6.4	.50	369.	859.	.26	1.08	136.	.85	33.	50.
900.	1620.	25.00	3626.	6.3	.49	378.	881.	.26	1.09	138.	.86	34.	50.
920.	1656.	25.00	3626.	6.1	.48	388.	903.	.26	1.09	140.	.87	34.	51.
940.	1692.	25.00	3626.	6.0	.47	397.	925.	.26	1.10	142.	.89	35.	52.
960.	1728.	25.00	3626.	5.9	.46	407.	947.	[illegible]	1.11	144.	.90	35.	52.
980.	1764.	25.00	3626.	5.8	.45	416.	969.	.27	1.11	146.	.91	35.	53.
1000.	1800.	25.00	3626.	5.6	.44	426.	991.	[illegible]	1.11	146.	.92	36.	53.

TABLE VI (cont.)

TEMPERATURE		PRESSURE		DENSITY		ENTHALPY		CP		THERMAL CONDUCTIVITY		VISCOSITY	
K	R	M PA	LB/SQ IN	LB/C FT	G/CC	BTU/LB	J/KG E-3	BTU/LB·R	J/KG·K E-3	BTU/FT·SR	W/M·K E-6	LB/FT·S E+6	KG/M·S E+6
100.	180.	30.00	4351.	72.2	5.62	-43.	-101.	.38	1.60	327.	2.04	145.	216.
120.	216.	30.00	4351.	67.1	5.22	-30.	-69.	.38	1.59	283.	1.77	95.	142.
140.	252.	30.00	4351.	61.8	4.81	-16.	-37.	.39	1.65	241.	1.51	70.	104.
160.	288.	30.00	4351.	56.2	4.37	-2.	-4.	.40	1.68	204.	1.27	56.	84.
180.	324.	30.00	4351.	50.2	3.91	13.	31.	.41	1.73	173.	1.08	48.	71.
200.	360.	30.00	4351.	44.2	3.44	28.	65.	.41	1.72	149.	.93	41.	61.
220.	396.	30.00	4351.	38.6	3.00	43.	99.	.40	1.66	132.	.82	35.	53.
240.	432.	30.00	4351.	33.8	2.63	57.	132.	.38	1.59	120.	.75	32.	47.
260.	468.	30.00	4351.	29.9	2.33	70.	162.	.35	1.46	113.	.70	29.	44.
280.	504.	30.00	4351.	26.8	2.08	82.	191.	.33	1.38	108.	.67	28.	41.
300.	540.	30.00	4351.	24.3	1.89	93.	217.	.31	1.29	105.	.65	27.	40.
320.	576.	30.00	4351.	22.2	1.73	104.	242.	.29	1.22	103.	.64	26.	39.
340.	612.	30.00	4351.	20.5	1.59	116.	269.	.29	1.20	102.	.63	26.	39.
360.	648.	30.00	4351.	19.2	1.50	126.	293.	.28	1.17	99.	.62	26.	39.
380.	684.	30.00	4351.	18.0	1.40	136.	316.	.27	1.15	99.	.62	26.	39.
400.	720.	30.00	4351.	16.7	1.30	146.	339.	.27	1.12	99.	.62	26.	39.
420.	756.	30.00	4351.	15.9	1.24	155.	361.	.26	1.11	100.	.63	26.	39.
440.	792.	30.00	4351.	15.1	1.18	165.	383.	.26	1.10	102.	.63	27.	40.
460.	828.	30.00	4351.	14.4	1.12	174.	405.	.26	1.09	103.	.64	27.	40.
480.	864.	30.00	4351.	13.7	1.07	183.	427.	.26	1.09	105.	.65	27.	40.
500.	900.	30.00	4351.	13.1	1.02	193.	448.	.26	1.08	106.	.66	27.	41.
520.	936.	30.00	4351.	12.7	.99	202.	470.	.26	1.08	107.	.67	28.	41.
540.	972.	30.00	4351.	12.3	.95	211.	491.	.26	1.08	109.	.68	28.	42.
560.	1008.	30.00	4351.	11.8	.92	220.	513.	.26	1.08	110.	.69	28.	42.
580.	1044.	30.00	4351.	11.4	.89	230.	534.	.26	1.08	112.	.70	29.	43.
600.	1080.	30.00	4351.	11.0	.85	239.	556.	.26	1.08	113.	.71	29.	43.
620.	1116.	30.00	4351.	10.6	.83	248.	577.	.26	1.08	115.	.72	29.	44.
640.	1152.	30.00	4351.	10.3	.80	257.	599.	.26	1.08	116.	.73	30.	44.
660.	1188.	30.00	4351.	10.0	.78	267.	621.	.26	1.08	118.	.74	30.	45.
680.	1224.	30.00	4351.	9.7	.75	276.	642.	.26	1.08	120.	.75	30.	45.
700.	1260.	30.00	4351.	9.4	.73	285.	664.	.26	1.08	121.	.76	31.	46.
720.	1296.	30.00	4351.	9.2	.71	295.	686.	.26	1.08	123.	.76	31.	46.
740.	1332.	30.00	4351.	9.0	.70	304.	707.	.26	1.08	124.	.77	31.	47.
760.	1368.	30.00	4351.	8.7	.68	313.	729.	.26	1.08	126.	.78	32.	47.
780.	1404.	30.00	4351.	8.5	.66	323.	751.	.26	1.08	127.	.79	32.	48.
800.	1440.	30.00	4351.	8.3	.65	332	773.	.26	1.08	129.	.81	32.	48.
820.	1476.	30.00	4351.	8.1	.63	341.	795.	.26	1.08	131.	.82	33.	49.
840.	1512.	30.00	4351.	7.9	.61	351.	817.	.26	1.08	133.	.83	33.	49.
860.	1548.	30.00	4351.	7.7	.60	360.	839.	.26	1.09	135.	.84	33.	50.
880.	1584.	30.00	4351.	7.6	.59	370.	861.	.26	1.09	137.	.86	34.	50.
900.	1620.	30.00	4351.	7.4	.58	379.	883.	.26	1.10	139.	.87	34.	51.
920.	1656.	30.00	4351.	7.2	.56	389.	905.	.26	1.10	141.	.88	35.	51.
940.	1692.	30.00	4351.	7.1	.55	398.	927.	.26	1.11	143.	.89	35.	52.
960.	1728.	30.00	4351.	6.9	.54	408.	949.	.27	1.11	145.	.90	35.	52.
980.	1764.	30.00	4351.	6.8	.53	417.	971.	.27	1.11	146.	.91	36.	53.
1000.	1800.	30.00	4351.	6.7	.52	427.	994.	.27	1.12	148.	.92	36.	53.

TABLE VI (cont.)

TEMPERATURE		PRESSURE		DENSITY		ENTHALPY		CP		THERMAL CONDUCTIVITY		VISCOSITY	
K	R	MPA	LB/SQ IN	LB/C FT	G/CC	BTU/LB	J/KG E-3	BTU/LB·F	J/KG·K E-3	BTU/FT·SR	W/M·K E-6	LB/FT·S F+6	KG/M·S E+6
100.	180.	34.47	4999.	72.7	5.66	-42.	-98.	.38	1.59	332.	2.07	152.	226.
120.	216.	34.47	4999.	67.8	5.28	-29.	-67.	.38	1.57	289.	1.80	100.	149.
140.	252.	34.47	4999.	62.7	4.88	-15.	-35.	.39	1.63	249.	1.55	73.	109.
160.	288.	34.47	4999.	57.5	4.47	-1.	-3.	.39	1.63	213.	1.33	59.	88.
180.	324.	34.47	4999.	52.0	4.05	13.	30.	.40	1.69	182.	1.14	51.	75.
200.	360.	34.47	4999.	46.6	3.62	27.	64.	.39	1.63	158.	.99	44.	65.
220.	396.	34.47	4999.	41.4	3.22	41.	96.	.37	1.55	141.	.88	38.	57.
240.	432.	34.47	4999.	36.8	2.87	55.	128.	.40	1.69	130.	.81	35.	51.
260.	468.	34.47	4999.	32.9	2.56	68.	158.	.34	1.45	121.	.75	32.	47.
280.	504.	34.47	4999.	29.7	2.31	80.	186.	.34	1.44	115.	.72	30.	45.
300.	540.	34.47	4999.	27.1	2.11	92.	213.	.31	1.29	112.	.70	29.	43.
320.	576.	34.47	4999.	24.9	1.94	103.	239.	.29	1.23	109.	.68	28.	42.
340.	612.	34.47	4999.	23.0	1.79	114.	266.	.29	1.22	107.	.67	28.	41.
360.	648.	34.47	4999.	21.7	1.68	125.	290.	.28	1.19	102.	.64	28.	41.
380.	684.	34.47	4999.	20.3	1.58	135.	313.	.28	1.17	102.	.64	28.	41.
400.	720.	34.47	4999.	18.9	1.47	145.	336.	.27	1.14	102.	.64	28.	41.
420.	756.	34.47	4999.	18.0	1.40	154.	359.	.27	1.13	103.	.65	28.	42.
440.	792.	34.47	4999.	17.0	1.33	164.	381.	.27	1.11	105.	.65	28.	42.
460.	828.	34.47	4999.	16.2	1.26	173.	404.	.26	1.11	106.	.66	28.	42.
480.	864.	34.47	4999.	15.5	1.21	183.	426.	.26	1.10	107.	.67	28.	42.
500.	900.	34.47	4999.	14.8	1.15	192.	447.	.26	1.09	109.	.68	29.	43.
520.	936.	34.47	4999.	14.3	1.12	202.	469.	.26	1.09	110.	.69	29.	43.
540.	972.	34.47	4999.	13.9	1.08	211.	491.	.26	1.09	111.	.69	29.	43.
560.	1008.	34.47	4999.	13.4	1.04	220.	513.	.26	1.09	113.	.70	29.	43.
580.	1044.	34.47	4999.	12.9	1.00	230.	534.	.26	1.09	114.	.71	29.	44.
600.	1080.	34.47	4999.	12.4	.96	239.	556.	.26	1.08	116.	.72	30.	44.
620.	1116.	34.47	4999.	12.0	.94	248.	578.	.26	1.09	117.	.73	30.	45.
640.	1152.	34.47	4999.	11.7	.91	258.	600.	.26	1.09	119.	.74	30.	45.
660.	1188.	34.47	4999.	11.3	.88	267.	621.	.26	1.09	120.	.75	30.	45.
680.	1224.	34.47	4999.	11.0	.85	276.	643.	.26	1.09	121.	.76	31.	46.
700.	1260.	34.47	4999.	10.6	.83	286.	665.	.26	1.09	123.	.77	31.	46.
720.	1296.	34.47	4999.	10.4	.81	295.	687.	.26	1.09	124.	.77	31.	47.
740.	1332.	34.47	4999.	10.1	.79	304.	708.	.26	1.09	126.	.78	32.	47.
760.	1368.	34.47	4999.	9.9	.77	314.	730.	.26	1.09	127.	.79	32.	47.
780.	1404.	34.47	4999.	9.7	.75	323.	752.	.26	1.09	129.	.80	32.	48.
800.	1440.	34.47	4999.	9.4	.73	332.	774.	.26	1.10	131.	.81	32.	48.
820.	1476.	34.47	4999.	9.2	.72	342.	796.	.26	1.10	132.	.83	33.	49.
840.	1512.	34.47	4999.	9.0	.70	351.	818.	.26	1.10	134.	.84	33.	49.
860.	1548.	34.47	4999.	8.8	.68	361.	840.	.26	1.10	136.	.85	34.	50.
880.	1584.	34.47	4999.	8.6	.67	370.	862.	.26	1.10	138.	.86	34.	50.
900.	1620.	34.47	4999.	8.4	.65	380.	884.	.26	1.11	140.	.87	34.	51.
920.	1656.	34.47	4999.	8.2	.64	389.	907.	.26	1.11	141.	.88	35.	52.
940.	1692.	34.47	4999.	8.0	.63	399.	929.	.27	1.11	143.	.89	35.	52.
960.	1728.	34.47	4999.	7.9	.61	409.	951.	.27	1.12	145.	.90	35.	53.
980.	1764.	34.47	4999.	7.7	.60	418.	973.	.27	1.12	147.	.91	36.	53.
1000.	1800.	34.47	4999.	7.6	.59	428.	996.	.27	1.12	148.	.92	36.	54.

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APPENDIX B

SUPERCRITICAL OXYGEN HEAT TRANSFER DATA

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The data used in developing a heat transfer correlation are listed in Table VII. This list includes data obtained from Powell (Ref. 2), and the previous Aerojet work by Rousar and Miller (IR&D) as well as data obtained during this investigation. Powell's data are listed first; the data obtained by Rousar and Miller are listed next, starting with Card No. 82 and continuing through Card No. 212; and the new data are listed last.

TABLE VII
SUPERCRITICAL OXYBEN HEAT TRANSFER DATA

PAGE 1

SUPERCRITICAL OXYGEN HEAT TRANSFER DATA

CARD NO.	P MPA	P PSIA	TB K	TB R	TW K	TW R	DIA. MM	DIA. IN.	L/D	NU *E-3	PR	RE *E-6	PHI *E-6 W/M²	RHO*V *E-3 Kg/M²s	$\frac{\phi}{\rho V}\frac{1}{1+\frac{2}{l/d}}$	$\frac{\rho b}{\rho w}$	$\frac{\mu b}{\mu w}$	$\frac{k b}{k w}$	$\frac{\bar{C}p}{Cp}$
1.	6.72	975.	134.	241.	556.	1000.	4.88	.192	53.0	1.04	1.71	1.29	8.8	22.2	.90	19.70	2.42	2.10	.69
2.	6.89	1000.	139.	251.	556.	1000.	4.88	.192	54.0	.93	1.82	1.16	7.2	18.6	.89	18.40	2.24	1.94	.65
3.	5.78	838.	278.	500.	556.	1000.	4.88	.192	111.0	1.88	.81	1.29	3.2	6.2	1.82	2.11	.67	.63	.97
4.	6.27	910.	106.	191.	556.	1000.	4.88	.192	10.4	1.15	1.79	.89	14.2	25.8	1.03	24.90	4.05	2.89	.79
5.	6.19	898.	111.	200.	556.	1000.	4.88	.192	14.0	1.06	1.70	1.06	12.4	27.2	.89	24.60	3.62	2.75	.75
6.	7.30	1059.	233.	420.	556.	1000.	4.88	.192	10.9	1.30	.93	1.09	2.6	5.2	1.30	2.74	.66	.64	.86
7.	7.14	1035.	272.	490.	556.	1000.	4.88	.192	7.1	1.10	.84	1.02	2.0	5.1	1.07	2.19	.69	.66	.94
8.	7.00	1015.	201.	361.	556.	1000.	4.88	.192	8.3	1.27	1.10	1.19	2.8	5.5	1.13	3.57	.65	.64	.72
9.	6.55	950.	243.	438.	556.	1000.	4.88	.192	9.9	1.24	.88	.86	2.3	4.0	1.55	2.54	.65	.62	.90
10.	6.23	904.	260.	468.	556.	1000.	4.88	.192	20.8	1.03	.84	.80	1.8	3.8	1.49	2.31	.66	.63	.94
11.	6.71	973.	156.	280.	556.	1000.	4.88	.192	185.0	.62	2.94	1.22	3.4	13.6	.62	14.60	1.57	1.45	.36
12.	6.94	1037.	146.	262.	556.	1000.	4.88	.192	19.8	.24	2.02	.21	1.7	3.0	1.23	17.10	2.03	1.75	.56
13.	6.94	1007.	154.	277.	556.	1000.	4.88	.192	66.7	.34	2.64	.44	1.9	5.2	.89	15.00	1.68	1.49	.42
14.	6.96	1009.	158.	285.	556.	1000.	4.88	.192	36.5	.27	3.35	.29	1.5	3.0	1.18	13.30	1.44	1.42	.22
15.	7.41	1075.	153.	276.	556.	1000.	4.88	.192	113.0	.41	2.44	.72	2.4	9.0	.65	14.50	1.74	1.51	.45
16.	7.41	1075.	170.	306.	556.	1000.	4.88	.192	193.0	.62	2.74	1.48	2.3	9.0	.66	6.89	.85	1.02	.25
17.	7.34	1064.	156.	280.	556.	1000.	4.88	.192	143.0	.49	2.64	.88	2.8	10.3	.66	14.00	1.54	1.47	.41
18.	7.34	1364.	169.	305.	556.	1000.	4.88	.192	204.0	.71	2.82	1.71	2.7	10.3	.66	6.97	.85	1.03	.25
19.	5.96	865.	296.	533.	[illegible]6.	1000.	4.88	.192	9.9	1.80	.80	1.14	2.9	5.6	1.68	1.96	.69	.66	.98
20.	5.45	790.	283.	510.	556.	1000.	4.88	.192	12.0	2.28	.80	1.46	3.8	7.0	1.70	2.06	.67	.63	.98
21.	4.38	635.	217.	390.	556.	1000.	4.88	.192	10.4	1.79	.8[illegible]	1.46	3.2	5.9	1.32	2.86	.57	.54	.90
22.	4.34	630.	244.	440.	556.	1000.	4.86	.192	7.3	1.92	.82	1.25	3.3	5.3	1.54	2.43	.60	.57	.95
23.	4.31	625.	261.	469.	556.	1000.	4.88	.192	13.5	1.70	.80	1.26	2.8	5.6	1.50	2.25	.62	.59	.97
24.	4.38	635.	296.	[illegible]33.	556.	1000.	4.88	.192	39.5	1.65	.78	1.23	2.6	5.8	1.62	1.93	.67	.63	.99
25.	4.23	613.	195.	351.	556.	1000.	4.88	.192	16.7	1.71	.92	1.90	3.1	7.3	1.04	3.34	.54	.52	.83
26.	3.61	524.	200.	370.	556.	1000.	4.84	.192	12.5	1.68	.86	1.54	2.9	5.8	1.21	3.01	.53	.51	.90
27.	4.14	600.	251.	452.	556.	1000.	4.88	.192	7.8	3.23	.80	2.02	5.4	8.7	1.62	2.34	.60	.57	.96
28.	4.41	640.	250.	450.	556.	1000.	4.88	.192	6.8	3.29	.81	2.14	5.6	9.3	1.51	2.37	.61	.58	.95
29.	4.39	6[illegible]	278.	500.	556.	1000.	4.88	.192	17.7	2.80	.79	2.03	4.5	9.3	1.58	2.08	.64	.61	.98
30.	3.10	449.	317.	570.	556.	1000.	4.88	.192	28.6	1.11	.76	.83	1.6	4.0	1.59	1.78	.67	.64	1.01
31.	2.68	385.	325.	585.	556.	1000.	4.88	.192	31.0	.76	.75	.57	1.1	2.7	1.60	1.73	.68	.64	1.02
32.	3.03	440.	212.	382.	556.	1000.	4.88	.192	7.8	1.58	.82	1.22	2.6	4.5	1.32	2.83	.52	.50	.93
33	3.17	460.	261.	470.	556.	1000.	4.88	.192	8.3	2.46	.78	1.58	3.9	6.7	1.60	2.21	.59	.56	.99
34.	1.77	256.	254.	455.	556.	1000.	4.88	.192	6.3	.91	.75	.53	1.4	2.1	1.64	2.23	.56	.52	1.01
35.	1.76	255.	324.	583.	556.	1000.	4.88	.192	47.0	.62	.74	.49	.9	2.3	1.54	1.72	.66	.63	1.02
36.	1.79	259.	339.	610.	556.	1000.	4.88	.192	47.0	.58	.74	.43	.9	2.3	1.65	1.66	.76	.72	1.02
37.	6.72	975.	129.	233.	333.	600.	4.88	.192	45.0	1.79	1.65	1.21	7.8	22.2	1.64	11.94	3.43	3.13	.87
38.	6.89	1000.	133.	240.	333.	600.	4.88	.192	51.0	1.58	1.69	1.07	6.4	18.6	1.66	11.32	3.24	2.97	.87
39.	7.07	1025.	128.	230.	333.	600.	4.88	.192	52.0	1.63	1.61	1.10	7.3	20.9	1.64	11.51	3.52	3.09	.91
40.	7.10	1030.	134.	242.	333.	600.	4.88	.192	45.0	1.90	1.71	1.29	7.6	22.[illegible]	1.64	10.91	3.19	2.91	.86
41.	6.19	898.	107.	193.	333.	600.	4.88	.192	8.3	1.78	1.76	.97	11.0	27.[illegible]	1.44	14.72	5.32	4.05	.96
42.	7.31	1060.	113.	203.	333.	600.	4.88	.192	15.1	1.67	1.68	1.00	9.6	25.[illegible]	1.51	12.15	4.67	3.77	1.02
43.	6.92	1004.	127.	228.	333.	600.	4.88	.192	35.0	1.74	1.61	1.22	8.0	23.5	1.55	11.83	3.59	3.24	.92
44.	6.23	904.	247.	445.	333.	600.	4.88	.192	15.6	1.56	.86	.89	.8	4.1	1.99	1.45	.87	.87	.94
45.	6.65	964.	125.	225.	333.	600.	4.88	.192	34.4	1.57	1.61	1.08	7.4	21.3	1.57	12.44	3.71	3.31	.92
46.	6.96	1010.	178.	320.	333.	600.	4.88	.192	10.4	1.73	1.63	1.18	1.9	5.9	1.75	2.93	.93	1.03	.52
47.	6.47	938.	115.	207.	333.	600.	4.88	.192	19.8	1.66	1.66	.98	9.1	23.5	1.62	13.55	4.49	3.72	.94
48.	6.48	940.	122.	220.	333.	600.	4.88	.192	23.4	1.67	1.61	1.11	8.2	23.[illegible]	1.56	12.97	3.90	3.43	.96
49.	6.85	994.	183.	330.	333.	600.	4.88	.192	23.4	1.93	1.37	1.22	1.9	[illegible]	2.00	2.60	.69	.96	.62
50.	6.21	900.	129.	233.	333.	600.	4.88	.192	48.0	1.62	1.66	1.19	7.0	21.7	1.52	12.90	3.44	3.14	.87

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TABLE VII (cont.)

PAGE 2

SUPERCRITICAL OXYGEN HEAT TRANSFER DATA

CARD NO.	P MPA	P PSIA	TB K	TB R	TW K	TW R	DIA. MM	DIA. IN.	L/D	NU *E-3	PR	RE *E-6	PHI *E-6 W/M2	RHO*V *E-3 Kg/M2S	$\frac{\phi}{\rho V}\frac{1}{1+\frac{2}{L/d}}$	$\frac{\rho b}{\rho w}$	$\frac{\mu b}{\mu w}$	$\frac{k b}{k w}$	$\frac{\overline{C_p}}{C_{p_b}}$
51.	6.71	973.	144.	260.	333.	600.	4.88	.192	167.0	.93	2.00	.93	3.0	13.6	1.15	10.46	2.74	2.49	.71
52.	6.94	1007.	125.	225.	333.	600.	4.88	.192	5.2	.31	1.61	.15	1.4	3.0	1.67	11.92	3.70	3.30	.94
53.	6.94	1007.	144.	260.	333.	600.	4.88	.192	53.6	.52	1.98	.36	1.7	5.3	1.62	10.14	2.74	2.49	.73
54.	6.96	1009.	137.	246.	333.	600.	4.88	.192	19.8	.33	1.76	.18	1.3	3.0	1.94	10.92	3.09	2.83	.88
55.	7.41	1075.	147.	265.	333.	600.	4.88	.192	92.0	.67	2.05	.63	2.0	9.0	1.20	9.26	2.62	2.38	.70
56.	7.34	1064.	151.	272.	333.	600.	4.88	.192	122.0	.82	2.29	.79	2.3	10.3	1.19	8.85	2.42	2.20	.63
57.	7.36	1068.	164.	295.	333.	600.	4.88	.192	21.9	.99	4.09	1.47	2.1	11.9	.96	5.89	1.50	1.83	.23
58.	5.95	863.	244.	440.	333.	600.	4.88	.192	6.8	1.79	.86	.82	.7	3.7	2.16	1.47	.86	.67	.94
59.	2.62	380.	297.	535.	333.	600.	4.88	.192	52.0	1.31	.76	.69	.3	3.1	2.33	1.13	.93	.92	1.00
60.	2.62	380.	278.	500.	333.	600.	4.88	.192	5.2	1.54	.76	.71	.5	3.1	1.97	1.22	.89	.88	.99
61.	6.36	922.	349.	628.	1000.	1800.	4.88	.192	26.0	1.01	.78	.98	4.6	5.4	1.23	2.97	.52	.49	1.04
62.	7.29	1057.	218.	393.	1000.	1801.	4.88	.192	29.7	.70	.99	1.26	3.3	5.9	.67	5.55	.45	.42	.81
63.	7.30	1059.	267.	480.	1000.	1800.	4.88	.192	33.0	.73	.65	1.07	3.4	5.2	.82	4.10	.47	.43	.96
64.	7.00	1015.	233.	419.	1000.	1800.	4.88	.192	37.5	.71	.92	1.18	3.3	5.5	.73	4.96	.44	.42	.88
65.	6.94	1007.	183.	330.	1000.	1800.	4.88	.192	48.0	.36	1.39	.63	2.0	3.0	.77	8.13	.46	.46	.55
66.	6.94	1007.	156.	280.	1000.	1800.	4.88	.192	86.0	.19	2.80	.46	2.3	5.2	.50	26.25	1.08	.97	.34
67.	6.94	1007.	160.	288.	1000.	1800.	4.88	.192	99.0	.20	3.43	.56	2.3	5.2	.52	22.44	.90	.93	.21
68.	6.96	1009.	202.	364.	1000.	1800.	4.88	.192	69.0	.36	1.08	.65	1.7	3.0	.70	6.35	.44	.42	.74
69.	6.96	1009.	247.	445.	1000.	1800.	4.88	.192	103.0	.38	.88	.63	1.7	3.0	.75	4.53	.45	.42	.92
70.	5.98	868.	566.	1019.	1000.	1500.	4.88	.192	117.0	.91	.76	.76	3.8	5.5	1.59	1.78	.69	.67	1.04
71.	5.67	823.	361.	650.	1000.	1800.	4.88	.192	39.0	1.22	.77	1.23	5.6	6.9	1.21	2.86	.53	.50	1.05
72.	4.34	633.	350.	630.	1000.	1800.	4.88	.192	52.0	.84	.76	.99	3.9	5.5	1.05	2.94	.52	.49	1.06
73.	4.50	653.	364.	655.	1000.	1800.	4.88	.192	52.0	.91	.76	.99	4.2	5.6	1.14	2.83	.53	.50	1.06
74.	4.41	640.	348.	627.	1000.	1800.	4.88	.192	53.0	1.49	.76	1.69	6.8	9.3	1.05	2.96	.52	.49	1.06
75.	4.48	650.	344.	620.	1000.	1800.	4.88	.192	44.0	1.48	.76	1.66	6.8	9.1	1.09	2.99	.52	.48	1.06
76.	3.09	448.	355.	639.	1000.	1800.	4.88	.192	28.6	.67	.75	.66	3.1	3.7	1.22	2.88	.53	.49	1.07
77.	3.12	452.	338.	609.	1000.	1800.	4.88	.192	20.8	.71	.75	.67	3.2	3.6	1.21	3.02	.51	.48	1.07
78.	2.75	399.	444.	800.	1000.	1800.	4.88	.192	62.0	.41	.74	.40	1.9	2.5	1.32	2.26	.59	.57	1.07
79.	1.77	256.	369.	665.	1000.	1800.	4.88	.192	51.6	.35	.74	.37	1.6	2.1	1.16	2.76	.54	.51	1.08
80.	1.78	258.	357.	642.	1000.	1800.	4.88	.192	40.1	.37	.74	.38	1.7	2.1	1.19	2.86	.53	.49	1.08
81.	1.75	254.	305.	549.	1000.	1800.	4.88	.192	16.7	.50	.74	[illegible]	2.0	2.1	1.19	3.33	.43	.40	1.08
82.	34.47	5000.	104.	188.	223.	402.	4.00	.158	5.0	1.22	2.09	.37	5.6	18.8	1.79	1.77	3.67	2.33	1.00
83.	34.47	5000.	107.	193.	229.	412.	4.00	.158	10.0	1.22	2.00	.39	5.6	18.8	2.05	1.81	3.56	2.35	1.00
84.	34.47	5000.	110.	198.	232.	418.	4.00	.158	15.0	[illegible]	1.92	.41	5.6	18.8	2.16	1.83	3.41	2.34	1.00
85.	34.47	5000.	113.	203.	237.	427.	4.00	.158	20.0	[illegible]	1.85	.44	5.6	18.9	2.18	1.86	3.30	2.34	1.00
86.	34.47	5000.	107.	193.	312.	562.	4.00	.158	5.0	1.14	2.00	.39	8.9	18.8	1.65	2.76	4.60	2.88	.96
87.	34.47	5000.	112.	201.	338.	609.	4.00	.158	10.0	1.07	1.88	.43	8.9	18.9	1.74	3.02	4.25	2.86	.94
88.	34.47	5000.	117.	210.	352.	633.	4.00	.158	15.0	1.07	1.75	.48	8.9	18.9	1.77	3.09	3.85	2.85	.92
89.	34.47	5000.	122.	219.	369.	664.	4.00	.158	20.0	1.05	1.65	.52	8.9	18.9	1.73	3.21	3.52	2.81	.90
90.	34.47	5000.	108	194.	479.	863.	4.00	.158	5.0	.89	1.99	.39	12.4	18.5	1.28	4.56	4.52	2.94	.84
91.	34.47	5000.	115.	207.	563.	1014.	4.00	.158	10.0	.77	1.79	.46	12.4	18.7	1.24	5.20	3.78	2.66	.81
92.	34.47	5000.	123.	221.	623.	1122.	4.00	.158	15.0	.73	1.63	.52	12.4	18.6	1.17	5.61	3.20	2.42	.80
93.	34.47	5000.	130.	234.	699.	1259.	4.00	.158	20.0	.68	1.54	.59	12.4	18.7	1.06	6.15	2.73	2.19	.78
94.	34.47	5000.	108.	195.	587.	1057.	4.00	.158	5.0	.76	1.97	.39	13.7	18.3	1.12	5.56	4.30	2.74	.82
95.	34.47	5000.	117.	211.	722.	1299.	4.00	.158	10.0	.64	1.74	.47	13.7	18.3	1.03	6.62	3.39	2.38	.77
96.	34.47	5000.	126.	226.	802.	1444.	4.00	.158	15.0	.61	1.59	.54	13.7	18.4	.97	7.05	2.79	2.12	.76
97.	34.47	5000.	134.	242.	900.	1620.	4.00	.158	20.0	.57	1.48	.53	13.7	15.4	1.05	7.63	2.31	1.86	.75
98.	34.47	5000.	107.	193.	151.	271.	4.00	.158	20.0	.83	2.00	.21	1.4	10.2	2.82	1.18	2.02	1.38	1.00
99.	34.47	5000.	108.	195.	152.	274.	4.00	.158	25.0	.83	1.97	.22	1.4	10.2	[illegible]	1.19	2.01	1.39	1.00
100.	34.47	5000.	109.	197.	160.	288.	4.00	.158	30.0	.73	1.94	.22	1.4	10.2	2.50	1.22	2.09	1.46	1.00

TABLE VII (cont.)

PAGE 3

SUPERCRITICAL OXYGEN HEAT TRANSFER DATA

CARD NO.	P MPA	P PSIA	TB K	TB R	TW K	TW R	DIA. MM	DIA. IN.	L/D	NU *E-3	PR	RE *E-6	PHI *E-6 W/M2	RHO*V *E-3 Kg/M2s	$\frac{\phi}{\rho V}\frac{1}{1+\frac{2}{l/d}}$	$\frac{\rho b}{\rho w}$	$\frac{\mu b}{\mu w}$	$\frac{k b}{k w}$	$\frac{\bar{C}_p}{C_{p_b}}$
101.	34.47	5000.	111.	200.	167.	300.	4.00	.158	35.0	.67	1.89	.23	1.4	10.2	2.31	1.26	2.14	1.52	1.00
102.	34.47	5000.	112.	202.	165.	297.	4.00	.158	40.0	.72	1.86	.24	1.4	10.2	2.45	1.24	2.05	1.49	1.00
103.	34.47	5000.	111.	199.	194.	350.	4.00	.158	20.0	.67	1.91	.22	2.1	9.9	2.28	1.46	2.66	1.59	1.00
104.	34.47	5000.	113.	203.	198.	357.	4.00	.158	25.0	.67	1.85	.23	2.1	9.9	2.28	1.48	2.62	1.90	1.00
105.	34.47	5000.	114.	206.	206.	371.	4.00	.158	30.0	.63	1.81	.24	2.1	10.0	2.15	1.54	[illegible]	1.97	1.00
106.	[illegible].47	5000.	117.	[illegible]10.	212.	382.	4.00	.158	35.0	.62	1.75	.25	2.1	10.0	2.08	1.58	2.65	2.01	1.01
107.	34.47	5000.	119.	214.	214.	385.	4.00	.158	40.0	.63	1.71	.26	2.1	9.9	2.11	1.59	2.57	2.00	1.01
108.	34.47	5000.	113.	204.	256.	461.	4.00	.158	20.0	.58	1.83	.23	3.0	9.7	1.99	2.07	3.53	2.49	.99
109.	34.47	5000.	117.	210.	264.	475.	4.00	.158	25.0	.58	1.75	.24	3.0	9.7	1.96	2.13	3.42	2.49	.99
110.	34.47	5000.	119.	215.	273.	492.	4.00	.158	30.0	.56	1.70	.26	3.0	9.7	1.90	2.21	3.33	2.49	.98
111.	34.47	5000.	122.	220.	281.	505.	4.00	.158	35.0	.56	1.64	.27	3.0	9.7	1.86	2.27	3.22	2.48	.98
112.	34.47	5000.	126.	226.	290.	522.	4.00	.158	40.0	.55	1.59	.29	3.0	9.7	1.81	2.35	3.12	2.46	.97
113.	34.30	4975.	119.	215.	317.	571.	4.00	.158	20.0	.57	1.70	.27	3.9	10.0	1.81	2.71	3.61	2.66	.95
114.	34.30	4975.	124.	223.	330.	594.	4.00	.158	25.0	.57	1.61	.29	3.9	10.0	1.76	2.80	3.38	2.60	.95
115.	34.30	4975.	128.	231.	343.	618.	4.00	.158	30.0	.56	1.54	.31	4.0	10.1	1.71	2.89	3.13	2.57	.92
116.	34.30	4975.	133.	240.	352.	633.	4.00	.158	35.0	.57	1.55	.33	3.9	10.0	1.70	2.91	2.92	2.53	.91
117.	34.30	4975.	138.	248.	373.	672.	4.00	.158	40.0	.55	1.47	.36	3.9	10.0	1.59	3.07	2.73	2.49	.89
118.	33.59	4872.	125.	225.	451.	812.	4.00	.158	20.0	.47	1.59	.29	5.1	9.9	1.43	4.10	3.25	2.66	.85
119.	33.59	4872.	131.	236.	479.	863.	4.00	.158	25.0	.46	1.52	.32	5.1	9.9	1.36	4.27	2.93	2.49	.84
120.	33.59	4872.	137.	247.	508.	915.	4.00	.158	30.0	.45	1.47	.35	5.1	9.9	1.29	4.[illegible]	2.66	2.33	.83
121.	33.59	4872.	145.	257.	529.	952.	4.00	.158	35.0	.45	1.40	.38	5.1	9.9	1.25	4.48	2.44	2.20	.80
122.	33.59	4972.	149.	268.	574.	1033.	4.00	.158	40.0	.[illegible]	1.42	.41	5.1	9.9	1.15	4.73	2.23	2.04	.79
123.	33.10	4800.	130.	234.	629.	1133.	4.00	.158	20.0	.36	1.53	.39	5.8	9.4	1.13	6.40	2.64	2.16	.78
124.	33.10	4800.	137.	247.	686.	1234.	4.00	.158	25.0	.35	1.47	.34	5.8	9.3	1.05	6.80	2.28	1.94	.77
125.	33.10	4800.	144.	260.	746.	1342.	4.00	.158	30.0	.34	1.42	.37	5.8	9.3	.97	7.23	1.98	1.73	.76
126.	33.10	4800.	152.	273.	786.	1414.	4.00	.158	35.0	.34	1.40	.40	5.8	9.4	.92	7.37	1.77	1.57	.75
127.	33.10	4800.	159.	286.	873.	1571.	4.00	.158	40.0	.32	1.34	.43	5.8	9.4	.83	7.72	1.60	1.40	.74
128.	32.68	4740.	131.	[illegible]36.	703.	1266.	4.00	.158	20.0	.36	1.52	.32	6.5	9.8	1.04	6.40	2.64	2.16	.78
129.	32.68	4740.	139.	250.	781.	1405.	4.00	.158	25.0	.34	1.46	.36	6.4	9.8	.95	6.80	2.28	1.94	.75
130.	32.68	4740.	147.	264.	856.	1540.	4.00	.158	30.0	.32	1.44	.40	6.4	9.8	.87	7.23	1.98	1.73	.75
131.	32.68	4740.	154.	278.	906.	1630.	4.00	.158	35.0	.32	1.34	.43	6.4	9.8	.82	7.37	1.77	1.57	.74
132.	32.68	4740.	162.	291.	989.	1780.	4.00	.158	40.0	.31	1.42	.46	6.4	9.8	.76	7.72	1.60	1.40	.74
173.	34.27	4970.	107.	193.	334.	601.	5.59	.220	3.6	.76	2.00	.28	4.7	9.6	1.37	3.03	4.68	2.93	.94
174.	34.27	4970.	111.	200.	367.	661.	5.59	.220	7.1	.68	1.89	.30	4.6	9.5	1.48	3.32	4.34	3.03	.91
175.	34.27	4970.	114.	206.	379.	682.	5.59	.220	10.7	.68	1.80	.32	4.6	9.6	1.55	3.41	4.03	2.96	.90
176.	34.27	4970.	118.	212.	380.	684.	5.59	.220	14.3	.70	1.73	.35	4.7	9.6	1.62	3.39	3.77	2.89	.90
177.	34.27	4970.	121.	218.	394.	710.	5.59	.220	17.8	.69	1.66	37	4.7	9.6	1.59	3.52	3.53	2.81	.89
178.	34.34	4980.	109.	196.	513.	924.	5.59	.220	3.6	.62	1.95	[illegible]	6.8	9.6	1.13	4.89	4.37	2.86	.83
179.	34.34	4980.	114.	206.	599.	1078.	5.59	.220	7.1	.54	1.81	.32	6.8	9.5	1.15	5.59	3.79	2.61	.80
180.	34.34	4980.	119.	215.	649.	1169.	5.59	.220	10.7	.52	1.70	.36	6.8	9.6	1.13	5.92	3.34	2.43	.79
181.	34.34	4980.	125.	225.	768.	1383.	5.59	.220	14.3	.44	1.59	.39	6.8	9.6	.97	6.81	2.87	2.18	.78
182.	34.34	4980.	131.	235.	722.	1300.	5.59	.220	17.8	.5[illegible]	1.53	.43	6.8	9.6	1.08	6.32	2.69	2.16	.78
183.	34.47	5000.	109.	196.	[illegible]7.	931.	5.59	.220	3.6	.61	1.95	.29	6.7	9.5	1.10	5.10	4.32	2.81	.82
184.	34.47	5000.	114.	206.	631.	1135.	5.59	.220	7.1	.53	1.51	.32	7.0	9.5	1.12	5.85	3.[illegible]	2.55	.80
185.	34.47	5000.	120.	216.	689.	1241.	5.59	.220	10.7	.50	1.69	.36	7.0	9.5	1.09	6.28	3.25	2.37	.79
186.	34.47	5000.	126.	226.	856.	1540.	5.59	.220	14.3	.40	1.59	.39	7.0	9.5	.89	7.56	2.71	2.05	.76
187.	34.47	5000.	132.	237.	867.	1560.	5.59	.220	17.8	.42	1.52	.43	7.0	9.5	.91	7.47	2.46	1.95	.75
188.	34.47	5000.	98.	176.	196.	352.	4.00	.158	5.0	1.55	2.35	.63	6.1	37.5	1.19	1.54	3.57	2.07	1.00
189.	34.47	5000.	99.	179.	200.	360.	4.00	.158	10.0	1.52	2.28	.65	6.1	37.4	1.35	1.57	3.56	2.11	1.00
190.	34.47	5000.	101.	181.	201.	362.	4.00	.158	15.0	1.53	2.23	.68	6.1	37.8	1.42	1.57	3.46	2.10	1.00

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TABLE VII (cont.)

SUPERCRITICAL OXYGEN HEAT TRANSFER DATA

CARD NO.	P MPA	P PSIA	TB K	TB R	TW K	TW R	DIA. MM	DIA. IN.	L/D	NU *E-3	PR	RE *E-6	Q/A *E6 W/M2	RHO*V *E-3 KG/M2S	$\frac{\phi}{\rho}\frac{1}{1+2/L/D}$	$\frac{\rho_B}{\rho_W}$	$\frac{\mu_B}{\mu_W}$	$\frac{k_B}{k_W}$	$\frac{\bar{C}_p}{C_{pB}}$
191.	34.47	5000.	102.	184.	206.	370.	4.00	.158	20.0	1.51	2.17	.70	6.1	37.7	1.43	1.69	3.48	2.14	1.05
192.	34.47	5000.	104.	187.	208.	374.	4.00	.158	25.0	1.51	2.11	.73	6.1	37.6	1.44	1.61	3.37	2.15	1.00
193.	34.47	5000.	101.	181.	279.	502.	4.00	.158	5.0	1.67	2.23	.65	11.8	36.3	1.39	2.43	5.01	2.86	.99
194.	34.47	5000.	104.	188.	296.	532.	4.00	.158	10.0	1.69	2.09	.71	11.8	36.3	1.42	2.59	4.75	2.87	.98
195.	34.47	5000.	108.	195.	297.	534.	4.00	.158	15.0	1.67	1.97	.77	11.8	36.4	1.52	2.57	4.37	2.80	.97
196.	34.47	5000.	112.	202.	316.	568.	4.00	.158	20.0	1.59	1.86	.84	11.9	36.4	1.46	2.75	4.18	2.79	.96
197.	34.47	5000.	116.	209.	320.	576.	4.00	.158	25.0	1.62	1.77	.91	11.8	36.4	1.47	2.76	3.85	2.72	.95
198.	34.47	5000.	102.	183.	393.	708.	4.00	.158	5.0	1.55	2.19	.68	17.8	37.2	1.17	3.74	5.26	3.21	.90
199.	34.47	5000.	108.	194.	443.	797.	4.00	.158	10.0	1.39	1.99	.78	17.7	37.0	1.19	4.19	4.56	3.02	.88
200.	34.47	5000.	113.	204.	463.	833.	4.00	.158	15.0	1.45	1.83	.88	17.8	37.2	1.21	4.30	4.02	2.86	.86
201.	34.47	5000.	119.	215.	517.	931.	4.00	.158	20.0	1.27	1.70	.98	17.7	36.9	1.09	4.72	3.55	2.65	.83
202.	34.47	5000.	125.	225.	542.	975.	4.00	.158	25.0	1.27	1.59	1.09	17.7	37.2	1.06	4.82	3.18	2.51	.82
203.	34.47	5000.	104.	187.	511.	920.	4.00	.158	5.0	1.31	2.11	.69	20.7	35.9	1.01	4.93	4.89	2.96	.85
204.	34.47	5000.	111.	199.	626.	1127.	4.00	.158	10.0	1.08	1.91	.81	20.7	36.1	.93	5.88	4.03	2.65	.81
205.	34.47	5000.	118.	212.	681.	1226.	4.00	.158	15.0	1.04	1.73	.93	20.7	36.0	.90	6.25	3.32	2.42	.79
206.	34.47	5000.	124.	224.	709.	1277.	4.00	.158	20.0	1.09	1.60	1.05	20.8	36.2	.89	6.35	2.98	2.27	.78
207.	34.47	4999.	132.	237.	790.	1422.	4.00	.158	25.0	.99	1.52	1.18	20.7	36.1	.81	6.80	2.56	2.05	.76
208.	33.65	4880.	104.	187.	564.	1016.	4.00	.158	5.0	1.26	2.10	.73	22.5	37.5	.93	5.51	4.75	2.86	.83
209.	33.58	4870.	112.	201.	709.	1277.	4.00	.158	10.0	1.02	1.87	.86	22.4	37.2	.84	6.85	3.79	2.49	.80
210.	33.44	4850.	119.	214.	786.	1415.	4.00	.158	15.0	.97	1.70	.99	22.5	37.0	.80	7.27	3.13	2.26	.76
211.	33.37	4840.	126.	227.	799.	1438.	4.00	.158	20.0	1.01	1.57	1.13	22.5	37.4	.81	7.29	2.75	2.12	.76
212.	33.23	4820.	133.	240.	900.	1620.	4.00	.158	25.0	.94	1.54	1.27	22.5	37.4	.73	7.89	2.31	1.87	.75
218.	25.05	3633.	108.	194.	154.	278.	2.41	.095	25.1	5.78	1.89	1.12	16.2	79.3	4.07	1.24	2.04	1.49	1.03
219.	24.43	3543.	113.	204.	161.	290.	2.41	.095	35.1	5.87	1.75	1.26	16.2	79.3	4.05	1.26	1.94	1.53	1.04
220.	23.82	3455.	118.	213.	166.	299.	2.41	.095	45.0	6.10	1.65	1.41	16.3	79.3	4.13	1.28	1.83	1.55	1.05
221.	23.22	3367.	124.	223.	173.	311.	2.41	.095	55.0	6.32	1.57	1.56	16.3	79.4	4.04	1.32	1.78	1.59	1.06
222.	22.59	3277.	129.	233.	186.	334.	2.41	.095	62.5	5.76	1.53	1.72	16.2	79.3	3.52	1.45	1.86	1.72	1.08
223.	25.02	3629.	113.	203.	211.	379.	2.41	.095	25.1	4.53	1.76	1.27	25.7	80.9	3.01	1.82	3.05	2.29	1.08
224.	24.32	3527.	121.	218.	222.	400.	2.41	.095	35.1	4.68	1.61	1.50	25.7	80.9	2.97	1.97	2.87	2.32	1.09
225.	23.64	3429.	129.	232.	233.	419.	2.41	.095	45.0	4.88	1.53	1.72	25.7	80.9	2.92	2.12	2.70	2.32	1.09
226.	22.95	3329.	137.	246.	247.	444.	2.41	.095	55.0	4.98	1.49	1.95	25.7	81.0	2.78	2.32	2.57	2.30	1.06
227.	22.20	3220.	144.	259.	273.	492.	2.41	.095	62.5	4.61	1.49	2.18	25.7	81.0	2.39	2.72	2.50	2.30	1.00
228.	24.07	3504.	117.	211.	268.	483.	2.41	.095	25.1	4.07	1.69	1.42	34.5	82.8	2.55	2.77	3.70	2.81	1.05
229.	23.81	3453.	127.	228.	294.	529.	2.41	.095	35.1	4.21	1.53	1.71	34.5	82.8	2.36	3.14	3.25	2.72	1.02
230.	23.04	3342.	136.	245.	319.	575.	2.41	.095	45.0	4.01	1.49	1.99	34.5	82.8	2.18	3.47	2.87	2.56	.95
231.	22.26	3229.	146.	263.	350.	630.	2.41	.095	55.0	3.97	1.48	2.27	34.5	82.9	1.97	3.89	2.52	2.37	.90
232.	21.48	3115.	155.	279.	403.	725.	2.41	.095	62.5	3.69	1.51	2.51	34.5	82.9	1.63	4.41	2.04	2.12	.83
233.	24.66	3576.	118.	213.	329.	592.	2.41	.095	25.1	3.59	1.65	1.42	41.8	80.4	2.20	3.69	3.62	2.93	.98
234.	23.88	3464.	130.	234.	404.	727.	2.41	.095	35.1	3.05	1.51	1.74	41.8	80.4	1.60	4.07	3.06	2.49	.89
235.	23.10	3350.	141.	254.	463.	834.	2.41	.095	45.0	2.88	1.47	2.06	41.8	80.5	1.54	5.27	2.55	2.32	.82
236.	22.38	3246.	152.	274.	527.	949.	2.41	.095	55.0	2.79	1.52	2.34	41.8	80.5	1.36	5.79	2.15	1.96	.75
237.	21.62	3136.	164.	295.	642.	1156.	2.41	.095	62.5	2.48	1.59	2.65	41.8	80.5	1.05	6.77	1.77	1.58	.88
238.	25.37	3680.	119.	214.	350.	631.	2.41	.095	25.1	3.56	1.65	1.34	45.5	76.3	2.38	3.90	3.77	2.95	.96
239.	24.62	3571.	131.	235.	457.	822.	.41	.095	35.1	2.78	1.51	1.65	45.5	76.3	1.73	5.21	2.96	2.56	.85
240.	23.90	3466.	142.	255.	596.	1073.	2.41	.095	45.0	2.21	1.45	1.95	45.5	76.3	1.25	6.66	2.38	2.17	.76
241.	23.15	3357.	153.	276.	697.	1254.	2.41	.095	55.0	2.70	1.51	2.22	45.5	76.4	1.38	7.57	1.93	1.71	.71
243.	31.43	4558.	107.	192.	260.	467.	4.00	.156	7.5	2.47	1.99	.88	14.3	41.7	1.76	2.28	4.22	2.73	1.02
244.	31.36	4549.	111.	200.	275.	495.	4.00	.158	11.2	2.37	1.86	.97	14.3	41.7	1.76	2.45	4.01	2.74	1.01
245.	31.32	4543.	115.	207.	279.	503.	4.00	.158	13.8	2.39	1.80	1.02	14.3	41.8	1.60	2.49	3.86	2.72	1.01
246.	31.28	4537.	119.	214.	283.	509.	4.00	.158	16.3	2.42	1.75	1.07	14.3	41.7	1.42	2.51	3.71	2.69	1.01

TABLE III (cont.)

SUPERCRITICAL OXYGEN HEAT TRANSFER DATA

CARD NO.	P MPA	P PSIA	TB K	TB R	TW K	TW R	DIA. MM	DIA. IN.	L/D	H *E-3	PW	HI *E-6	PHI *E-6 W/M2	RHO*V *E-3 KG/M2S	$\frac{\phi}{\phi V}\frac{1}{1+Z/Wd}$	$\frac{\rho b}{\rho w}$	$\frac{\mu b}{\mu w}$	$\frac{kb}{kw}$	$\frac{\bar{C}p}{Cp_b}$
247.	31.25	4532.	119.	213.	287.	516.	4.00	.158	19.2	2.44	1.76	1.12	14.3	41.8	1.04	2.54	3.58	2.66	1.01
248.	31.22	4528.	109.	196.	401.	722.	4.00	.158	7.5	2.05	1.92	.91	22.3	41.0	1.47	4.06	4.53	3.08	.91
249.	31.16	4519.	116.	208.	458.	825.	4.00	.158	11.2	1.84	1.75	1.05	22.3	41.0	1.34	4.58	3.86	2.64	.88
250.	31.13	4515.	119.	215.	479.	863.	4.00	.158	13.8	1.80	1.68	1.13	22.3	41.0	1.32	4.74	3.57	2.73	.87
251.	31.10	4511.	123.	221.	499.	897.	4.00	.158	16.3	1.77	1.61	1.20	22.3	41.0	1.29	4.90	3.32	2.62	.86
252.	31.08	4507.	126.	227.	544.	979.	4.00	.158	19.2	1.64	1.56	1.28	22.3	41.0	1.18	5.23	3.06	2.48	.84
253.	30.93	4486.	109.	197.	477.	859.	4.00	.158	7.5	1.87	1.90	.94	25.4	41.3	1.32	4.52	4.34	2.93	.87
254.	30.87	4477.	117.	211.	565.	1017.	4.00	.158	11.2	1.63	1.72	1.10	25.4	41.4	1.16	5.64	3.56	2.62	.83
255.	30.83	4472.	121.	218.	604.	1087.	4.00	.158	13.8	1.56	1.64	1.18	25.4	41.4	1.11	6.00	3.24	2.47	.82
256.	30.81	4469.	125.	225.	645.	1162.	4.00	.158	16.3	1.49	1.56	1.27	25.4	41.4	1.05	6.29	2.95	2.33	.81
257.	30.77	4463.	129.	233.	720.	1296.	4.00	.158	19.2	1.36	1.53	1.36	25.5	41.4	.94	5.91	2.65	2.16	.78
258.	30.75	4460.	110.	198.	583.	1049.	4.00	.158	7.5	1.63	1.89	.95	28.4	41.6	1.15	6.03	4.08	2.73	.83
259.	30.68	4449.	119.	214.	733.	1319.	4.00	.158	11.2	1.34	1.66	1.13	28.4	41.4	.95	7.33	3.16	2.32	.79
260.	30.61	4440.	123.	222.	817.	1471.	4.00	.158	13.8	1.23	1.60	1.23	28.4	41.4	.86	8.01	2.78	2.11	.78
261.	30.63	4443.	128.	230.	953.	1715.	4.00	.158	19.2	1.08	1.54	1.33	28.4	41.5	.75	5.14	2.39	1.86	.76
262.	26.90	3901.	107.	192.	202.	363.	4.00	.158	7.4	5.51	1.94	1.53	19.4	68.3	2.55	1.68	3.17	2.20	1.06
263.	26.67	3868.	111.	200.	211.	380.	4.00	.158	11.2	5.45	1.81	1.69	19.4	68.3	2.42	1.78	3.10	2.27	1.07
264.	26.57	3853.	113.	204.	224.	403.	4.00	.158	13.7	5.01	1.76	1.77	19.4	68.3	2.25	1.95	3.24	2.40	1.07
265.	26.45	3836.	116.	208.	240.	431.	4.00	.158	16.1	4.53	1.72	1.85	19.4	68.4	2.04	2.18	3.38	2.54	1.07
266.	26.35	3821.	118.	212.	229.	413.	4.00	.158	19.2	5.12	1.68	1.95	19.4	68.3	2.30	2.01	3.09	2.40	1.08
267.	26.92	3904.	110.	197.	304.	547.	4.00	.158	7.4	4.58	1.86	1.63	32.3	68.4	1.91	3.19	4.47	3.03	1.00
268.	26.68	3869.	116.	209.	346.	623.	4.00	.158	11.2	4.08	1.71	1.87	32.3	68.5	1.74	3.73	3.96	2.96	.96
269.	26.56	3852.	119.	215.	376.	677.	4.00	.158	13.7	3.75	1.65	1.99	32.3	68.5	1.60	4.08	3.71	2.92	.93
270.	26.44	3835.	123.	221.	412.	742.	4.00	.158	16.1	3.41	1.59	2.11	32.3	68.5	1.45	4.54	3.46	2.81	.90
271.	26.33	3819.	126.	226.	397.	714.	4.00	.158	19.2	3.74	1.55	2.23	32.3	68.5	1.57	4.31	3.29	2.76	.91
272.	27.05	3923.	111.	199.	394.	710.	4.00	.158	7.4	3.83	1.83	1.66	39.5	68.2	1.59	4.49	4.38	3.09	.92
273.	26.80	3887.	119.	214.	488.	878.	4.00	.158	11.2	3.17	1.66	1.95	39.5	68.2	1.33	5.48	3.57	2.74	.86
274.	26.69	3871.	123.	221.	531.	955.	4.00	.158	13.7	2.96	1.60	2.09	39.5	68.2	1.24	5.88	3.24	2.58	.84
275.	26.57	3853.	127.	228.	596.	1074.	4.00	.158	16.1	2.65	1.54	2.24	39.5	68.3	1.10	6.57	2.91	2.38	.81
276.	26.46	3837.	130.	234.	598.	1077.	4.00	.158	19.2	2.75	1.51	2.38	39.5	68.3	1.12	6.51	2.74	2.30	.80
277.	27.19	3944.	113.	204.	470.	846.	4.00	.158	7.4	3.42	1.77	1.73	43.0	67.5	1.41	5.31	4.00	2.88	.87
278.	26.95	3909.	122.	220.	605.	1089.	4.00	.158	11.2	2.71	1.61	2.05	43.0	67.5	1.12	6.70	3.12	2.45	.81
279.	26.84	3892.	126.	227.	651.	1172.	4.00	.158	13.7	2.57	1.55	2.20	43.0	67.5	1.06	7.09	2.82	2.29	.80
280.	26.72	3875.	130.	235.	752.	1354.	4.00	.158	16.1	2.25	1.51	2.36	43.0	67.6	.91	8.03	2.47	2.06	.77
281.	26.61	3859.	134.	242.	781.	1406.	4.00	.158	19.2	2.24	1.49	2.51	43.0	67.6	.89	8.21	2.29	1.96	.75
282.	27.17	3941.	117.	211.	479.	863.	4.00	.158	7.4	3.63	1.69	1.88	44.9	67.7	1.44	5.35	3.69	2.78	.86
283.	26.96	3910.	126.	227.	625.	1125.	4.00	.158	11.2	2.82	1.55	2.20	44.9	67.7	1.13	6.79	2.88	2.34	.80
284.	26.86	3896.	130.	234.	694.	1249.	4.00	.158	13.7	2.59	1.51	2.35	44.9	67.7	1.03	7.46	2.58	2.15	.78
285.	26.76	3881.	134.	242.	779.	1402.	4.00	.158	16.1	2.35	1.49	2.51	44.9	67.8	.92	8.15	2.29	1.96	.75
287.	27.70	4018.	104.	187.	245.	441.	4.00	.158	7.5	4.80	2.03	1.36	25.7	65.3	2.20	2.29	4.38	2.78	1.05
288.	27.50	3989.	110.	197.	279.	502.	4.00	.158	11.2	4.17	1.87	1.54	25.7	65.3	1.97	2.77	4.30	2.93	1.03
289.	27.41	3975.	112.	202.	288.	518.	4.00	.158	13.7	4.10	1.80	1.63	25.7	65.3	1.95	2.88	4.13	2.91	1.02
290.	27.30	3960.	115.	207.	291.	524.	4.00	.158	16.2	4.18	1.74	1.73	25.7	65.3	1.98	2.91	3.93	2.86	1.01
291.	27.20	3945.	118.	212.	290.	522.	4.00	.158	19.1	4.37	1.68	1.83	25.7	65.3	2.07	2.87	3.71	2.80	1.02
292.	27.72	4021.	105.	189.	310.	557.	4.00	.158	7.5	4.23	2.00	1.39	32.6	65.4	1.92	3.26	4.96	3.12	.99
293.	27.52	3991.	112.	201.	372.	669.	4.00	.158	11.2	3.50	1.82	1.61	32.6	65.4	1.63	4.03	4.33	3.08	.94
294.	27.41	3976.	115.	207.	388.	699.	4.00	.158	13.7	3.42	1.74	1.72	32.6	65.4	1.59	4.22	4.04	2.99	.92
295.	27.31	3961.	118.	213.	400.	719.	4.00	.158	16.2	3.41	1.68	1.84	32.6	65.5	1.58	4.36	3.78	2.91	.91
296.	27.21	3946.	122.	219.	405.	729.	4.00	.158	19.1	3.48	1.62	1.96	32.6	65.5	1.59	4.37	3.54	2.83	.91
297.	27.81	4034.	106.	191.	414.	746.	4.00	.158	7.5	3.46	1.97	1.42	39.8	65.0	1.57	4.66	4.82	3.16	.91

TABLE VII (cont.)

SUPERCRITICAL OXYGEN HEAT TRANSFER DATA

CARD NO.	P MPA	P PSIA	TB K	TB R	TW K	TW R	DIA. MM	DIA. IN.	L/D	NU *E-3	PR	RE *E-5	Q/A *E-4 W/M2	G *E-3 KG/M2S	[illegible]	ρ_B/ρ_W	μ_B/μ_W	k_B/k_W	$\bar{C}_p/C_{p_B}$
298.	27.61	4004.	114.	205.	509.	917.	4.00	.158	11.2	2.86	1.70	1.69	39.8	65.1	1.31	5.69	3.86	2.79	.85
300.	27.41	3975.	122.	220.	592.	1066.	4.00	.158	16.2	2.56	1.61	1.96	39.8	65.1	1.16	6.46	3.15	2.48	.81
301.	27.30	3960.	126.	227.	621.	1118.	4.00	.158	19.1	2.52	1.55	2.11	39.8	65.1	1.12	6.68	2.89	2.35	.80
302.	27.83	4036.	107.	192.	478.	860.	4.00	.158	7.5	3.10	1.95	1.44	43.4	65.3	1.41	5.00	4.62	3.01	.87
303.	27.62	4006.	115.	207.	606.	1092.	4.00	.158	11.2	2.53	1.73	1.73	43.4	65.4	1.15	6.76	3.56	2.59	.81
305.	27.41	3976.	124.	223.	740.	1332.	4.00	.158	16.2	2.16	1.58	2.03	43.4	65.4	.96	7.97	2.79	2.20	.78
306.	27.31	3961.	128.	231.	802.	1443.	4.00	.158	19.1	2.05	1.53	2.19	43.4	65.4	.89	8.47	2.50	2.03	.77
307.	27.87	4042.	107.	192.	519.	933.	4.00	.158	7.5	2.97	1.94	1.45	45.4	65.4	1.55	5.90	4.67	2.92	.85
308.	27.66	4012.	116.	209.	671.	1208.	4.00	.158	11.2	2.36	1.72	1.75	45.4	65.5	1.06	7.43	3.37	2.66	.80
312.	27.97	4057.	107.	193.	559.	1006.	4.00	.158	7.5	2.82	1.93	1.47	47.0	65.3	1.26	6.32	4.31	2.63	.83
317.	25.33	3673.	105.	190.	132.	237.	2.41	.095	12.5	3.75	1.96	1.38	6.0	103.0	1.93	1.11	1.65	1.23	1.00
318.	24.86	3605.	107.	193.	133.	239.	2.41	.095	17.5	3.86	1.90	1.44	6.0	103.0	2.04	1.11	1.61	1.23	1.01
319.	24.45	3546.	109.	196.	134.	242.	2.41	.095	22.4	3.94	1.86	1.49	6.0	103.1	2.10	1.11	1.58	1.23	1.01
320.	23.98	3478.	111.	199.	135.	243.	2.41	.095	27.6	4.17	1.81	1.56	6.0	103.1	2.23	1.11	1.54	1.23	1.01
321.	23.56	3417.	112.	202.	135.	243.	2.41	.095	31.8	4.56	1.77	1.62	6.0	103.1	2.42	1.10	1.49	1.21	1.01
322.	25.26	3664.	106.	191.	136.	245.	2.41	.095	12.5	4.12	1.94	1.40	7.6	103.5	2.10	1.13	1.72	1.28	1.01
323.	24.77	3592.	108.	194.	136.	245.	2.41	.095	17.5	4.45	1.88	1.47	7.6	103.4	2.33	1.13	1.66	1.26	1.01
324.	24.35	3532.	110.	197.	133.	240.	2.41	.095	22.4	4.57	1.83	1.53	7.6	103.4	2.41	1.13	1.63	1.26	1.01
325.	23.88	3464.	112.	201.	141.	253.	2.41	.095	27.6	4.53	1.79	1.60	7.6	103.4	2.38	1.14	1.62	1.28	1.02
326.	23.43	3398.	113.	204.	139.	250.	2.41	.095	31.8	5.17	1.76	1.67	7.6	103.4	2.70	1.12	1.53	1.25	1.02
327.	25.13	3645.	106.	191.	141.	253.	2.41	.095	12.5	4.53	1.94	1.41	9.6	104.2	2.30	1.16	1.84	1.33	1.01
328.	24.64	3574.	108.	195.	140.	252.	2.41	.095	17.5	5.01	1.88	1.49	9.6	104.2	2.65	1.15	1.76	1.31	1.01
329.	24.22	3513.	110.	198.	141.	255.	2.41	.095	22.4	5.17	1.83	1.55	9.6	104.1	2.70	1.15	1.70	1.31	1.02
330.	23.75	3445.	112.	202.	146.	262.	2.41	.095	27.6	4.93	1.77	1.63	9.7	104.3	2.56	1.17	1.72	1.34	1.02
331.	23.28	3377.	114.	205.	144.	260.	2.41	.095	31.8	5.59	1.73	1.71	9.6	104.2	2.68	1.15	1.62	1.37	1.02
332.	25.27	3665.	107.	192.	147.	265.	2.41	.095	12.5	4.51	1.92	1.42	11.9	103.5	2.46	1.19	1.90	1.40	1.02
333.	24.79	3595.	109.	197.	145.	261.	2.41	.095	17.5	5.55	1.85	1.51	11.9	103.5	2.67	1.17	1.81	1.35	1.02
334.	24.36	3533.	111.	200.	146.	263.	2.41	.095	22.4	5.88	1.79	1.59	11.9	103.5	3.05	1.17	1.74	1.34	1.02
335.	23.88	3463.	114.	205.	153.	270.	2.41	.095	27.6	5.28	1.74	1.68	11.9	103.5	2.73	1.20	1.77	1.42	1.03
336.	23.41	3395.	116.	209.	151.	272.	2.41	.095	31.8	6.25	1.69	1.77	11.9	103.5	3.19	1.18	1.65	1.35	1.03
337.	24.92	3614.	109.	197.	158.	285.	2.4	5	12.5	4.88	1.85	1.50	14.3	102.6	2.45	1.26	2.05	1.53	1.03
338.	24.44	3545.	112.	202.	155.	279.	2.	5	17.5	5.08	1.78	1.59	14.3	102.4	2.90	1.23	1.88	1.46	1.03
339.	24.02	3483.	115.	206.	156.	281.	2.	.95	22.4	6.05	1.72	1.68	14.3	102.6	3.09	1.22	1.80	1.45	1.03
340.	23.53	3413.	117.	211.	166.	298.	2.41	.095	27.6	5.29	1.67	1.77	14.3	102.4	2.68	1.29	1.87	1.56	1.05
341.	23.06	3345.	120.	216.	161.	289.	2.41	.095	31.8	6.50	1.62	1.89	14.3	102.6	3.28	1.23	1.69	1.45	1.06
342.	24.05	3488.	111.	200.	169.	305.	2.41	.095	12.5	4.98	1.80	1.56	17.0	101.1	2.49	1.35	2.19	1.69	1.05
343.	23.59	3421.	114.	205.	165.	297.	2.41	.095	17.5	5.65	1.73	1.66	17.0	101.2	2.96	1.30	1.98	1.59	1.05
344.	23.17	3361.	117.	210.	166.	299.	2.41	.095	22.4	6.16	1.67	1.76	17.0	101.1	3.12	1.30	1.90	1.58	1.05
345.	22.71	3293.	120.	216.	178.	321.	2.41	.095	27.6	5.40	1.62	1.87	17.0	101.2	2.79	1.40	2.02	1.76	1.07
346.	22.26	3228.	123.	221.	173.	311.	2.41	.095	31.8	6.52	1.58	1.99	17.0	101.2	3.29	1.33	1.81	1.61	1.07
347.	23.02	3339.	113.	203.	179.	322.	2.41	.095	12.5	5.26	1.75	1.66	19.8	101.5	2.56	1.45	2.32	1.85	1.07
348.	22.51	3265.	117.	211.	174.	313.	2.41	.095	17.5	6.23	1.68	1.76	19.8	101.6	3.07	1.38	2.06	1.72	1.06
349.	22.07	3201.	120.	215.	176.	316.	2.41	.095	22.4	6.51	1.63	1.88	19.8	101.5	3.19	1.39	2.00	1.72	1.07
350.	21.57	3128.	123.	221.	193.	347.	2.41	.095	27.6	5.43	1.58	2.01	19.8	101.5	2.62	1.60	2.26	1.94	1.11
351.	21.08	3057.	126.	227.	188.	338.	2.41	.095	31.8	6.39	1.54	2.13	19.8	101.5	3.01	1.50	2.03	1.82	1.10
352.	22.38	3246.	115.	207.	194.	349.	2.41	.095	12.5	5.11	1.71	1.73	22.9	100.8	2.47	1.65	2.53	2.08	1.09
353.	21.87	3172.	119.	214.	188.	339.	2.41	.095	17.5	6.00	1.64	1.86	22.9	100.9	2.91	1.56	2.33	1.94	1.09
354.	21.42	3107.	122.	220.	189.	340.	2.41	.095	22.4	6.68	1.59	1.97	22.9	100.9	3.12	1.55	2.21	1.90	1.10
355.	20.92	3034.	126.	227.	209.	377.	2.41	.095	27.6	5.38	1.54	2.12	22.9	100.9	2.53	1.69	2.55	2.18	1.13
356.	20.43	2963.	130.	233.	202.	363.	2.41	.095	31.8	6.47	1.53	2.26	22.9	100.9	2.78	1.74	2.29	2.00	1.12

TABLE VII (cont.)

SUPERCRITICAL OXYGEN HEAT TRANSFER DATA

CARD NO.	P MPA	P PSIA	TB K	TB R	TW K	TW R	DIA. MM	DIA. IN.	L/D	NU *E-3	PR	RE *E-6	PHI *E-6 W/M2	RHO*V *E-3 Kg/M2.s	$\frac{\varphi}{\rho V}\frac{1}{1+\frac{2}{\sqrt{d}}}$	$\frac{\rho b}{\rho w}$	$\frac{\mu b}{\mu w}$	$\frac{k b}{k w}$	$\frac{\bar{C}p}{Cp_b}$
357.	19.93	2890.	109.	196.	191.	343.	2.41	.095	12.5	6.28	1.81	1.78	29.9	115.9	2.73	1.72	2.98	2.21	1.11
358.	19.25	2792.	113.	204.	183.	330.	2.41	.095	17.5	7.63	1.72	1.97	30.0	116.0	3.32	1.59	2.53	2.02	1.11
359.	18.65	2705.	117.	211.	187.	337.	2.41	.095	22.4	7.94	1.65	2.15	30.0	115.9	3.41	1.65	2.47	2.04	1.13
360.	17.97	2606.	122.	219.	214.	385.	2.41	.095	27.6	6.29	1.59	2.35	30.0	116.0	2.62	2.27	3.05	2.48	1.17
361.	17.32	2512.	126.	227.	207.	372.	2.41	.095	31.8	7.48	1.54	2.55	30.0	116.0	3.01	2.11	2.73	2.31	1.18
362.	19.88	2883.	112.	202.	270.	486.	2.41	.095	12.5	5.03	1.74	1.91	45.2	116.2	2.13	3.43	4.31	3.16	1.08
363.	19.17	2780.	116.	213.	276.	497.	2.41	.095	17.5	5.30	1.64	2.17	45.2	116.2	2.21	3.59	3.90	3.07	1.07
364.	18.53	2688.	123.	222.	282.	508.	2.41	.095	22.4	5.54	1.57	2.40	45.2	116.2	2.24	3.75	3.59	2.99	1.06
365.	17.82	2585.	129.	233.	341.	614.	2.41	.095	27.6	4.42	1.54	2.68	45.2	116.2	1.71	4.90	3.24	2.85	.94
366.	17.13	2485.	135.	243.	329.	591.	2.41	.095	31.8	5.15	1.52	2.94	45.2	116.3	1.19	4.70	3.01	2.71	.94
367.	20.05	2908.	115.	207.	380.	683.	2.41	.095	12.5	3.97	1.69	2.01	58.6	115.7	1.65	5.34	4.04	3.18	.93
368.	19.33	2804.	122.	220.	448.	806.	2.41	.095	17.5	3.46	1.58	2.32	58.6	115.8	1.40	6.51	3.39	2.82	.87
369.	18.71	2714.	129.	231.	484.	872.	2.41	.095	22.4	3.37	1.54	2.61	58.6	115.8	1.31	7.06	2.96	2.56	.82
370.	18.00	2610.	136.	244.	598.	1076.	2.41	.095	27.6	2.80	1.52	2.93	58.6	115.8	1.02	8.76	2.43	2.13	.75
371.	17.31	2511.	143.	257.	637.	1147.	2.41	.095	31.8	2.64	1.53	3.24	58.6	115.9	.96	9.23	2.14	1.90	.71
372.	19.56	2837.	116.	209.	433.	780.	2.41	.095	12.5	3.59	1.67	2.06	62.6	115.0	1.48	6.36	3.84	3.02	.88
373.	18.85	2734.	124.	223.	541.	974.	2.41	.095	17.5	2.93	1.56	2.38	62.6	115.0	1.17	8.01	3.08	2.53	.81
374.	18.22	2643.	130.	235.	598.	1076.	2.41	.095	22.4	2.80	1.52	2.68	62.6	115.0	1.07	8.92	2.64	2.25	.77
375.	17.52	2541.	138.	248.	759.	1366.	2.41	.095	27.6	2.29	1.52	3.02	62.6	115.1	.82	11.15	2.07	1.81	.70
376.	16.84	2442.	145.	261.	908.	1634.	2.41	.095	31.8	2.03	1.57	3.32	62.7	115.2	.67	13.24	1.69	1.47	.66
377.	19.64	2849.	116.	209.	314.	566.	2.41	.095	12.5	7.10	1.67	2.06	77.2	114.9	2.93	4.28	4.08	3.15	1.01
378.	18.93	2745.	124.	223.	466.	839.	2.41	.095	17.5	4.41	1.56	2.39	77.2	114.9	1.76	6.86	3.25	2.73	.85
379.	18.31	2655.	130.	235.	543.	977.	2.41	.095	22.4	3.91	1.52	2.68	77.3	115.0	1.50	7.98	2.75	2.37	.79
380.	17.59	2551.	138.	248.	747.	1344.	2.41	.095	27.6	2.87	1.52	3.02	77.2	115.0	1.03	10.94	2.09	1.83	.71
382.	19.73	2861.	117.	211.	460.	828.	2.41	.095	12.5	3.56	1.65	2.09	66.5	114.8	1.46	6.72	3.69	2.91	.87
383.	18.99	2754.	125.	225.	598.	1077.	2.41	.095	17.5	2.77	1.55	2.43	66.5	114.8	1.10	8.85	2.90	2.37	.79
384.	18.33	2659.	132.	237.	678.	1220.	2.41	.095	22.4	2.57	1.52	2.73	66.5	114.8	.97	9.97	2.43	2.08	.74
385.	17.60	2552.	139.	251.	952.	1714.	2.41	.095	27.6	1.88	1.52	3.07	66.5	114.9	.66	13.90	1.77	1.53	.68
387.	24.21	3511.	108.	194.	190.	342.	2.41	.095	7.4	6.54	1.89	1.54	32.5	108.9	2.85	1.59	2.88	2.08	1.07
388.	23.57	3418.	112.	202.	206.	371.	2.41	.095	12.4	6.01	1.76	1.72	32.5	108.8	2.75	1.61	3.03	2.27	1.09
389.	22.93	3325.	117.	211.	178.	321.	2.41	.095	17.3	9.63	1.66	1.92	32.5	108.9	4.40	1.41	2.12	1.77	1.07
390.	22.30	3234.	122.	220.	193.	347.	2.41	.095	21.2	8.68	1.59	2.11	32.5	108.9	3.87	1.56	2.26	1.94	1.10
391.	24.24	3516.	108.	195.	229.	412.	2.41	.095	7.4	6.14	1.87	1.58	44.6	109.8	2.65	2.20	3.86	2.66	1.09
392.	23.57	3419.	114.	206.	259.	466.	2.41	.095	12.4	5.40	1.73	1.80	44.6	109.7	2.42	2.73	3.87	2.66	1.07
393.	22.91	3322.	120.	216.	223.	402.	2.41	.095	17.3	7.99	1.62	2.04	44.6	109.8	3.53	2.08	3.00	2.40	1.11
394.	22.25	3227.	126.	227.	254.	456.	2.41	.095	21.2	6.82	1.54	2.27	44.6	109.8	2.91	2.63	3.12	2.61	1.08
395.	24.32	3527.	110.	197.	258.	464.	2.41	.095	7.4	5.83	1.84	1.61	51.3	108.9	2.51	2.69	4.21	2.92	1.07
396.	23.65	3430.	116.	209.	303.	545.	2.41	.095	12.4	4.89	1.69	1.86	51.3	108.8	2.17	3.45	3.97	2.99	1.01
397.	22.97	3332.	123.	221.	273.	492.	2.41	.095	17.3	6.45	1.58	2.12	51.3	108.9	2.81	2.94	3.41	2.77	1.05
398.	22.32	3237.	130.	233.	341.	613.	2.41	.095	21.2	4.88	1.53	2.39	51.3	108.9	2.04	4.01	3.17	2.74	.95
399.	24.28	3522.	111.	199.	291.	523.	2.41	.095	7.4	5.45	1.81	1.65	57.8	109.1	2.32	3.25	4.38	3.07	1.03
400.	23.61	3424.	115.	212.	355.	639.	2.41	.095	12.4	4.41	1.66	1.93	57.8	109.2	1.93	4.21	3.84	3.02	.96
401.	22.93	3325.	125.	226.	332.	597.	2.41	.095	17.3	5.40	1.55	2.22	57.8	109.2	2.30	3.86	3.41	2.81	.97
402.	22.26	3229.	133.	239.	398.	717.	2.41	.095	21.2	4.49	1.50	2.51	57.8	109.2	1.82	4.81	2.95	2.66	.89
403.	24.36	3533.	111.	199.	349.	628.	2.41	.095	7.4	4.69	1.81	1.65	65.7	108.9	2.00	4.14	4.45	3.17	.97
404.	23.67	3433.	119.	213.	432.	777.	2.41	.095	12.4	3.81	1.65	1.94	65.7	108.8	1.66	5.31	3.68	2.91	.89
405.	22.98	3333.	126.	228.	435.	783.	2.41	.095	17.3	4.15	1.54	2.25	65.7	108.9	1.75	5.31	3.19	2.72	.88
406.	22.31	3235.	134.	241.	533.	960.	2.41	.095	21.2	3.45	1.50	2.56	65.8	108.9	1.38	6.48	2.65	2.33	.80
407.	24.26	3518.	112.	202.	409.	735.	2.41	.095	7.4	4.20	1.78	1.71	72.7	109.5	1.76	5.04	4.23	3.11	.91
408.	23.57	3419.	121.	217.	521.	939.	2.41	.095	12.4	3.35	1.61	2.04	72.6	109.5	1.43	6.44	3.34	2.64	.83

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TABLE VII (cont.)

SUPERCRITICAL OXYGEN HEAT TRANSFER DATA

CARD NO.	P M PA	P PSIA	TB K	TB R	TW K	TW R	DIA. MM	DIA. IN.	L/D	NU *E-3	PR	RE *E-6	PHI *E-6 W/M2	RHO*V *E-3 Kg/M2s	$\frac{\phi}{\rho V}\frac{1}{1+\frac{2}{\ell/d}}$	$\frac{\rho b}{\rho w}$	$\frac{\mu b}{\mu w}$	$\frac{k b}{k w}$	$\frac{\bar{C}_p}{C_{p_b}}$
409.	22.88	3319.	130.	233.	568.	1022.	2.41	.095	17.3	3.32	1.53	2.38	72.7	109.6	1.36	6.92	2.78	2.36	.79
410.	22.27	3222.	138.	249.	711.	1279.	2.41	.095	21.2	2.76	1.49	2.72	72.7	109.6	1.06	8.57	2.22	1.94	.74
411.	24.50	3554.	113.	203.	462.	831.	2.41	.095	7.4	3.94	1.76	1.72	79.7	108.6	1.66	5.70	4.05	2.95	.87
412.	23.83	3456.	122.	220.	618.	1113.	2.41	.095	12.4	3.00	1.59	2.07	79.7	108.6	1.27	7.57	3.05	2.41	.80
413.	23.15	3358.	132.	237.	749.	1348.	2.41	.095	17.3	2.64	1.51	2.44	79.8	108.7	1.07	8.93	2.37	2.01	.75
414.	22.49	3262.	141.	254.	864.	1555.	2.41	.095	21.2	2.47	1.48	2.80	79.7	108.7	.93	10.11	1.92	1.68	.71
415.	24.46	3547.	114.	204.	488.	878.	2.41	.095	7.4	3.84	1.75	1.74	82.8	108.5	1.61	6.03	3.93	2.87	.86
416.	23.72	3440.	123.	222.	668.	1203.	2.41	.095	12.4	2.87	1.58	2.11	82.8	108.5	1.21	8.16	2.89	2.30	.78
419.	24.19	3508.	115.	207.	504.	907.	2.41	.095	7.4	3.89	1.72	1.80	86.2	109.3	1.60	6.27	3.79	2.81	.85
420.	23.39	3393.	125.	225.	722.	1299.	2.41	.095	12.4	2.77	1.55	2.19	86.2	109.3	1.14	8.85	2.70	2.18	.77
423.	24.63	3572.	116.	208.	554.	998.	2.41	.095	7.4	3.61	1.71	1.80	90.0	108.2	1.49	6.74	3.62	2.68	.83
424.	33.88	4913.	108.	194.	242.	435.	2.41	.095	7.4	2.79	1.98	.91	23.4	71.3	1.93	1.96	3.76	2.47	1.02
425.	33.68	4884.	112.	202.	253.	456.	2.41	.095	12.4	2.73	1.85	1.00	23.4	71.3	2.00	2.07	3.60	2.51	1.02
426.	33.50	4858.	116.	209.	263.	474.	2.41	.095	17.5	2.70	1.75	1.09	23.4	71.3	2.00	2.16	3.44	2.51	1.02
427.	33.30	4830.	121.	218.	254.	457.	2.41	.095	21.1	3.09	1.66	1.19	23.4	71.3	2.25	2.02	3.06	2.37	1.03
428.	33.82	4905.	109.	196.	294.	530.	2.41	.095	7.4	2.69	1.94	.94	30.9	71.5	1.84	2.57	4.30	2.80	.99
429.	33.61	4875.	115.	207.	318.	572.	2.41	.095	12.4	2.56	1.79	1.06	30.9	71.6	1.83	2.80	3.96	2.76	.97
430.	33.42	4847.	120.	216.	338.	608.	2.41	.095	17.5	2.49	1.68	1.18	30.9	71.6	1.78	2.98	3.63	2.71	.96
431.	33.21	4816.	126.	227.	326.	588.	2.41	.095	21.1	2.82	1.57	1.31	30.9	71.6	1.97	2.81	3.26	2.57	.97
432.	33.92	4919.	110.	198.	371.	668.	2.41	.095	7.4	2.47	1.91	.95	39.7	70.9	1.69	3.40	4.40	3.05	.93
433.	33.70	4887.	118.	212.	426.	767.	2.41	.095	12.4	2.21	1.73	1.11	39.7	70.9	1.56	3.93	3.75	2.84	.90
434.	33.50	4858.	125.	224.	475.	855.	2.41	.095	17.5	2.05	1.60	1.26	39.7	70.9	1.44	4.34	3.26	2.62	.87
435.	33.28	4826.	132.	238.	483.	869.	2.41	.095	21.1	2.17	1.57	1.43	39.7	71.0	1.46	4.31	2.87	2.46	.82
436.	33.89	4915.	111.	200.	436.	784.	2.41	.095	7.4	2.23	1.89	.98	44.2	71.3	1.50	4.12	4.26	2.96	.89
437.	33.68	4884.	119.	215.	511.	919.	2.41	.095	12.4	1.96	1.69	1.15	44.3	71.5	1.36	4.75	3.53	2.66	.85
438.	33.47	4854.	127.	229.	570.	1027.	2.41	.095	17.5	1.84	1.56	1.32	44.3	71.4	1.26	5.15	3.02	2.42	.83
439.	33.25	4822.	136.	244.	594.	1070.	2.41	.095	21.1	1.90	1.48	1.51	44.3	71.5	1.23	5.24	2.61	2.23	.81
440.	33.90	4916.	112.	201.	525.	946.	2.41	.095	7.4	1.98	1.87	.99	49.8	71.5	1.32	4.98	4.09	2.78	.85
441.	33.67	4883.	121.	218.	626.	1130.	2.41	.095	12.4	1.73	1.66	1.19	49.8	71.6	1.18	5.78	3.27	2.44	.82
442.	33.46	4853.	130.	234.	706.	1270.	2.41	.095	17.5	1.62	1.53	1.38	49.8	71.6	1.08	6.34	2.71	2.18	.79
443.	33.23	4820.	139.	251.	746.	1342.	2.41	.095	21.1	1.66	1.46	1.60	49.8	71.6	1.05	6.42	2.31	1.98	.77
444.	33.96	4925.	112.	202.	572.	1030.	2.41	.095	7.4	1.87	1.86	.99	52.4	71.2	1.26	5.40	3.99	2.70	.83
445.	33.73	4892.	122.	220.	686.	1235.	2.41	.095	12.4	1.64	1.64	1.20	52.4	71.2	1.12	6.30	3.13	2.34	.80
446.	33.52	4862.	131.	236.	795.	1431.	2.41	.095	17.5	1.50	1.52	1.41	52.4	71.3	1.00	7.00	2.54	2.04	.78
447.	33.30	4829.	141.	254.	837.	1507.	2.41	.095	21.1	1.55	1.46	1.63	52.4	71.3	.97	7.13	2.15	1.83	.75
448.	34.05	4939.	113.	203.	625.	1125.	2.41	.095	7.4	1.78	1.84	1.01	55.1	70.8	1.20	5.87	3.83	2.59	.82
449.	33.83	4907.	123.	222.	773.	1392.	2.41	.095	12.4	1.52	1.62	1.23	55.1	70.8	1.03	6.97	2.93	2.20	.79
450.	33.63	4878.	133.	240.	929.	1673.	2.41	.095	17.5	1.33	1.55	1.44	55.1	70.9	.88	8.08	2.30	1.84	.73
451.	33.41	4845.	144.	259.	892.	1605.	2.41	.095	21.1	1.55	1.41	1.67	55.3	70.9	.95	7.47	2.02	1.73	.77
452.	33.98	4928.	114.	204.	642.	1155.	2.41	.095	7.4	1.80	1.82	1.02	57.2	71.2	1.20	6.02	3.75	2.55	.81
453.	33.74	4893.	125.	224.	816.	1469.	2.41	.095	12.4	1.49	1.60	1.26	57.2	71.2	1.00	7.34	2.81	2.12	.78
454.	19.08	2767.	107.	193.	188.	339.	2.41	.095	7.6	9.03	1.85	1.82	43.6	122.7	3.45	1.73	3.09	2.24	1.12
455.	18.25	2647.	113.	204.	213.	383.	2.41	.095	12.6	7.79	1.71	2.10	43.6	122.8	3.07	2.31	3.55	2.65	1.16
456.	17.49	2537.	119.	214.	230.	414.	2.41	.095	17.8	7.40	1.62	2.37	43.6	122.8	2.87	2.78	3.57	2.82	1.17
457.	16.63	2412.	125.	225.	237.	426.	2.41	.095	21.2	7.88	1.55	2.69	43.6	122.8	2.91	3.02	3.33	2.79	1.16
458.	19.35	2806.	108.	194.	211.	380.	2.41	.095	7.6	8.40	1.83	1.84	53.9	121.5	3.41	2.20	3.79	3.05	1.14
459.	18.51	2684.	115.	207.	257.	462.	2.41	.095	12.6	6.89	1.68	2.15	53.9	121.6	2.70	3.32	4.07	3.10	1.11
460.	17.74	2573.	121.	218.	292.	526.	2.41	.095	17.8	6.08	1.59	2.45	54.0	121.6	2.33	4.14	3.76	3.09	1.04
461.	16.87	2447.	129.	232.	320.	576.	2.41	.095	21.2	5.87	1.54	2.81	54.0	121.7	2.12	4.75	3.33	2.90	.97
462.	19.64	2849.	109.	196.	261.	469.	2.41	.095	7.6	7.39	1.81	1.86	65.5	121.0	2.43	3.31	4.57	3.21	1.09

TABLE VII (cont.)

SUPERCRITICAL OXYGEN HEAT TRANSFER DATA

CARD NO.	P MPA	P PSIA	TB K	TB R	TW K	TW R	DIA. MM	DIA. IN.	L/D	NU *E-3	PR	RE *E-6	PHI *E-6 W/M2	RHO*V *E-3 KG/M2S	$\frac{\phi}{\rho V}\frac{1}{1+\frac{2}{\sqrt{a}}}$	$\frac{\rho b}{\rho w}$	$\frac{\mu b}{\mu w}$	$\frac{k b}{k w}$	$\frac{\bar{C}p}{Cp_b}$
463.	18.82	2730.	117.	210.	346.	623.	2.41	.095	12.6	5.25	1.05	2.22	65.5	121.0	2.04	5.02	4.00	3.17	.97
464.	18.07	2621.	124.	224.	444.	799.	2.41	.095	17.8	4.04	1.56	2.56	65.5	121.0	1.52	6.77	3.28	2.74	.86
465.	17.22	2498.	133.	239.	514.	925.	2.41	.095	21.2	3.70	1.52	2.96	65.5	121.0	1.30	7.89	2.71	2.38	.79
466.	33.65	4880.	103.	186.	122.	220.	2.41	.095	25.1	1.56	2.12	.76	1.9	67.0	1.39	1.07	1.46	1.14	1.00
467.	33.35	4837.	105.	189.	123.	221.	2.41	.095	35.1	1.66	2.06	.81	1.9	67.0	1.49	1.07	1.43	1.13	1.00
468.	33.06	4795.	106.	192.	126.	227.	2.41	.095	45.1	1.51	2.01	.84	1.9	67.0	1.36	1.08	1.47	1.15	1.00
469.	32.77	4752.	108.	194.	128.	230.	2.41	.095	55.2	1.51	1.96	.87	1.9	67.0	1.35	1.08	1.46	1.16	1.00
470.	32.47	4709.	110.	197.	129.	232.	2.41	.095	63.2	1.60	1.91	.90	1.9	67.0	1.43	1.07	1.43	1.15	1.00
471.	33.63	4878.	104.	187.	128.	230.	2.41	.095	25.1	1.71	2.10	.79	2.6	67.2	1.51	1.09	1.58	1.18	.99
472.	33.34	4835.	106.	190.	129.	232.	2.41	.095	35.1	1.77	2.04	.83	2.6	67.2	1.57	1.09	1.56	1.18	1.00
473.	33.04	4792.	107.	193.	132.	238.	2.41	.095	45.1	1.69	1.98	.86	2.6	67.2	1.50	1.10	1.58	1.20	1.00
474.	32.74	4749.	109.	196.	134.	241.	2.41	.095	55.2	1.70	1.93	.89	2.6	67.2	1.51	1.10	1.56	1.20	1.00
475.	32.45	4706.	111.	199.	136.	244.	2.41	.095	63.2	1.72	1.88	.93	2.6	67.2	1.51	1.10	1.55	1.20	1.00
476.	33.52	4862.	104.	187.	131.	236.	2.41	.095	25.1	1.76	2.10	.79	3.1	66.5	1.57	1.11	1.67	1.22	1.00
477.	33.23	4819.	106.	190.	132.	237.	2.41	.095	35.1	1.86	2.03	.82	3.1	66.5	1.67	1.10	1.62	1.21	1.00
478.	32.94	4777.	108.	194.	136.	244.	2.41	.095	45.1	1.75	1.97	.85	3.1	66.5	1.57	1.11	1.65	1.23	1.00
479.	32.64	4734.	109.	197.	137.	246.	2.41	.095	55.2	1.81	1.92	.89	3.0	66.5	1.62	1.11	1.62	1.23	1.00
480.	32.34	4691.	111.	200.	139.	249.	2.41	.095	63.2	1.83	1.87	.93	3.1	66.6	1.62	1.11	1.60	1.23	1.00
481.	33.41	4846.	105.	189.	134.	242.	2.41	.095	25.1	1.85	2.07	.79	3.5	65.8	1.66	1.12	1.73	1.24	1.00
482.	33.12	4803.	107.	192.	136.	244.	2.41	.095	35.1	1.92	2.00	.83	3.5	65.8	1.74	1.11	1.68	1.23	1.00
483.	32.83	4761.	109.	196.	139.	250.	2.41	.095	45.1	1.86	1.94	.87	3.5	65.8	1.68	1.12	1.69	1.25	1.00
484.	32.53	4718.	111.	199.	140.	252.	2.41	.095	55.2	1.94	1.88	.91	3.5	65.8	1.73	1.12	1.65	1.25	1.00
485.	32.24	4676.	113.	203.	143.	258.	2.41	.095	63.2	1.89	1.83	.95	3.5	65.8	1.67	1.13	1.65	1.26	1.01
486.	33.48	4855.	104.	187.	137.	246.	2.41	.095	25.1	1.90	2.10	.78	4.0	66.0	1.71	1.13	1.82	1.27	1.00
487.	33.19	4813.	106.	191.	138.	249.	2.41	.095	35.1	1.95	2.02	.82	4.0	66.0	1.77	1.13	1.77	1.27	1.00
488.	32.90	4771.	108.	195.	141.	254.	2.41	.095	45.1	1.95	1.96	.86	4.0	65.9	1.76	1.14	1.76	1.28	1.00
489.	32.60	472 .	110.	199.	142.	256.	2.41	.095	55.2	2.03	1.89	.90	4.0	66.0	1.82	1.13	1.71	1.27	1.00
490.	32.30	4685.	112.	202.	146.	262.	2.41	.095	63.2	2.00	1.83	.94	4.0	65.9	1.77	1.14	1.70	1.29	1.01
491.	33.38	4841.	105.	188.	140.	253.	2.41	.095	25.1	1.94	2.08	.80	4.5	66.9	1.72	1.15	1.89	1.30	1.00
492.	33.08	4797.	107.	192.	142.	256.	2.41	.095	35.1	1.99	2.00	.84	4.5	66.9	1.77	1.15	1.85	1.30	1.00
493.	32.78	4754.	109.	196.	144.	260.	2.41	.095	45.1	2.05	1.93	.89	4.5	66.9	1.81	1.15	1.80	1.31	1.00
494.	32.47	4709.	111.	200.	146.	262.	2.41	.095	55.2	2.14	1.87	.93	4.5	66.9	1.88	1.15	1.74	1.30	1.01
495.	32.17	4665.	114.	205.	150.	269.	2.41	.095	63.2	2.08	1.81	.98	4.5	66.9	1.60	1.16	1.74	1.32	1.01
496.	33.41	4846.	106.	190.	145.	261.	2.41	.095	25.1	2.02	2.04	.82	5.0	67.1	1.77	1.16	1.95	1.34	1.00
497.	33.10	4801.	108.	194.	147.	265.	2.41	.095	35.1	2.05	1.96	.87	5.0	67.2	1.80	1.17	1.91	1.34	1.00
498.	32.81	4758.	110.	199.	149.	269.	2.41	.095	45.1	2.11	1.89	.92	5.0	67.2	1.84	1.17	1.85	1.34	1.01
499.	32.50	4713.	113.	203.	151.	271.	2.41	.095	55.2	2.21	1.82	.97	5.0	67.1	1.91	1.17	1.79	1.34	1.01
500.	32.19	4669.	115.	208.	155.	280.	2.41	.095	63.2	2.13	1.76	1.02	5.0	67.1	1.82	1.18	1.78	1.37	1.01
501.	33.48	4856.	106.	190.	148.	266.	2.41	.095	25.1	2.08	2.04	.82	5.6	66.9	1.83	1.18	2.03	1.37	1.00
502.	33.18	4812.	108.	195.	151.	271.	2.41	.095	35.1	2.12	1.96	.87	5.6	66.9	1.67	1.18	1.97	1.38	1.01
503.	32.88	4768.	111.	200.	152.	274.	2.41	.095	45.1	2.23	1.88	.92	5.6	66.9	1.95	1.18	1.89	1.37	1.01
504.	32.57	4724.	114.	205.	154.	277.	2.41	.095	55.2	2.32	1.81	.98	5.6	66.8	2.00	1.18	1.83	1.37	1.01
505.	32.26	4679.	116.	209.	159.	287.	2.41	.095	63.2	2.21	1.74	1.03	5.6	66.8	1.88	1.20	1.81	1.40	1.02
506.	33.57	4869.	106.	191.	152.	274.	2.41	.095	25.1	2.13	2.02	.82	6.2	66.6	1.87	1.20	2.10	1.41	1.00
507.	33.27	4825.	109.	196.	155.	279.	2.41	.095	35.1	2.18	1.93	.88	6.2	66.6	1.92	1.20	2.03	1.42	1.01
508.	32.96	4781.	112.	201.	156.	281.	2.41	.095	45.1	2.30	1.86	.94	6.2	66.6	2.00	1.20	1.93	1.41	1.01
509.	32.66	4737.	115.	207.	158.	285.	2.41	.095	55.2	2.40	1.78	1.00	6.2	66.6	2.06	1.20	1.85	1.41	1.02
510.	32.35	4692.	118.	212.	165.	296.	2.41	.095	63.2	2.28	1.71	1.06	6.2	66.6	1.92	1.22	1.83	1.45	1.02
511.	33.58	4870.	106.	192.	156.	281.	2.41	.095	25.1	2.18	2.02	.83	6.8	66.7	1.91	1.22	2.17	1.45	1.00
512.	33.28	4826.	110.	197.	159.	286.	2.41	.095	35.1	2.24	1.92	.89	6.8	66.7	1.96	1.22	2.07	1.46	1.01

TABLE VII (cont.)

SUPERCRITICAL OXYGEN HEAT TRANSFER DATA

CARD NO.	P M PA	P PSIA	TB K	TB R	TW K	TW R	DIA. MM	DIA. IN.	L/D	NU *E-3	PR	RE *E-6	PHI *E-6 W/M2	RHO*V *E-3 KG/M2.	$\frac{\phi}{\rho V}\frac{1}{1+\frac{2}{L/d}}$	$\frac{\rho b}{\rho w}$	$\frac{\mu b}{\mu w}$	$\frac{k b}{k w}$	$\frac{\bar{C}_p}{C_{p_b}}$
513.	32.96	4781.	113.	203.	160.	288.	2.41	.095	45.1	2.38	1.84	.95	6.8	66.7	2.06	1.22	1.96	1.44	1.01
514.	32.65	4736.	116.	209.	162.	292.	2.41	.095	55.2	2.50	1.76	1.02	6.8	66.8	2.12	1.22	1.87	1.44	1.02
515.	32.34	4691.	119.	214.	169.	305.	2.41	.095	63.2	2.37	1.69	1.09	6.8	66.8	1.97	1.25	1.86	1.49	1.03
516.	33.28	4827.	108.	194.	167.	301.	2.41	.095	25.1	2.21	1.98	.86	8.2	66.8	1.91	1.28	2.30	1.58	1.01
517.	32.96	4781.	111.	200.	170.	307.	2.41	.095	35.1	2.28	1.87	.93	8.2	66.8	1.97	1.29	2.18	1.58	1.02
518.	32.65	4736.	115.	207.	172.	309.	2.41	.095	45.1	2.45	1.78	1.00	8.2	66.9	2.08	1.28	2.04	1.56	1.02
519.	32.34	4690.	119.	214.	173.	312.	2.41	.095	55.2	2.60	1.69	1.08	8.2	66.8	2.16	1.28	1.93	1.55	1.03
520.	32.01	4643.	123.	221.	181.	326.	2.41	.095	63.2	2.50	1.62	1.16	8.2	66.9	2.03	1.32	1.92	1.60	1.04
521.	32.30	4684.	111.	200.	181.	327.	2.41	.095	25.1	2.25	1.87	.91	9.6	65.3	1.94	1.37	2.40	1.74	1.03
522.	31.99	4639.	115.	207.	185.	334.	2.41	.095	35.1	2.34	1.77	.99	9.7	65.4	1.99	1.39	2.27	1.74	1.03
523.	31.68	4594.	120.	215.	186.	335.	2.41	.095	45.1	2.53	1.68	1.08	9.7	65.4	2.12	1.38	2.11	1.71	1.04
524.	31.37	4549.	124.	223.	189.	340.	2.41	.095	55.2	2.70	1.60	1.17	9.7	65.4	2.19	1.38	1.99	1.69	1.04
525.	31.05	4503.	128.	231.	198.	357.	2.41	.095	63.2	2.59	1.53	1.27	9.7	65.4	2.04	1.44	1.99	1.75	1.06
526.	31.20	4525.	112.	201.	192.	346.	2.41	.095	25.1	2.32	1.85	.93	11.3	65.4	1.98	1.47	2.58	1.90	1.04
527.	30.88	4478.	117.	210.	198.	356.	2.41	.095	35.1	2.39	1.73	1.03	11.3	65.4	2.01	1.50	2.44	1.91	1.05
528.	30.56	4432.	121.	218.	199.	358.	2.41	.095	45.1	2.60	1.64	1.13	11.3	65.5	2.13	1.49	2.25	1.86	1.05
529.	30.23	4384.	126.	227.	201.	362.	2.41	.095	55.2	2.80	1.56	1.24	11.3	65.5	2.22	1.49	2.11	1.82	1.06
530.	29.90	4337.	131.	236.	214.	385.	2.41	.095	63.2	2.60	1.51	1.35	11.3	65.5	2.02	1.60	2.15	1.91	1.05
531.	30.35	4402.	113.	204.	207.	373.	2.41	.095	25.1	2.32	1.80	.97	13.0	65.4	1.95	1.63	2.81	2.09	1.05
532.	30.02	4354.	119.	214.	214.	385.	2.41	.095	35.1	2.40	1.68	1.09	13.0	65.5	1.97	1.68	2.65	2.10	1.05
533.	29.70	4307.	124.	224.	216.	388.	2.41	.095	45.1	2.61	1.59	1.20	13.0	65.5	2.08	1.67	2.44	2.04	1.06
534.	29.36	4258.	130.	234.	218.	393.	2.41	.095	55.2	2.82	1.53	1.33	13.0	65.5	2.16	1.67	2.27	1.98	1.06
535.	29.03	4210.	135.	244.	235.	423.	2.41	.095	63.2	2.63	1.49	1.45	13.0	65.5	1.93	1.84	2.31	2.06	1.04
536.	29.49	4277.	115.	206.	223.	402.	2.41	.095	25.1	2.34	1.76	1.02	14.9	66.0	1.92	1.83	3.06	2.28	1.05
537.	29.15	4228.	121.	217.	231.	415.	2.41	.095	35.1	2.42	1.64	1.15	14.9	66.0	1.94	1.89	2.85	2.27	1.06
538.	28.82	4180.	127.	228.	233.	420.	2.41	.095	45.1	2.63	1.54	1.28	14.9	66.0	2.03	1.89	2.61	2.20	1.06
539.	28.48	4130.	133.	240.	237.	427.	2.41	.095	55.2	2.83	1.51	1.42	14.9	66.0	2.08	1.91	2.43	2.14	1.04
540.	28.13	4080.	139.	251.	257.	463.	2.41	.095	63.2	2.64	1.47	1.55	14.9	66.0	1.85	2.13	2.42	2.18	1.02
541.	28.71	4164.	117.	210.	243.	437.	2.41	.095	25.1	2.32	1.71	1.04	16.7	64.3	1.92	2.10	3.28	2.49	1.05
542.	28.37	4114.	124.	223.	253.	455.	2.41	.095	35.1	2.38	1.59	1.19	16.7	64.3	1.91	2.20	3.02	2.44	1.05
543.	28.03	4065.	130.	235.	257.	463.	2.41	.095	45.1	2.57	1.51	1.34	16.7	64.3	1.97	2.22	2.75	2.35	1.04
544.	27.68	4015.	137.	247.	263.	474.	2.41	.095	55.2	2.75	1.47	1.48	16.7	64.3	1.99	2.25	2.54	2.26	1.02
545.	27.35	3966.	144.	260.	286.	518.	2.41	.095	63.2	2.57	1.45	1.63	16.8	64.4	1.76	2.52	2.45	2.24	.98
546.	28.10	4075.	119.	215.	264.	474.	2.41	.095	25.1	2.33	1.66	1.11	18.9	64.5	1.88	2.41	3.39	2.61	1.04
547.	27.75	4025.	127.	228.	277.	499.	2.41	.095	35.1	2.38	1.54	1.27	18.9	64.6	1.84	2.55	3.08	2.54	1.03
548.	27.40	3974.	134.	242.	282.	508.	2.41	.095	45.1	2.58	1.49	1.43	18.9	64.6	1.89	2.56	2.78	2.42	1.01
549.	27.05	3923.	142.	256.	294.	529.	2.41	.095	55.2	2.69	1.43	1.60	18.9	64.7	1.86	2.65	2.55	2.31	1.00
550.	26.69	3871.	150.	269.	325.	584.	2.41	.095	63.2	2.51	1.44	1.76	18.9	64.6	1.62	2.95	2.40	2.20	.92
551.	33.05	4793.	118.	212.	259.	465.	2.41	.095	25.1	2.32	1.72	1.05	19.0	66.9	1.87	2.11	3.32	2.47	1.02
552.	32.70	4742.	125.	225.	271.	489.	2.41	.095	35.1	2.36	1.59	1.21	19.0	67.0	1.84	2.22	3.02	2.42	1.02
553.	32.34	4691.	132.	238.	281.	506.	2.41	.095	45.1	2.47	1.55	1.37	19.0	67.0	1.83	2.28	2.75	2.34	.97
554.	31.99	4640.	140.	252.	291.	525.	2.41	.095	55.2	2.58	1.47	1.53	19.0	67.0	1.81	2.34	2.53	2.25	.97
555.	31.63	4588.	148.	266.	320.	576.	2.41	.095	63.2	2.42	1.44	1.68	19.0	67.1	1.60	2.59	2.40	2.18	.93
556.	33.08	4797.	120.	215.	293.	527.	2.41	.095	25.1	2.26	1.68	1.09	22.4	66.8	1.80	2.49	3.49	2.61	1.00
557.	32.71	4744.	128.	231.	310.	559.	2.41	.095	35.1	2.29	1.54	1.27	22.4	66.8	1.74	2.63	3.09	2.50	.99
558.	32.35	4692.	137.	246.	324.	584.	2.41	.095	45.1	2.38	1.47	1.45	22.4	66.8	1.71	2.72	2.76	2.37	.95
559.	31.98	4638.	146.	262.	342.	616.	2.41	.095	55.2	2.44	1.43	1.63	22.4	66.8	1.64	2.82	2.48	2.27	.93
560.	31.61	4585.	154.	278.	376.	678.	2.41	.095	63.2	2.34	1.29	1.81	22.5	66.9	1.47	3.05	2.25	2.18	.97
561.	33.10	4801.	123.	221.	346.	627.	2.41	.095	25.1	2.14	1.62	1.15	27.0	66.2	1.67	3.07	3.45	2.72	.96
562.	32.72	4745.	135.	240.	378.	680.	2.41	.095	35.1	2.14	1.54	1.36	27.0	66.3	1.58	3.28	2.91	2.58	.89

TABLE VII (cont.)

SUPERCRITICAL OXYGEN HEAT TRANSFER DATA

CARD NO.	P MPA	P PSIA	TB K	TB R	TW K	TW R	DIA. MM	DIA. IN.	L/D	NU *E-3	PR	RE *E-6	PHI *E-6 W/M^2	RHO*V *E-3 Kg/M^{2}s	$\frac{\phi}{V}\frac{1}{1+\frac{2}{\sqrt{d}}}$	$\frac{\rho b}{\rho w}$	$\frac{\mu b}{\mu w}$	$\frac{k b}{k w}$	$\frac{\bar{C_p}}{C_{p_b}}$
563.	32.34	4690.	143.	258.	405.	728.	2.41	.095	45.1	2.17	1.40	1.57	27.0	66.3	1.49	3.47	2.53	2.56	.90
564.	31.95	4634.	154.	277.	430.	774.	2.41	.095	55.2	2.24	1.42	1.78	27.0	66.4	1.42	3.56	2.23	2.14	.84
565.	31.56	4577.	164.	295.	478.	861.	2.41	.095	63.2	2.16	1.44	1.94	27.0	66.4	1.26	3.84	2.01	1.90	.80
566.	32.98	4783.	125.	225.	396.	713.	2.41	.095	25.1	2.07	1.58	1.22	30.8	67.4	1.57	3.59	3.30	2.73	.92
567.	32.58	4725.	137.	246.	439.	790.	2.41	.095	35.1	2.03	1.47	1.46	30.8	67.4	1.43	3.87	2.73	2.45	.87
568.	32.18	4667.	148.	267.	476.	857.	2.41	.095	45.1	2.06	1.42	1.69	30.9	67.4	1.34	4.07	2.33	2.18	.83
569.	31.77	4607.	160.	287.	511.	920.	2.41	.095	55.2	2.12	1.38	1.90	30.9	67.5	1.26	4.19	2.06	1.93	.82
570.	31.36	4548.	171.	308.	571.	1029.	2.41	.095	63.2	2.06	1.45	2.09	30.9	67.5	1.11	4.43	1.82	1.69	.75
571.	33.08	4797.	127.	229.	452.	814.	2.41	.095	25.1	1.91	1.55	1.24	33.6	66.8	1.43	4.13	3.14	2.61	.88
572.	32.66	4737.	140.	251.	507.	912.	2.41	.095	35.1	1.87	1.46	1.50	33.6	66.8	1.30	4.46	2.56	2.29	.83
573.	32.25	4678.	152.	274.	559.	1006.	2.41	.095	45.1	1.86	1.42	1.75	33.6	66.8	1.18	4.67	2.16	2.00	.79
574.	31.84	4618.	165.	296.	605.	1088.	2.41	.095	55.2	1.92	1.44	1.56	33.6	66.9	1.10	4.82	1.89	1.75	.75
575.	31.43	4558.	177.	319.	674.	1214.	2.41	.095	63.2	1.89	1.45	2.17	33.6	66.9	.98	5.06	1.65	1.50	.73
576.	33.21	4816.	128.	231.	492.	885.	2.41	.095	25.1	1.79	1.54	1.25	35.1	66.3	1.35	4.48	3.04	2.52	.87
577.	32.79	4756.	141.	254.	553.	995.	2.41	.095	35.1	1.75	1.46	1.52	35.0	66.3	1.22	4.78	2.46	2.20	.80
578.	32.39	4697.	154.	277.	616.	1109.	2.41	.095	45.1	1.76	1.35	1.77	35.5	66.3	1.11	5.10	2.06	1.89	.85
579.	31.97	4637.	167.	301.	669.	1203	2.41	.095	55.2	1.79	1.44	1.98	35.1	66.4	1.02	5.23	1.80	1.64	.74
580.	31.56	4577.	180.	324.	742.	1336.	2.41	.095	63.2	1.78	1.47	2.21	35.1	66.4	.91	5.43	1.56	1.41	.71
581.	32.91	4773.	129.	232.	507.	912.	2.41	.095	25.1	1.81	1.54	1.30	36.6	68.0	1.32	4.64	3.00	2.49	.85
582.	32.47	4709.	142.	256.	571.	1027.	2.41	.095	35.1	1.78	1.40	1.58	36.6	68.0	1.19	4.96	2.41	2.15	.83
583.	32.03	4646.	155.	279.	639.	1149.	2.41	.095	45.1	1.78	1.37	1.85	37.1	68.0	1.08	5.29	2.00	1.85	.81
584.	31.59	4581.	169.	304.	695.	1251.	2.41	.095	55.2	1.81	1.45	2.06	36.6	68.0	.99	5.46	1.75	1.59	.73
585.	31.14	4517.	182.	328.	765.	1376.	2.41	.095	63.2	1.83	1.47	2.31	36.6	68.1	.90	5.56	1.51	1.36	.70
586.	33.05	4794.	129.	233.	531.	956.	2.41	.095	25.1	1.74	1.53	1.30	37.3	67.1	1.28	4.81	2.94	2.44	.84
587.	32.62	4731.	143.	257.	602.	1083.	2.41	.095	35.1	1.70	1.40	1.58	37.3	67.2	1.15	5.22	2.35	2.09	.81
588.	32.19	4668.	157.	282.	673.	1212.	2.41	.095	45.1	1.64	1.48	1.84	36.3	67.1	1.00	5.53	1.95	1.79	.87
589.	31.74	4604.	170.	306.	734.	1321.	2.41	.095	55.2	1.74	1.44	2.06	37.3	67.2	.95	5.66	1.69	1.54	.73
590.	31.31	4541.	184.	331.	806.	1451.	2.41	.095	63.2	1.77	1.47	2.31	37.3	67.2	.86	5.78	1.46	1.31	.70
591.	33.26	4824.	130.	235.	566.	1018.	2.41	.095	25.1	1.65	1.53	1.29	38.1	66.1	1.23	5.07	2.86	2.37	.83
592.	32.83	4761.	145.	260.	646.	1163.	2.41	.095	35.1	1.61	1.42	1.58	38.2	66.1	1.09	5.52	2.26	2.01	.79
593.	32.40	4699.	159.	285.	726.	1306.	2.41	.095	45.1	1.60	1.34	1.84	38.2	66.2	.97	5.86	1.87	1.71	.79
594.	31.97	4636.	173.	311.	795.	1430.	2.41	.095	55.2	1.65	1.45	2.06	38.1	66.2	.89	5.98	1.61	1.45	.71
595.	31.53	4573.	187.	337.	866.	1559.	2.41	.095	63.2	1.69	1.47	2.32	38.1	66.2	.82	6.08	1.38	1.23	.69
596.	33.08	4798.	131.	235.	563.	1014.	2.41	.095	25.1	1.70	1.52	1.32	38.8	67.3	1.23	5.06	2.85	2.37	.83
597.	32.63	4733.	145.	261.	651.	1172.	2.41	.095	35.1	1.63	1.42	1.62	38.9	67.3	1.08	5.57	2.25	2.00	.78
598.	32.19	4669.	159.	286.	728.	1311.	2.41	.095	45.1	1.63	1.36	1.88	38.9	67.4	.97	5.90	1.86	1.70	.78
599.	31.74	4604.	173.	312.	797.	1434.	2.41	.095	55.2	1.68	1.45	2.11	38.9	67.4	.89	6.01	1.60	1.44	.71
600.	31.29	4538.	187.	337.	867.	1560.	2.41	.095	63.2	1.73	1.47	2.38	38.9	67.4	.82	6.10	1.37	1.22	.69
601.	33.28	4827.	131.	237.	609.	1096.	2.41	.095	25.1	1.58	1.52	1.31	39.7	66.0	1.17	5.45	2.76	2.28	.81
602.	32.84	4763.	146.	263.	704.	1267.	2.41	.095	35.1	1.52	1.45	1.61	39.7	66.1	1.02	6.00	2.16	1.92	.75
603.	32.39	4698.	161.	289.	789.	1419.	2.41	.095	45.1	1.53	1.42	1.86	39.7	66.1	.92	6.26	1.79	1.62	.73
604.	31.94	4633.	175.	315.	868.	1563.	2.41	.095	55.2	1.57	1.43	2.10	39.7	66.1	.84	6.46	1.52	1.35	.72
605.	31.49	4567.	190.	342.	913.	1643.	2.41	.095	63.2	1.69	1.47	2.37	39.7	66.1	.81	6.28	1.31	1.16	.69
606.	33.17	4811.	131.	237.	623.	1121.	2.41	.095	25.1	1.57	1.52	1.33	40.5	66.7	1.15	5.57	2.75	2.26	.81
607.	32.73	4747.	146.	263.	723.	1302.	2.41	.095	35.1	1.51	1.45	1.63	40.6	66.7	1.00	6.14	2.13	1.90	.75
608.	32.28	4682.	161.	289.	814.	1465.	2.41	.095	45.1	1.51	1.42	1.89	40.6	66.8	.89	6.47	1.76	1.58	.73
609.	31.83	4617.	176.	316.	860.	1547.	2.41	.095	55.2	1.63	1.44	2.13	40.6	66.8	.86	6.41	1.52	1.35	.71
610.	31.38	4551.	.91.	343.	927.	1668.	2.41	.095	63.2	1.71	1.47	2.41	40.6	66.8	.80	6.37	1.30	1.14	.69
611.	22.20	3220.	110.	198.	272.	489.	4.00	.158	3.8	5.62	1.81	2.09	32.1	82.4	1.58	3.16	4.39	3.10	1.06
612.	22.06	3200.	113.	204.	303.	546.	4.00	.158	6.3	4.89	1.73	2.23	32.0	82.0	1.56	3.71	4.26	3.13	1.02

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TABLE VII (cont.)

SUPERCRITICAL OXYGEN HEAT TRANSFER DATA

CARD NO.	P M PA	P PSIA	TB K	TB R	TW K	TW R	DIA. MM	DIA. IN.	L/D	NU *E-3	PR	RE *E-6	PHI *E-6 W/M2	RHO*V *E-3 KG/M2S	$\frac{\phi}{\rho V}\frac{1}{1+\frac{2}{l/d}}$	$\frac{\rho b}{\rho w}$	$\frac{\mu b}{\mu w}$	$\frac{k b}{k w}$	$\frac{\bar{C_p}}{C_{p_b}}$
613.	21.93	3180.	116.	209.	328.	590.	4.00	.158	8.8	4.51	1.68	2.37	32.1	82.3	1.50	4.11	4.04	3.07	.98
614.	21.72	3150.	119.	215.	327.	589.	4.00	.158	12.8	4.71	1.63	2.52	32.0	81.9	1.62	4.07	3.81	3.00	.98
615.	27.89	4045.	96.	173.	245.	441.	4.00	.158	7.5	4.27	2.31	1.15	25.4	66.3	2.03	2.35	5.25	2.93	1.05
616.	27.70	4017.	101.	182.	246.	443.	4.00	.158	11.2	4.53	2.12	1.29	25.4	66.3	2.24	2.33	4.70	2.85	1.05
617.	27.59	4002.	104.	186.	256.	461.	4.00	.158	13.7	4.39	2.04	1.37	25.4	66.3	2.19	2.47	4.61	2.89	1.05
618.	27.50	3989.	106.	191.	263.	473.	4.00	.158	16.3	4.34	1.97	1.45	25.4	66.3	2.18	2.56	4.46	2.90	1.04
619.	27.39	3973.	108.	195.	275.	495.	4.00	.158	19.3	4.16	1.89	1.53	25.4	66.3	2.08	2.73	4.37	2.93	1.03
620.	28.07	4071.	98.	176.	297.	535.	4.00	.158	7.5	4.09	2.25	1.18	32.3	65.9	1.94	3.12	5.76	3.23	1.00
621.	27.89	4045.	104.	187.	327.	588.	4.00	.158	11.2	3.82	2.03	1.37	32.3	65.9	1.87	3.49	5.12	3.17	.97
622.	27.79	4031.	107.	193.	348.	627.	4.00	.158	13.7	3.61	1.94	1.47	32.3	65.9	1.77	3.76	4.78	3.15	.96
623.	27.70	4018.	110.	198.	367.	661.	4.00	.158	16.3	3.47	1.86	1.57	32.3	66.0	1.70	3.96	4.47	3.11	.94
624.	27.61	4004.	113.	204.	401.	722.	4.00	.158	19.3	3.17	1.78	1.67	32.3	65.9	1.54	4.42	4.16	3.02	.91
625.	26.80	3887.	99.	179.	397.	714.	4.00	.158	7.5	3.40	2.17	1.24	39.3	65.5	1.60	4.70	5.63	3.35	.92
630.	25.02	3629.	104.	187.	507.	912.	4.00	.158	7.5	2.83	2.00	1.40	42.8	65.2	1.29	6.39	4.79	3.04	.85
635.	33.59	4871.	99.	178.	272.	490.	4.00	.158	7.6	2.57	2.29	.87	17.8	49.8	1.63	2.40	5.14	2.68	1.00
636.	33.41	4845.	103.	186.	267.	481.	4.00	.158	12.6	2.79	2.12	.96	17.8	49.9	1.87	2.31	4.58	2.78	1.01
637.	33.23	4820.	108.	194.	260.	469.	4.00	.158	17.6	3.08	1.98	1.06	17.7	49.8	2.09	2.20	4.08	2.66	1.02
638.	33.06	4795.	112.	202.	298.	537.	4.00	.158	22.5	2.61	1.85	1.16	17.8	49.8	1.76	2.63	4.09	2.78	.99
639.	32.89	4770.	116.	209.	242.	436.	4.00	.158	25.6	3.98	1.75	1.27	17.8	49.9	2.62	1.94	3.19	2.36	1.03
640.	33.50	4902.	99.	179.	265.	476.	4.00	.158	7.6	3.18	2.28	.89	21.0	51.2	1.96	2.30	4.99	2.62	1.01
641.	33.63	4878.	104.	188.	258.	465.	4.00	.158	12.6	3.53	2.08	1.01	21.0	51.2	2.30	2.19	4.34	2.69	1.02
642.	33.48	4855.	109.	197.	389.	700.	4.00	.158	17.6	2.02	1.93	1.13	21.0	51.2	1.32	3.66	4.46	3.07	.92
643.	33.32	4832.	115.	206.	297.	534.	4.00	.158	22.5	3.20	1.79	1.25	21.0	51.2	2.07	2.58	3.87	2.72	.99
644.	33.16	4809.	120.	215.	251.	453.	4.00	.158	25.6	4.60	1.68	1.38	21.0	51.2	2.69	2.01	3.11	2.38	1.03
645.	34.25	4967.	101.	182.	309.	556.	4.00	.158	7.6	3.40	2.22	.90	28.0	49.9	2.13	2.80	5.27	2.99	.97
646.	34.12	4948.	108.	194.	338.	608.	4.00	.158	12.6	3.22	1.98	1.06	28.0	50.0	2.10	3.08	4.63	2.95	.96
647.	33.99	4929.	115.	206.	365.	657.	4.00	.158	17.6	3.11	1.80	1.22	28.0	50.0	2.01	3.28	4.02	2.96	.94
648.	33.85	4910.	121.	219.	429.	773.	4.00	.158	22.5	2.66	1.65	1.39	28.0	50.0	1.67	3.90	3.49	2.76	.90
649.	33.72	4891.	126.	231.	394.	710.	4.00	.158	25.6	3.24	1.54	1.56	28.1	50.0	1.96	3.47	3.14	2.67	.92
650.	34.41	4991.	102.	183.	342.	616.	4.00	.158	7.6	3.20	2.19	.90	30.4	49.3	2.03	3.16	5.32	3.09	.95
651.	34.28	4972.	109.	196.	386.	694.	4.00	.158	12.6	2.93	1.94	1.07	30.4	49.3	1.92	3.56	4.48	3.07	.92
652.	34.16	4954.	117.	210.	422.	760.	4.00	.158	17.6	2.79	1.75	1.24	30.4	49.3	1.81	3.87	3.33	2.67	.90
653.	34.03	4935.	124.	223.	496.	892.	4.00	.158	22.5	2.43	1.61	1.43	30.4	49.3	1.52	4.50	3.27	2.59	.86
654.	33.90	4916.	131.	237.	462.	832.	4.00	.158	25.6	2.89	1.52	1.61	30.4	49.3	1.73	4.07	2.92	2.51	.87
655.	34.56	5012.	102.	184.	383.	689.	4.00	.156	7.6	2.99	2.17	.91	32.8	48.7	1.90	3.59	5.20	3.21	.92
656.	34.43	4994.	111.	199.	444.	800.	4.00	.158	12.6	2.65	1.90	1.03	32.8	48.8	1.74	4.17	4.28	2.95	.89
657.	34.30	4975.	119.	214.	498.	897.	4.00	.158	17.6	2.47	1.71	1.28	32.8	48.8	1.59	4.60	3.60	2.69	.86
658.	34.18	4957.	127.	228.	583.	1049.	4.00	.158	22.5	2.18	1.57	1.48	32.8	48.8	1.36	5.19	3.03	2.41	.83
659.	34.05	4938.	135.	243.	554.	997.	4.00	.158	25.6	2.53	1.48	1.68	32.9	48.8	1.49	4.79	2.70	2.31	.83
660.	33.33	4834.	103.	185.	442.	796.	4.00	.158	7.6	2.66	2.13	.91	35.2	47.5	1.73	4.37	5.07	3.12	.89
661.	33.21	4816.	112.	201.	538.	968.	4.00	.158	12.6	2.26	1.86	1.10	35.2	47.5	1.50	5.17	4.05	2.76	.84
662.	33.08	4798.	121.	217.	623.	1121.	4.00	.158	17.6	2.04	1.66	1.31	35.2	47.6	1.32	5.82	3.29	2.46	.82
663.	32.96	4780.	129.	233.	716.	1288.	4.00	.158	22.5	1.87	1.53	1.53	35.2	47.6	1.16	6.50	2.70	2.17	.79
664.	32.83	4762.	138.	249.	720.	1296.	4.00	.158	25.6	2.07	1.46	1.74	35.2	47.6	1.18	6.32	2.37	2.03	.78
665.	34.43	4993.	144.	260.	239.	431.	4.00	.158	7.4	3.21	1.41	1.20	8.8	30.9	2.36	1.67	2.00	1.87	1.03
666.	34.35	4982.	148.	266.	255.	459.	4.00	.158	12.3	2.92	1.42	1.20	8.8	30.9	2.28	1.80	2.05	1.92	.98
667.	34.28	4972.	151.	272.	258.	464.	4.00	.158	16.0	3.03	1.40	1.31	8.8	31.0	2.37	1.80	2.00	1.88	1.00
668.	34.25	4967.	153.	276.	266.	478.	4.00	.158	18.3	2.92	1.41	1.34	8.8	31.0	2.28	1.86	2.00	1.89	.98
669.	34.21	4962.	155.	279.	265.	477.	4.00	.158	22.3	3.02	1.50	1.36	8.8	31.0	2.38	1.84	1.97	1.87	1.06
670.	34.56	5013.	145.	262.	267.	481.	4.00	.158	7.4	3.05	1.41	1.18	10.7	29.9	2.50	1.93	2.20	2.02	1.00

TABLE VII (cont.)

SUPERCRITICAL OXYGEN HEAT TRANSFER DATA

CARD NO.	P MPA	P PSIA	TB K	TB R	TW K	TW R	DIA. MM	DIA. IN.	L/D	NU *E-3	PR	RE *E-6	PHI *E-6 W/M²	RHO*V *E-3 KG/M².S	$\frac{\phi}{\rho V}\frac{1}{1+\frac{2}{x/d}}$	$\frac{\rho_b}{\rho_w}$	$\frac{\mu_b}{\mu_w}$	$\frac{k_b}{k_w}$	$\frac{\bar{C}_p}{C_{p_b}}$
671.	34.50	5003.	150.	270.	292.	526.	4.00	.158	12.3	2.70	1.41	1.24	10.7	30.0	2.15	2.15	2.22	2.05	.96
672.	34.43	4993.	154.	277.	297.	535.	4.00	.158	16.0	2.69	1.25	1.30	10.3	30.0	2.14	2.16	2.15	1.99	.98
673.	34.39	4988.	156.	281.	311.	560.	4.00	.158	18.3	2.62	1.48	1.33	10.6	30.0	2.07	2.26	2.14	1.99	.88
674.	34.36	4984.	158.	285.	309.	556.	4.00	.158	22.3	2.74	1.29	1.35	10.7	30.0	2.17	2.23	2.10	1.96	1.02
675.	34.43	4993.	145.	261.	306.	552.	4.00	.158	7.4	2.88	1.41	1.22	13.3	31.0	2.10	2.33	2.41	2.16	.97
676.	34.35	4982.	151.	271.	340.	613.	4.00	.158	12.3	2.56	1.40	1.30	13.3	31.1	1.95	2.61	2.33	2.15	.93
677.	34.28	4971.	156.	281.	352.	633.	4.00	.158	16.0	2.67	1.52	1.37	13.8	31.1	2.02	2.65	2.20	2.12	.91
678.	34.23	4965.	159.	286.	372.	670.	4.00	.158	18.3	2.43	1.50	1.41	13.4	31.1	1.82	2.79	2.14	2.11	.95
679.	34.20	4960.	161.	290.	371.	667.	4.00	.158	22.3	2.52	1.40	1.43	13.4	31.1	1.88	2.75	2.11	2.07	.88
680.	34.50	5003.	147.	264.	354.	637.	4.00	.158	7.4	2.61	1.45	1.23	15.4	30.6	1.91	2.76	2.43	2.28	.90
681.	34.42	4992.	153.	276.	404.	727.	4.00	.158	12.3	2.27	1.41	1.32	15.4	30.7	1.72	3.17	2.25	2.19	.86
682.	34.34	4981.	159.	287.	427.	769.	4.00	.158	16.0	2.24	1.32	1.40	15.4	30.7	1.67	3.28	2.11	2.06	.90
683.	34.30	4975.	163.	293.	453.	816.	4.00	.158	18.3	2.11	1.41	1.43	15.4	30.7	1.55	3.46	2.04	1.98	.83
684.	34.27	4970.	165.	297.	482.	867.	4.00	.158	22.3	1.98	1.42	1.46	15.4	30.7	1.45	3.64	1.99	1.90	.80
685.	33.64	4879.	147.	265.	381.	686.	4.00	.158	7.4	2.49	1.44	1.24	16.4	30.6	1.80	3.07	2.41	2.31	.88
686.	33.56	4867.	154.	277.	446.	803.	4.00	.158	12.3	2.11	1.41	1.34	16.4	30.6	1.58	3.59	2.21	2.13	.83
687.	33.48	4855.	160.	288.	478.	861.	4.00	.158	16.0	2.04	1.41	1.41	16.4	30.6	1.50	3.76	2.07	1.98	.82
688.	33.43	4848.	164.	295.	512.	921.	4.00	.158	18.3	1.92	1.42	1.45	16.4	30.6	1.39	3.97	1.99	1.68	.79
689.	33.39	4843.	166.	300.	540.	972.	4.00	.158	22.3	1.83	1.43	1.49	16.4	30.6	1.32	4.11	1.93	1.81	.78
690.	32.69	4741.	148.	266.	445.	800.	4.00	.158	7.4	2.25	1.42	1.25	18.5	30.3	1.62	3.74	2.36	2.23	.85
691.	32.60	4728.	156.	280.	554.	997.	4.00	.158	12.3	1.78	1.33	1.36	18.4	30.3	1.31	4.51	2.09	1.95	.83
692.	32.52	4716.	163.	293.	606.	1090.	4.00	.158	16.0	1.70	1.43	1.44	18.	30.3	1.22	4.80	1.92	1.78	.76
693.	32.48	4710.	167.	300.	642.	1156.	4.00	.158	18.3	1.64	1.43	1.49	18.5	30.3	1.16	4.97	1.83	1.68	.75
694.	32.43	4704.	170.	306.	696.	1253.	4.00	.158	22.3	1.52	1.44	1.52	18.5	30.3	1.06	5.34	1.74	1.58	.73
695.	31.99	4639.	148.	266.	483.	869.	4.00	.158	7.4	2.13	1.42	1.27	19.7	30.5	1.52	4.16	2.33	2.17	.82
696.	31.90	4626.	156.	281.	615.	1106.	4.00	.158	12.3	1.75	1.48	1.38	20.7	30.5	1.27	5.10	2.02	1.87	.83
697.	31.81	4613.	164.	294.	682.	1228.	4.00	.158	16.0	1.57	1.44	1.47	19.8	30.5	1.11	5.47	1.83	1.67	.74
698.	31.76	4606.	168.	302.	727.	1309.	4.00	.158	18.3	1.51	1.44	1.52	19.8	30.5	1.04	5.69	1.75	1.58	.73
699.	31.72	4601.	171.	308.	796.	1432.	4.00	.158	22.3	1.39	1.45	1.56	19.8	30.5	.95	6.07	1.63	1.47	.72
700.	31.23	4529.	150.	270.	523.	942.	4.00	.158	7.4	2.02	1.42	1.30	20.4	30.3	1.42	4.54	2.24	2.08	.80
701.	31.14	4516.	158.	284.	680.	1224.	4.00	.158	12.3	1.55	1.36	1.40	20.4	30.3	1.11	5.69	1.91	1.75	.78
702.	31.05	4503.	166.	299.	762.	1371.	4.00	.158	16.0	1.45	1.44	1.50	20.4	30.3	1.00	6.08	1.72	1.56	.72
703.	31.00	4[illegible]6.	170.	306.	827.	1489.	4.00	.158	18.3	1.36	1.4[illegible]	1.55	20.4	30.3	.92	6.46	1.60	1.44	.71
704.	30.96	4490.	174.	313.	898.	1616.	4.00	.158	22.3	1.27	1.4[illegible]	1.59	20.4	30.3	.85	6.88	1.50	1.33	.70
705.	21.10	3060.	167.	300.	340.	612.	4.00	.158	25.1	2.52	1.62	1.38	8.9	24.4	1.96	3.37	2.07	1.91	.83
706.	21.0[illegible]	[illegible]	174.	313.	364.	656.	4.00	.158	35.0	2.46	1.66	1.49	8.9	24.4	1.82	3.45	1.89	1.79	.77
707.	20.95	[illegible]	181.	327.	395.	712.	4.00	.158	45.3	2.36	1.68	1.62	8.9	24.4	1.64	3.60	1.71	1.64	.71
708.	20.92	[illegible]	189.	340.	403.	725.	4.00	.158	55.2	2.52	1.67	1.77	8.9	24.4	1.65	3.44	1.57	1.53	.69
709.	20.86	3026.	196.	353.	408.	734.	4.00	.158	63.5	2.71	1.63	1.91	8.9	24.4	1.68	3.25	1.45	1.44	.68
710.	[illegible]	[illegible]	180.	325.	476.	858.	4.00	.158	25.1	1.98	1.67	1.49	10.6	22.9	1.44	4.40	1.66	1.55	.68
711.	[illegible]	[illegible]	189.	340.	542.	976.	4.00	.158	35.0	1.79	1.65	1.64	10.6	22.9	1.24	4.64	1.44	1.35	.63
712.	[illegible]	[illegible]	[illegible]	358.	583.	1050.	4.00	.158	45.3	1.78	1.61	1.81	10.6	22.9	1.15	4.58	1.27	1.20	.62
713.	[illegible]	3094.	[illegible]	375.	641.	1155.	4.00	.158	55.2	1.69	1.54	1.98	10.6	22.9	1.03	4.59	1.12	1.07	.62
714.	21.25	[illegible]	[illegible]	[illegible]91.	636.	1145.	4.00	.158	63.5	1.86	1.46	2.12	10.6	22.9	1.07	4.18	1.05	1.01	.63

*FIN

APPENDIX C

SUPERCRITICAL OXYGEN HEAT TRANSFER CORRELATION

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82

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Table VIII is a listing of the heat transfer parameter:

$$\frac{\phi}{\rho V} \frac{I}{I + \frac{2}{\ell/d}}$$

Calculated from the recommended correlating equation:

$$\frac{\phi}{\rho V} \frac{I}{I + \frac{2}{\ell/d}} = .0025 \left(\frac{k_b}{\mu_b}\right)^{.6} Cp_b^{\ .4} (T_w - T_b) \left(\frac{\rho_b}{\rho_w}\right)^{-1/2} \left(\frac{k_b}{k_w}\right)^{1/2} \left(\frac{\overline{Cp}}{Cp_b}\right)^{2/3} \left(\frac{P}{P_{cr}}\right)^{-1/5}$$

For wall temperatures from 100 K to 1000 K (180 R to 1800 R), bulk temperatures from 80 K to 400 K (144 R to 720 R), and pressures from the 5.04 MPa (730 psia) to 34.47 MPa (5000 psia). These tables are intended to aid rocket engine designers who may not have access to the computer routines necessary to solve the above equation.

Table VIII

SUPERCRITICAL OXYGEN HEAT TRANSFER CORRELATION

SUPERCRITICAL OXYGEN HEAT TRANSFER CORRELATION (WATT PER KG/SEC DEG K)

5.04 MEGAPASCALS
(730 PSIA)
WALL TEMP (DEG K)

BULK TEMP (DEG K)	100	200	300	400	500	600	700	800	900	1000
80	2.501	2.527	1.364	.924	.717	.591	.507	.446	.395	.356
90	2.649	2.644	1.501	1.027	.796	.656	.563	.493	.440	.398
100	.000	2.732	1.633	1.112	.861	.709	.608	.535	.475	.430
110	.000	3.165	1.722	1.167	.902	.743	.637	.561	.498	.451
120	.000	3.615	1.755	1.183	.913	.752	.645	.566	.505	.457
130	.000	3.330	1.709	1.146	.884	.728	.625	.551	.489	.443
140	.000	3.191	1.574	1.050	.810	.668	.570	.506	.450	.408
150	.000	2.694	1.371	.916	.707	.565	.503	.446	.395	.359
160	.000	2.539	1.647	1.183	.954	.810	.710	.635	.572	.523
170	.000	2.671	1.746	1.270	1.033	.881	.775	.695	.627	.574
180	.000	2.976	1.855	1.358	1.109	.948	.836	.750	.677	.621
190	.000	3.169	1.953	1.430	1.179	1.010	.891	.801	.723	.664
200	.000	.000	2.049	1.515	1.245	1.068	.943	.848	.766	.703
210	.000	.000	2.137	1.585	1.305	1.121	.993	.891	.806	.740
220	.000	.000	2.224	1.653	1.363	1.172	1.037	.933	.844	.775
230	.000	.000	2.310	1.720	1.421	1.223	1.082	.974	.881	.809
240	.000	.000	2.394	1.786	1.477	1.272	1.126	1.014	.915	.843
250	.000	.000	2.475	1.850	1.533	1.321	1.172	1.054	.954	.876
260	.000	.000	2.561	1.914	1.588	1.370	1.213	1.093	.990	.909
270	.000	.000	2.643	1.977	1.643	1.417	1.256	1.132	1.025	.942
280	.000	.000	2.719	2.035	1.693	1.462	1.296	1.168	1.058	.972
290	.000	.000	2.804	2.098	1.749	1.511	1.340	1.207	1.093	1.005
300	.000	.000	.000	2.160	1.804	1.559	1.382	1.240	1.129	1.037
310	.000	.000	.000	2.221	1.858	1.606	1.425	1.285	1.164	1.070
320	.000	.000	.000	2.280	1.912	1.653	1.467	1.323	1.198	1.101
330	.000	.000	.000	2.336	1.965	1.700	1.509	1.361	1.233	1.135
340	.000	.000	.000	2.521	2.080	1.791	1.586	1.429	1.293	1.188
350	.000	.000	.000	2.586	2.134	1.838	1.628	1.467	1.328	1.220
360	.000	.000	.000	2.654	2.190	1.887	1.672	1.506	1.363	1.253
370	.000	.000	.000	2.722	2.247	1.936	1.715	1.545	1.399	1.285
380	.000	.000	.000	2.793	2.305	1.987	1.760	1.586	1.436	1.319
390	.000	.000	.000	2.865	2.365	2.039	1.807	1.628	1.474	1.354
400	.000	.000	.000	.000	2.426	2.092	1.854	1.671	1.513	1.390

$$1\ \frac{W/K}{kg/s} = 2.387 \times 10^{-4}\ \frac{BTU}{lb°R}$$

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84

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TABLE VIII (cont.)

SUPERCRITICAL OXYGEN HEAT TRANSFER CORRELATION (WATT PER KG/SEC PER DEG K)

10 MEGAPASCALS
(1450 PSIA)

	WALL TEMP (DEG K)									
BULK TEMP (DEG K)	100	200	300	400	500	600	700	800	900	1000
80	1.990	2.361	1.500	1.083	.844	.699	.602	.531	.472	.428
90	2.226	2.675	1.678	1.208	.940	.778	.670	.591	.526	.477
100	.000	2.963	1.832	1.313	1.070	.844	.727	.641	.571	.517
110	.000	3.202	1.945	1.388	1.077	.891	.767	.677	.603	.547
120	.000	3.373	2.006	1.425	1.105	.914	.787	.695	.618	.561
130	.000	3.449	2.000	1.414	1.095	.906	.780	.689	.614	.557
140	.000	3.405	1.916	1.349	1.044	.864	.714	.658	.586	.532
150	.000	3.306	1.795	1.259	.975	.807	.696	.615	.549	.499
160	.000	3.200	1.679	1.171	.908	.753	.651	.576	.514	.466
170	.000	3.267	1.662	1.174	.916	.763	.661	.587	.525	.478
180	.000	3.339	1.743	1.254	.939	.830	.723	.645	.578	.528
190	.000	3.350	1.831	1.341	1.067	.901	.788	.704	.633	.579
200	.000	.000	1.917	1.421	1.138	.965	.846	.758	.682	.625
210	.000	.000	1.992	1.490	1.198	1.018	.895	.802	.723	.663
220	.000	.000	2.064	1.554	1.254	1.068	.940	.844	.761	.698
230	.000	.000	2.133	1.615	1.307	1.116	.983	.883	.797	.731
240	.000	.000	2.202	1.675	1.359	1.161	1.024	.920	.831	.763
250	.000	.000	2.270	1.734	1.409	1.206	1.064	.957	.865	.793
260	.000	.000	2.336	1.792	1.459	1.249	1.103	.993	.897	.823
270	.000	.000	2.403	1.850	1.507	1.292	1.141	1.027	.929	.853
280	.000	.000	2.459	1.899	1.549	1.328	1.174	1.058	.956	.878
290	.000	.000	2.529	1.959	1.600	1.373	1.211	1.094	.989	.909
300	.000	.000	.000	2.019	1.649	1.416	1.253	1.129	1.021	.938
310	.000	.000	.000	2.079	1.698	1.459	1.291	1.164	1.053	.967
320	.000	.000	.000	2.139	1.747	1.501	1.329	1.198	1.084	.996
330	.000	.000	.000	2.199	1.795	1.543	1.366	1.232	1.115	1.024
340	.000	.000	.000	2.215	1.821	1.569	1.391	1.254	1.136	1.044
350	.000	.000	.000	2.254	1.855	1.598	1.417	1.278	1.157	1.064
360	.000	.000	.000	2.297	1.890	1.629	1.444	1.303	1.180	1.085
370	.000	.000	.000	2.356	1.939	1.672	1.483	1.338	1.212	1.114
380	.000	.000	.000	2.420	1.992	1.718	1.524	1.376	1.246	1.145
390	.000	.000	.000	2.488	2.048	1.766	1.567	1.414	1.281	1.178
400	.000	.000	.000	.000	2.103	1.815	1.611	1.454	1.317	1.211

TABLE VIII (cont.)

SUPERCRITICAL OXYGEN HEAT TRANSFER CORRELATION (WATT PER KG/SEC PER DEG K)

15 MEGAPASCALS
(2175 PSIA)

BULK TEMP (DEG K)	WALL TEMP (DEG K) 100	200	300	400	500	600	700	800	900	1000
80	1.777	2.169	1.540	1.155	.910	.759	.657	.582	.519	.471
90	1.969	2.446	1.725	1.289	1.015	.847	.732	.649	.579	.526
100	.000	2.704	1.887	1.406	1.106	.922	.798	.707	.631	.573
110	.000	2.916	2.015	1.495	1.175	.979	.847	.751	.670	.609
120	.000	3.070	2.090	1.550	1.216	1.014	.877	.776	.694	.631
130	.000	3.159	2.119	1.561	1.223	1.020	.882	.783	.699	.635
140	.000	3.164	2.083	1.528	1.197	.993	.864	.767	.685	.623
150	.000	3.096	1.993	1.457	1.141	.951	.824	.732	.654	.595
160	.000	3.020	1.893	1.380	1.081	.903	.782	.695	.622	.566
170	.000	3.001	1.829	1.332	1.045	.874	.759	.675	.604	.550
180	.000	3.067	1.823	1.331	1.048	.878	.764	.681	.610	.556
190	.000	3.164	1.853	1.362	1.076	.905	.789	.705	.633	.578
200	.000	.000	1.905	1.414	1.124	.949	.830	.742	.667	.610
210	.000	.000	1.963	1.469	1.173	.994	.871	.781	.702	.643
220	.000	.000	2.020	1.524	1.223	1.039	.912	.819	.737	.675
230	.000	.000	2.077	1.578	1.271	1.082	.952	.855	.771	.707
240	.000	.000	2.135	1.633	1.315	1.125	.991	.891	.804	.737
250	.000	.000	2.189	1.685	1.364	1.165	1.028	.925	.835	.766
260	.000	.000	2.244	1.736	1.409	1.205	1.064	.958	.865	.794
270	.000	.000	2.297	1.787	1.453	1.244	1.099	.991	.895	.822
280	.000	.000	2.341	1.835	1.490	1.278	1.129	1.018	.921	.845
290	.000	.000	2.402	1.885	1.536	1.318	1.166	1.052	.951	.874
300	.000	.000	.000	1.941	1.583	1.359	1.203	1.085	.982	.902
310	.000	.000	.000	1.996	1.628	1.399	1.239	1.118	1.012	.930
320	.000	.000	.000	2.052	1.674	1.439	1.274	1.151	1.041	.957
330	.000	.000	.000	2.109	1.719	1.478	1.309	1.182	1.070	.983
340	.000	.000	.000	2.096	1.724	1.486	1.318	1.192	1.079	.992
350	.000	.000	.000	2.110	1.737	1.498	1.330	1.202	1.089	1.001
360	.000	.000	.000	2.128	1.752	1.512	1.342	1.214	1.099	1.011
370	.000	.000	.000	2.178	1.795	1.550	1.374	1.245	1.128	1.037
380	.000	.000	.000	2.235	1.843	1.592	1.410	1.279	1.159	1.066
390	.000	.000	.000	2.298	1.894	1.637	1.454	1.315	1.192	1.096
400	.000	.000	.000	000	1.945	1.682	1.494	1.352	1.225	1.127

TABLE VIII (cont.)

SUPERCRITICAL OXYGEN HEAT TRANSFER CORRELATION (WATT PER KG/SEC PER DEG K)

20 MEGAPASCALS
(2900 PSIA)

BULK TEMP (DEG K)	WALL TEMP (DEG K) 100	200	300	400	500	600	700	800	900	1000
80	1.627	1.974	1.527	1.178	.946	.794	.690	.614	.550	.500
90	1.822	2.223	1.712	1.318	1.057	.887	.771	.686	.614	.558
100	.000	2.451	1.878	1.441	1.155	.969	.842	.750	.671	.610
110	.000	2.645	2.013	1.540	1.233	1.034	.899	.801	.716	.652
120	.000	2.792	2.108	1.608	1.286	1.078	.939	.835	.747	.680
130	.000	2.879	2.153	1.636	1.308	1.096	.954	.849	.760	.692
140	.000	2.902	2.146	1.626	1.298	1.089	.947	.844	.756	.688
150	.000	2.861	2.087	1.577	1.258	1.055	.919	.819	.734	.668
160	.000	2.794	2.007	1.512	1.207	1.012	.882	.786	.705	.642
170	.000	2.751	1.944	1.461	1.167	.980	.854	.762	.684	.623
180	.000	2.747	1.907	1.433	1.146	.963	.841	.751	.674	.615
190	.000	2.793	1.910	1.437	1.151	.970	.847	.758	.681	.622
200	.000	.000	1.934	1.460	1.172	.990	.866	.776	.698	.638
210	.000	.000	1.963	1.488	1.199	1.015	.890	.798	.719	.657
220	.000	.000	2.004	1.527	1.235	1.047	.920	.826	.744	.681
230	.000	.000	2.048	1.570	1.273	1.082	.952	.856	.772	.707
240	.000	.000	2.093	1.615	1.313	1.118	.985	.887	.801	.734
250	.000	.000	2.140	1.660	1.353	1.155	1.019	.917	.829	.760
260	.000	.000	2.186	1.705	1.393	1.190	1.051	.948	.857	.786
270	.000	.000	2.231	1.750	1.433	1.226	1.084	.978	.884	.811
280	.000	.000	2.268	1.789	1.467	1.256	1.112	1.003	.908	.833
290	.000	.000	2.320	1.841	1.511	1.295	1.147	1.036	.937	.861
300	.000	.000	.000	1.894	1.556	1.335	1.183	1.069	.968	.889
310	.000	.000	.000	1.947	1.598	1.373	1.216	1.099	.996	.915
320	.000	.000	.000	2.002	1.643	1.411	1.251	1.131	1.025	.941
330	.000	.000	.000	2.062	1.688	1.450	1.286	1.163	1.053	.968
340	.000	.000	.000	2.022	1.679	1.449	1.287	1.166	1.057	.972
350	.000	.000	.000	2.025	1.665	1.454	1.293	1.171	1.062	.977
360	.000	.000	.000	2.034	1.692	1.462	1.300	1.176	1.068	.983
370	.000	.000	.000	2.073	1.727	1.492	1.328	1.203	1.091	1.004
380	.000	.000	.000	2.119	1.766	1.527	1.359	1.231	1.117	1.028
390	.000	.000	.000	2.171	1.807	1.563	1.392	1.261	1.145	1.053
400	.000	.000	.000	.000	1.850	1.601	1.426	1.293	1.173	1.080

TABLE VIII (cont.)

SUPERCRITICAL OXYGEN HEAT TRANSFER CORRELATION (WATT PER KG/SEC PER DEG K)

25 MEGAPASCALS
(3625 PSIA)

BULK TEMP (DEG K)	WALL TEMP (DEG K)									
	100	200	300	400	500	600	700	800	900	1000
80	1.511	1.606	1.490	1.176	.958	.814	.741	.636	.570	.520
90	1.494	2.034	1.671	1.316	1.072	.911	.795	.711	.638	.582
100	.000	2.243	1.836	1.443	1.174	.997	.871	.779	.699	.637
110	.000	2.423	1.975	1.546	1.259	1.069	.933	.835	.749	.684
120	.000	2.564	2.079	1.626	1.320	1.121	.979	.876	.786	.718
130	.000	2.655	2.139	1.668	1.354	1.149	1.004	.899	.806	.736
140	.000	2.687	2.149	1.671	1.355	1.151	1.005	.900	.808	.738
150	.000	2.681	2.127	1.650	1.337	1.136	.992	.889	.798	.729
160	.000	2.620	2.058	1.592	1.290	1.096	.958	.859	.771	.705
170	.000	2.576	2.004	1.547	1.254	1.066	.932	.836	.751	.687
180	.000	2.548	1.959	1.511	1.225	1.042	.912	.819	.736	.673
190	.000	2.553	1.942	1.497	1.215	1.035	.907	.815	.733	.671
200	.000	.000	1.950	1.505	1.223	1.043	.915	.823	.741	.678
210	.000	.000	1.964	1.518	1.236	1.056	.927	.835	.752	.689
220	.000	.000	1.986	1.540	1.256	1.075	.945	.852	.768	.704
230	.000	.000	2.018	1.570	1.284	1.100	.969	.874	.789	.724
240	.000	.000	2.055	1.605	1.315	1.129	.995	.899	.811	.745
250	.000	.000	2.092	1.641	1.348	1.159	1.023	.924	.835	.767
260	.000	.000	2.131	1.680	1.362	1.190	1.052	.951	.860	.790
270	.000	.000	2.170	1.719	1.417	1.222	1.081	.978	.884	.813
280	.000	.000	2.207	1.757	1.450	1.252	1.109	1.004	.908	.835
290	.000	.000	2.252	1.804	1.490	1.288	1.141	1.034	.936	.861
300	.000	.000	.000	1.851	1.530	1.323	1.173	1.063	.963	.886
310	.000	.000	.000	1.899	1.569	1.358	1.205	1.092	.989	.911
320	.000	.000	.000	1.950	1.610	1.394	1.237	1.122	1.016	.936
330	.000	.000	.000	2.004	1.651	1.429	1.269	1.151	1.043	.961
340	.000	.000	.000	1.967	1.645	1.430	1.272	1.156	1.049	.966
350	.000	.000	.000	1.971	1.651	1.437	1.279	1.162	1.055	.972
360	.000	.000	.000	1.982	1.660	1.446	1.287	1.170	1.062	.979
370	.000	.000	.000	2.018	1.691	1.474	1.313	1.196	1.084	.999
380	.000	.000	.000	2.059	1.727	1.506	1.342	1.220	1.108	1.021
390	.000	.000	.000	2.107	1.765	1.539	1.372	1.248	1.133	1.045
400	.000	.000	.000	.000	1.803	1.574	1.403	1.277	1.160	1.069

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TABLE VIII (cont.)

SUPERCRITICAL OXYGEN HEAT TRANSFER CORRELATION (WATT PER KG/SEC PER DEG K)

30 MEGAPASCALS
(4350 PSIA)
WALL TEMP (DEG K)

BULK TEMP (DEG K)	100	200	300	400	500	600	700	800	900	1000
80	1.417	1.672	1.841	1.167	.960	.824	.723	.650	.584	.534
90	1.588	1.880	1.617	1.308	1.075	.923	.809	.726	.654	.599
100	.000	2.074	1.779	1.437	1.180	1.013	.889	.799	.719	.657
110	.000	2.243	1.919	1.547	1.270	1.090	.956	.859	.773	.708
120	.000	2.381	2.029	1.632	1.339	1.149	1.008	.906	.816	.746
130	.000	2.476	2.101	1.686	1.382	1.186	1.040	.936	.842	.771
140	.000	2.513	2.121	1.699	1.392	1.194	1.048	.943	.849	.777
150	.000	2.532	2.126	1.699	1.391	[illegible]	1.048	.943	.849	.778
160	.000	2.490	2.076	1.656	1.355	1.163	1.021	.919	.828	.759
170	.000	2.446	2.025	1.613	1.320	1.133	.995	.897	.808	.741
180	.000	2.412	1.983	1.577	1.291	1.109	.975	.879	.792	.726
190	.000	2.393	1.954	1.553	1.272	1.093	.962	.867	.783	.718
200	.000	.000	1.952	1.551	1.271	1.094	.963	.869	.785	.720
210	.000	.000	1.948	1.550	1.271	1.095	.965	.872	.787	.723
220	.000	.000	1.967	1.567	1.287	1.110	.979	.885	.800	.735
230	.000	.000	1.986	1.585	1.304	1.126	.994	.899	.813	.748
240	.000	.000	2.010	1.608	1.324	1.146	1.013	.917	.830	.763
250	.000	.000	2.044	1.640	1.353	1.172	1.037	.939	.851	.782
260	.000	.000	2.077	1.672	1.381	1.198	1.061	.962	.871	.802
270	.000	.000	2.111	1.706	1.411	1.225	1.086	.985	.893	.822
280	.000	.000	2.147	1.742	1.443	1.254	1.112	1.009	.915	.843
290	.000	.000	2.187	1.783	1.478	1.285	1.141	1.036	.940	.866
300	.000	.000	.000	1.828	1.516	1.320	1.172	1.065	.967	.891
310	.000	.000	.000	1.872	1.552	1.352	1.202	1.092	.992	.914
320	.000	.000	.000	1.919	1.589	1.385	1.231	1.120	1.017	.937
330	.000	.000	.000	1.970	1.627	1.418	1.261	1.147	1.042	.961
340	.000	.000	.000	1.925	1.614	1.413	1.260	1.146	1.043	.963
350	.000	.000	.000	1.921	1.613	1.414	1.261	1.144	1.045	.964
360	.000	.000	.000	1.923	1.615	1.416	1.263	1.151	1.047	.967
370	.000	.000	.000	1.953	1.642	1.441	1.286	1.172	1.066	.985
380	.000	.000	.000	1.990	1.674	1.469	1.312	1.196	1.089	1.005
390	.000	.000	.000	2.034	1.708	1.500	1.340	1.222	1.112	1.027
400	.000	.000	.000	.000	1.745	1.534	1.371	1.251	1.138	1.051

TABLE VIII (cont.)

SUPERCRITICAL OXYGEN HEAT TRANSFER CORRELATION (WATT PER KG/SEC PER DEG K)

34.5 MEGAPASCALS
(5000 PSIA)
WALL TEMP (DEG K)

BULK TEMP (DEG K)	100	200	300	400	500	600	700	800	900	1000
80	1.345	1.566	1.393	1.159	.959	.827	.729	.657	.594	.544
90	1.508	1.763	1.564	1.300	1.075	.927	.817	.737	.666	.610
100	.000	1.946	1.723	1.431	1.182	1.019	.898	.810	.732	.671
110	.000	2.108	1.862	1.544	1.275	1.099	.969	.874	.790	.724
120	.000	2.243	1.976	1.636	1.350	1.163	1.026	.925	.837	.767
130	.000	2.340	2.054	1.697	1.400	1.206	1.064	.960	.868	.796
140	.000	2.381	2.082	1.717	1.416	1.220	1.076	.971	.878	.806
150	.000	2.413	2.102	1.731	1.426	1.229	1.084	.979	.886	.812
160	.000	2.398	2.077	1.707	1.406	1.212	1.070	.966	.874	.802
170	.000	2.353	2.028	1.664	1.371	1.162	1.048	.943	.853	.783
180	.000	2.309	1.980	1.623	1.337	1.153	1.019	.921	.834	.766
190	.000	2.287	1.954	1.601	1.319	1.139	1.007	.910	.825	.758
200	.000	.000	1.950	1.597	1.316	1.137	1.006	.910	.825	.758
210	.000	.000	1.907	1.562	1.289	1.114	.986	.893	.810	.744
220	.000	.000	1.963	1.609	1.329	1.150	1.019	.923	.837	.770
230	.000	.000	1.981	1.625	1.343	1.163	1.031	.935	.849	.781
240	.000	.000	1.946	1.599	1.323	1.147	1.018	.923	.839	.772
250	.000	.000	2.007	1.655	1.371	1.190	1.057	.960	.872	.803
260	.000	.000	2.036	1.682	1.395	1.212	1.077	.979	.890	.820
270	.000	.000	2.067	1.712	1.421	1.236	1.099	.990	.909	.837
280	.000	.000	2.075	1.723	1.432	1.249	1.109	1.009	.918	.846
290	.000	.000	2.130	1.781	1.481	1.291	1.150	1.046	.952	.878
300	.000	.000	.000	1.823	1.517	1.322	1.179	1.073	.977	.901
310	.000	.000	.000	1.860	1.547	1.349	1.203	1.096	.998	.921
320	.000	.000	.000	1.903	1.581	1.380	1.231	1.121	1.022	.943
330	.000	.000	.000	1.951	1.617	1.411	1.259	1.147	1.046	.965
340	.000	.000	.000	1.895	1.592	1.396	1.248	1.139	1.039	.959
350	.000	.000	.000	1.875	1.577	1.384	1.238	1.130	1.031	.952
360	.000	.000	.000	1.859	1.564	1.373	1.229	1.122	1.024	.946
370	.000	.000	.000	1.882	1.586	1.393	1.247	1.139	1.040	.961
380	.000	.000	.000	1.913	1.613	1.417	1.279	1.160	1.059	.979
390	.000	.000	.000	1.953	1.643	1.445	1.295	1.183	1.080	.999
400	.000	.000	.000	.000	1.683	1.481	1.328	1.213	1.108	1.024

APPENDIX D

SYMBOLS

Cp = Constant pressure specific heat, J/(Kg·K)

$\overline{Cp}$ = Integrated average specific heat from Tw to Tb

d = Inside tube diameter, m

h = Heat transfer coefficient, w/(m^2·K)

k = Thermal conductivity, w/(m·K)

L = Heated tube length, in.

ℓ = Length from start of heated tube to each temperature measurement station, m

$\dot{m}$ = Mass flow rate, Kg/s

Nu = Nusselt Number (Nu = hd/K)

P = Local static pressure, MPa

Pr = Prandtl Number (Pr = Cpμ/K)

Q = Heat

Re = Reynold's Number (Re = ρdV/μ)

UL = Length of unheated inlet portion of test section, m

V = Fluid velocity, m/s

μ = Dynamic viscosity, Kg/(m·s)

ρ = Density, Kg/m^3

ϕ = Heat flux, w/m^2

Subscripts:

b = Evaluated at bulk temperature

cr = Critical

in = Inlet

nf = No flow through test section

nh = No heat applied to test section

out = Outlet

ref = Reference

w = Evaluated at wall temperature

f = Evaluated at film temperature

94