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THERMOPHYSICAL PROPERTY DATA AND SAFETY INFORMATION

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The accuracy of any calculation is usually dependent upon the quality of the input data. The National Bureau of Standards is the largest source of reliable data on the properties of materials and on bibliographic information at cryotemperatures. Precision measurements of the properties of oxygen over a wide range of temperature and pressure are complete. The primary remaining effort, which is in progress, is the representation of these data in the most usable format such as tables, equations, diagrams, and computer programs. In addition, safety data are essential to proper design, operation, and failure analysis. All of the available information on oxygen safety is being reviewed, evaluated and indexed for quick retrieval through the NASA Aerospace Safety Research and Data Institute program. This paper discusses the availability of data, where the major gaps in data occur, and retrieval of bibliographic information.

A prime function of the NBS-Cryogenic Division is to supply data for low temperature design and analysis. Table 1 shows the Functional Activities of the division and is intended to illustrate some of the resources available to the cryogenic engineer. The Cryogenics Division is the largest source of data on the properties of materials and bibliographic information at cryotemperatures. The Division is also the source of information on other areas of cryogenics such as safety, metrology, and process equipment. The primary objective of this paper, in relation to the Apollo program is to; a) summarize the sources of available data, b) discuss deficiencies in available data, c) review ongoing programs to alleviate these deficiencies, and d) discuss requirements for future space applications.

TABLE 1. Functional Activities of the NBS-Cryogenics Division

Cryogenic Data Center

- Documentation
- Compilation and Critical Evaluation

Cryogenic Properties of Solids

- Electrical Properties
- Thermal Properties
- Mechanical/Metallurgical Properties

Properties of Cryogenic Fluids

- Pure Fluids
- Mixtures

Cryogenic Systems

- Systems Evaluation
- Consultation
- Slush Cryogens

Metrology

- Flowmetering
- Pressure/Temperature/Density/State

Fluid Transport Processes

- Heat Transfer
- Infrared Properties

Cryoelectronics

Data for Analysis and Design

A complete review of the information service provided by the Cryogenic Data Center for the field of cryogenics has recently been published by Olien.[1] A thorough and continuous search of current published literature is conducted. We review over 300 journals cover-to-cover, search other abstracting services, patents, conference proceedings, and report literature. Dissemination is made each week through the Current Awareness Service as illustrated in Figure 1. In addition, two specialized bibliographies are published quarterly, The Superconducting Devices and Materials Quarterly and the Liquefied Natural Gas Quarterly. Documents from these lists are then selected for entry into the information retrieval system. Punched cards in machine-readable form containing title, author, byline, reference, abstract reference, and indexing terms are prepared for each of the selected documents. Over 7500 new documents are added each year and our total file contains over 70,000 documents.

The availability of these data on magnetic tape permits rapid access to a vast amount of information. For example, Table 2 shows a list of bibliographies prepared for NASA and NASA contractors immediately after the Apollo 13 incident. Selected data from these references were scanned by the NBS staff and transmitted over the telephone. The entire bibliography was then forwarded, usually within hours after being requested. The rapid availability of these data saved many laborious manhours in conducting literature searches for creditable data and tended to assure the investigators that all pertinent sources of data had been utilized.

Thermophysical Properties of Oxygen

Data on the thermodynamic and transport properties of oxygen have been measured by NBS over a wide range of temperature and pressure.[2] These measurements were made at the request of NASA-OART.[3] Available tables, charts, graphs, and computer programs were supplied in copious quantities to assist in the Apollo investigation. The diverse nature of subsequent calculations (as illustrated by today's program) reemphasized the fact that the data, although available, were not always in the most usable format. In response to this need, NBS has undertaken a program for NASA-MSC to compile the thermophysical data in a format which is more readily usable by the design engineer.[4] The first of these documents is in final form for editorial

TABLE 2. Prepared Bibliographies Related to the Apollo 13 Incident

Compatibility of Oxygen with Various Materials and Contamination, Hazards and Safety with Liquid Oxygen

Handling and Safety with Liquid Oxygen

Liquid Oxygen Storage, Transfer, Loading, etc., Procedures and Equipment

Flow, Temperature and Pressure Measurement of Liquid and Supercritical Oxygen

Heat Transfer to Supercritical Oxygen at Zero Gravity

Properties of Thermal Insulation for Use at Cryogenic Temperatures

Critical Properties of Oxygen

Thermal Conductivity and Specific Heat of Inconel

Thermodynamic Diagrams of Oxygen

Thermodynamic Properties of Oxygen

Thermodynamic and Transport Properties of Teflon review and printing. R. D. McCarty and L. A. Weber[5] have compiled and critically evaluated the "Thermophysical Properties of Oxygen from the Freezing Liquid Line to 600 R for Pressures to 5000 psia." The tables include, entropy, enthalphy, internal energy, density, volume, speed of sound, specific heat, thermal conductivity, viscosity, $(\partial P/\partial V)_T$, $(\partial P/\partial T)_\rho$, $V(\partial H/\partial V)_P$, $V(\partial P/\partial U)_V$, $-V(\partial P/\partial V)_T$, $1/V(\partial V/\partial T)_P$, thermal diffusivity, Prandtl number and the dielectric constant for 79 isobars. In addition to the isobaric tables, tables for the saturated vapor and liquid are given which include all of the above properties, plus the surface tension. Tables for the pressure-temperature relationship of the freezing liquid and the derived Joule-Thomson inversion curve are also presented. The specific heat at constant saturation and the index of refraction are given in graphical form. Figures 2 and 3 show a representative table of data and a temperature entropy chart.

Thermodynamic Property Diagrams

Thermodynamic and phase diagrams permit the properties of a fluid to be visualized in a familiar frame of reference. They are often used for preliminary design and occasionally for final design, even though greater accuracy can be obtained from tables, computer routines or greatly enlarged charts. Diagrams are also useful in the analysis of malfunctions because they provide rapid access to property values without the difficulty of two-dimensional interpolation. Table 3 outlines the types of charts in most common use. Each chart has its adherents and, in general, each serves a slightly different purpose. Preparation of all of these charts for a given fluid would be very expensive. To be complete, all eight charts (in three, four and five variables) in SI, British, and modified units would require at least 30 different diagrams. In order to cover all ranges of temperature and pressure to adequate accuracy, some diagrams must be prepared in sections. Selected diagrams are currently in preparation by McCarty and Weber.

TABLE 3. Thermodynamic Diagrams

	3 variable charts	4 variable charts	5 variable charts
Variables	P, V or ρ, T	P, V or ρ, T, Z	P, V or ρ, T, H or U, S
Coordinate axes (the other variables are shown as constant property lines)	P vs T P vs V or ρ ρ vs T	Z vs log P	H vs S T vs S P or log P vs H P or log P vs U

Computer Programs for Thermophysical Properties of Oxygen

Several approaches to the development of computer programs for thermophysical properties of oxygen have been taken. The equation of state approach is very useful because it allows the direct calculation of the thermodynamic properties from an easily programmable mathematical function. The equation of state for oxygen developed by Stewart[6] has been used extensively, and although it does not give the best representation of existing experimental data, the accuracy is sufficient for many purposes. However, it is necessary to proceed with caution since equations of state often give erroneous results in the critical region and should not be used for extrapolation beyond the limits of experimental data.

Another method of computerizing thermodynamic properties is the so-called "Tab Code" method, which allows rapid calculations by interpolations of tables stored in the computer. This method was used for hydrogen,[7] but to this authors' knowledge no such program is available for oxygen. The primary problem with this method is interpolation error. If accurate calculations are required, the size of the tables to be stored in the computer becomes prohibitively large.

A third method of computerizing thermodynamic properties is by programming a series of independently derived mathematical functions (multifunction) such as isochores or isotherms or both. These functions are then joined together in the computer program by various means. Although this approach gives the most accurate results, it usually produces a program which allows very little, if any, versatility and the program is relatively slow on the computer. Because it is the most accurate way to present data, we have prepared the oxygen data in this manner for NASA-MSC under our present contract.[4] The problem of determining which calculational approach is best has no single answer but depends upon the individual user's requirements. The following table can be used as a guide. In addition, the National Bureau of Standards is constantly striving to fulfill the needs of the scientific and engineering community for computerized property data.

Type of Program	Speed	Versatility	Accuracy
Equation of State	medium	best	medium
Tab Code	best	very little	medium
Multifunction	slow	none	best

Radiation Properties of Oxygen

Measurement of the spectral transmission of infrared radiation in oxygen has been reported by several experimenters. These data are being compiled, critically evaluated and used to calculate total hemispherical radiation properties necessary for heat transfer calculations.[8]

Safety of Oxygen

An extensive program is underway to provide data for the safe handling of cryogenic fluid oxygen. Under the sponsorship of NASA Aerospace Safety Research and Data Institute (ASRDI) information on oxygen is being synthesized for quick retrieval through the NASA automated data processing system.[9] The technical objectives of the program are to:

(1) develop a thesaurus (dictionary) for information retrieval of safety related information,

(2) conduct an exhaustive literature search and acquire the documents,

(3) index and abstract these documents using the thesaurus,

(4) enter these documents into the NASA data bank for retrieval, and

(5) prepare a summary report on the properties of oxygen, giving "best values" for design.

An exhaustive search by our laboratory of both formal and informal sources of information is about 90 percent complete and has yielded over 3500 documents. Over half of these articles concern properties data and at least 400 are being evaluated in detail for the preparation of "best values."

The indexing thesaurus has been developed by the NBS and ASRDI staff and used to code a large number of cryogenic fluid safety papers. Coding is performed by members of the NBS senior staff which permits a critical evaluation by specialists in a particular field. The final input contains an abstract, major subject(s), minor subject(s), and links. The links are sequences of key words which permit retrieval (and sorting) of papers by a combination or words rather than single isolated words, i.e., a link is a set of indexing terms connected together to represent a detailed subject discussed in the report or paper.

Summary

Many of the thermophysical properties of oxygen below 5000 psi are extremely well known (relative to other fluids) and the development of "best values" along with tables, charts and computer programs should suffice for nearly all requirements. Future demands will require additional specialized data, data near the critical point, and most importantly, data above 5000 psi. The most severe and immediate problem to be solved is the criteria for compatibility as a function of temperature, pressure, density, etc., and the development of correlations between test procedures and service failure.

The Cryogenics Division is engaged in a program for NASA-MSC to compile the thermophysical properties of H_2, He, and N_2 in a format similar to the oxygen properties work of McCarty and Weber mentioned above.[4] Gaps in the data and uncertainties will, in many cases, limit the accuracy of calculations which can be made using these fluids. Details of these uncertainties will be given in the individual reports, but two potential problems should be outlined to this group. First, there exists a complete lack of data on helium in certain regions of the thermodynamic diagram, and in other regions, major discrepencies exist which can only be resolved by additional measurements. Secondly, no data on hydrogen exist at low temperatures above 5000 psi. This lack of data could be a severe problem for the shuttle engine design and, in collaboration with NASA-OART, we are planning on; (1) extrapolating existing data and estimating the uncertainties, and (2) evaluating the need for new measurements.

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References

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2 A synthesis of the oxygen properties data from all sources is given in Ref. 5.

3 V. J. Johnson and D. E. Diller, "Thermodynamic and Transport Properties of Fluids and Selected Solids for Cryogenic Applications," Summary Report of work performed on NASA Contracts R-06-006-046 and W-12,745, unpublished.

4 "Properties of Oxygen, Hydrogen, Helium and Nitrogen," NASA-MSC Contract T-1813A.

5 Robert D. McCarty and Lloyd A. Weber, "Thermophysical Properties of Oxygen from the Freezing Liquid Line to 600 R for Pressures to 5000 PSIA." NBS Tech. Note (in press).

6 R. B. Stewart, "The Thermodynamic Properties of Oxygen," University of Iowa, Iowa City, Ph.D. Thesis (1966).

7 W. J. Hall, R. D. McCarty, and H. M. Roder, "Computer Programs for Thermodynamic and Transport Properties of Hydrogen," unpublished report.

8 "Absorption Coefficients," NASA-Langley Research Center, Contract No. L-62,510.

9 "Oxygen Safety and Cryogenic Fluids Safety Grid." NASA-Lewis Research Center Contract C-81608-B.

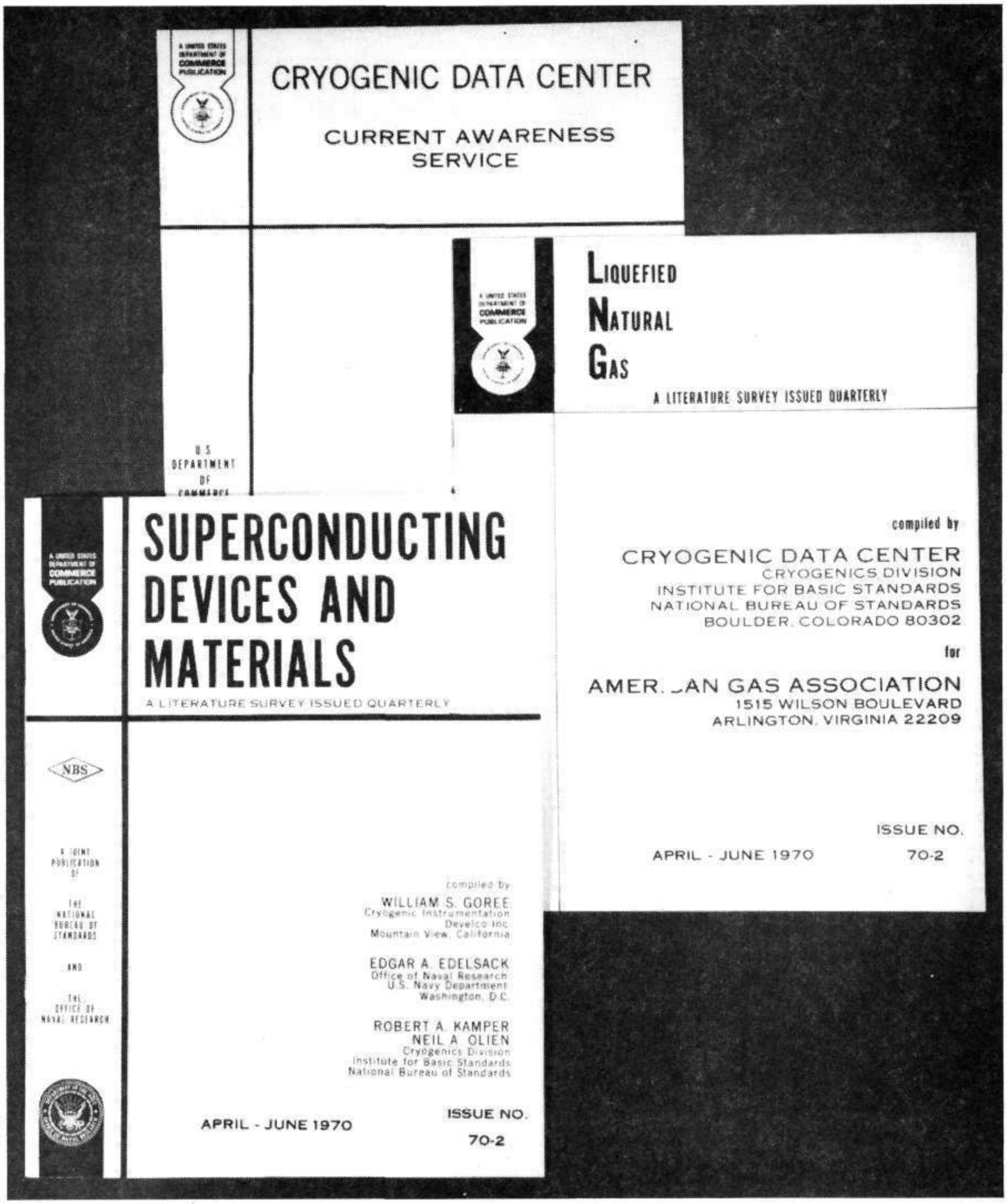

Figure 1. Three Subscription Services of the Cryogenic Data Center

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TEMPERATURE DEG. R	VOLUME CU FT/LB	ISOTHERM DERIVATIVE CU FT-PSIA/LB	ISOCHORE DERIVATIVE PSIA/R	INTERNAL ENERGY BTU/LB	ENTHALPY BTU/LB	ENTROPY BTU/LB-R	C_v BTU / LB -R	C_p BTU / LB -R	VELOCITY OF SOUND FT/SEC
* 104.777	0.01208	2390.44	320.1	-82.324	-71.151	0.50834	0.268	0.389	4010
105	0.01208	2386.51	319.5	-82.241	-71.064	0.50917	0.268	0.389	4008
110	0.01218	2299.59	307.6	-80.388	-69.120	0.52726	0.264	0.388	3958
115	0.01228	2215.35	296.1	-78.541	-67.180	0.54451	0.261	0.388	3907
120	0.01238	2133.71	285.0	-76.698	-65.243	0.56099	0.257	0.387	3855
125	0.01248	2054.63	274.3	-74.861	-63.310	0.57677	0.254	0.386	3803
130	0.01259	1978.03	254.0	-73.029	-61.381	0.59191	0.251	0.385	3750
135	0.01269	1903.88	254.0	-71.202	-59.456	0.60644	0.248	0.385	3697
140	0.01280	1832.10	244.4	-69.380	-57.533	0.62042	0.246	0.384	3643
145	0.01291	1762.65	235.1	-67.563	-55.615	0.63388	0.243	0.383	3589
150	0.01303	1695.46	226.2	-65.752	-53.699	0.64687	0.240	0.383	3535
155	0.01314	1630.48	217.7	-63.945	-51.787	0.65941	0.238	0.382	3481
160	0.01326	1567.66	209.4	-62.144	-49.878	0.67153	0.236	0.381	3427
165	0.01337	1506.93	201.5	-60.348	-47.973	0.68326	0.234	0.381	3374
170	0.01350	1448.24	193.9	-58.557	-46.070	0.69462	0.231	0.380	3320
175	0.01362	1391.54	186.6	-56.771	-44.170	0.70563	0.229	0.380	3267
180	0.01374	1336.78	179.6	-54.990	-42.273	0.71632	0.227	0.379	3214
185	0.01387	1283.88	172.9	-53.214	-40.379	0.72670	0.225	0.379	3163
190	0.01400	1232.82	166.5	-51.444	-38.487	0.73679	0.223	0.378	3111
195	0.01414	1183.52	160.3	-49.679	-36.598	0.74661	0.221	0.378	3061
200	0.01427	1135.95	154.5	-47.919	-34.711	0.75616	0.219	0.377	3012
205	0.01441	1090.04	148.8	-46.164	-32.827	0.76547	0.216	0.377	2964
210	0.01456	1045.76	143.4	-44.416	-30.945	0.77454	0.214	0.376	2918
215	0.01471	1003.05	138.3	-42.672	-29.066	0.78339	0.211	0.375	2873
220	0.01486	961.87	133.4	-40.935	-27.189	0.79202	0.209	0.375	2830
225	0.01501	922.17	128.7	-39.204	-25.315	0.80044	0.206	0.374	2789
230	0.01517	883.92	124.3	-37.480	-23.442	0.80866	0.202	0.374	2750
235	0.01534	852.76	119.4	-35.741	-21.552	0.81679	0.206	0.377	2069
240	0.01551	826.75	120.4	-33.982	-19.635	0.82487	0.205	0.392	2718
245	0.01568	788.34	110.8	-32.239	-17.733	0.83271	0.204	0.378	2549
250	0.01585	750.71	107.1	-30.498	-15.829	0.84040	0.203	0.381	2554
255	0.01604	719.26	105.0	-28.747	-13.908	0.84801	0.202	0.388	2529
260	0.01622	681.83	97.5	-27.023	-12.014	0.85537	0.201	0.377	2435
265	0.01642	651.37	97.3	-25.275	-10.085	0.86272	0.200	0.392	2432
270	0.01662	625.00	92.5	-23.527	-8.151	0.86995	0.199	0.388	2377
275	0.01683	598.70	89.5	-21.790	-6.223	0.87703	0.197	0.390	2342
280	0.01703	560.81	81.9	-20.072	-4.312	0.88391	0.196	0.376	2232
285	0.01726	550.11	75.6	-18.331	-2.363	0.89081	0.195	0.358	2165
290	0.01748	516.84	78.0	-16.623	-0.453	0.89745	0.198	0.391	2176
295	0.01771	496.88	75.7	-14.876	1.511	0.90417	0.196	0.393	2150
300	0.01795	479.62	73.2	-13.131	3.480	0.91079	0.195	0.395	2122
310	0.01846	444.22	67.7	-9.656	7.423	0.92372	0.194	0.396	2049
320	0.01899	407.72	61.6	-6.202	11.367	0.93624	0.193	0.392	1957
330	0.01956	380.41	58.1	-2.749	15.346	0.94849	0.192	0.400	1913
340	0.02016	354.16	53.6	0.672	19.321	0.96035	0.191	0.398	1850
350	0.02079	330.93	49.7	4.059	23.293	0.97137	0.189	0.398	1797
360	0.02145	307.04	45.6	7.385	27.231	0.98296	0.187	0.395	1733
370	0.02215	288.27	42.2	10.663	31.154	0.99371	0.185	0.393	1695
380	0.02289	277.37	42.2	13.912	35.095	1.00422	0.182	0.419	1718
390	0.02368	272.27	37.7	17.102	39.008	1.01438	0.180	0.391	1655
400	0.02445	258.76	33.6	20.192	42.813	1.02431	0.179	0.372	1579
410	0.02525	246.19	31.8	23.232	46.594	1.03335	0.178	0.376	1554
420	0.02608	235.52	29.1	26.204	50.331	1.04236	0.177	0.367	1506
430	0.02694	230.45	27.9	29.139	54.063	1.05114	0.176	0.371	1501
440	0.02786	236.33	27.6	32.057	57.831	1.05990	0.175	0.378	1540
450	0.02875	237.55	25.4	34.869	61.469	1.06798	0.174	0.361	1512
460	0.02962	233.99	23.5	37.588	64.998	1.07573	0.173	0.350	1480
470	0.03051	231.83	22.2	40.250	68.461	1.08323	0.172	0.344	1465
480	0.03141	230.64	21.1	42.851	71.912	1.09045	0.171	0.340	1458
490	0.03231	230.80	20.1	45.396	75.294	1.09743	0.170	0.335	1451
500	0.03322	231.62	19.2	47.885	78.626	1.10416	0.169	0.331	1449
510	0.03416	235.52	18.9	50.337	81.941	1.11072	0.168	0.336	1476
520	0.03509	239.60	17.9	52.730	85.192	1.11703	0.167	0.325	1470
530	0.03599	240.90	16.9	55.060	88.362	1.12307	0.166	0.316	1456
540	0.03690	243.09	16.2	57.351	91.493	1.12892	0.165	0.313	1460
550	0.03780	245.38	15.4	59.594	94.564	1.13456	0.164	0.304	1452
560	0.03869	248.24	14.9	61.799	97.598	1.14002	0.163	0.301	1457
570	0.03959	251.54	14.4	63.966	100.594	1.14533	0.162	0.298	1462
580	0.04048	255.15	13.9	66.096	103.551	1.15047	0.161	0.294	1469
590	0.04137	258.99	13.4	68.191	106.469	1.15546	0.160	0.291	1475
600	0.04226	262.99	13.0	70.251	109.350	1.16030	0.159	0.287	1482

Figure 2a. Thermodynamic Properties of Oxygen

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TEMPERATURE DEG. R	DENSITY LB/CU FT	V(DH/DV) BTU/LB	V(DP/DU) PSIA-CU FT/BTU	-V(DP/DV) PSIA	-(DV/DT)/V DEG. R	THERMAL CONDUCTIVITY BTU/FT-HR-R	VISCOSITY LB/FT-SEC X 10[5]	THERMAL DIFFUSIVITY SQ FT/HR	DIELECTRIC CONSTANT	PRANDTL NUMBER
* 104.777	82.80994	240.72	14.420	197952.53	0.0016169	0.11425	48.928	0.00354	1.57872	6.0009
105	82.73009	240.62	14.410	197555.14	0.0016175	0.11420	48.738	0.00354	1.57846	5.9796
110	82.11091	238.40	14.183	188821.79	0.0016293	0.11304	44.681	0.00354	1.57306	5.5272
115	81.44227	236.18	13.951	180423.32	0.0016414	0.11181	41.065	0.00354	1.56766	5.1184
120	80.77411	233.94	13.714	172348.63	0.0016539	0.11052	37.678	0.00354	1.56231	4.7486
125	80.10636	231.69	13.475	164588.53	0.0016667	0.10917	34.652	0.00353	1.55694	4.4139
130	79.43893	229.43	13.232	157132.81	0.0016800	0.10777	31.928	0.00352	1.55163	4.1107
135	78.77175	227.14	12.988	149971.76	0.0016937	0.10633	29.449	0.00351	1.54631	3.8358
140	78.10471	224.84	12.743	143095.78	0.0017080	0.10486	27.202	0.00350	1.54100	3.5864
145	77.43770	222.51	12.498	136495.47	0.0017228	0.10335	25.152	0.00348	1.53572	3.3611
150	76.77060	220.16	12.254	130161.62	0.0017382	0.10181	23.312	0.00347	1.53042	3.1545
155	76.10326	217.77	12.012	124085.16	0.0017542	0.10024	21.632	0.00345	1.52514	2.9678
160	75.43554	215.36	11.773	118257.23	0.0017710	0.09866	20.106	0.00343	1.51986	2.7982
165	74.76725	212.90	11.538	112669.13	0.0017886	0.09706	18.720	0.00341	1.51462	2.6441
170	74.09822	210.41	11.307	107312.37	0.0018070	0.09544	17.453	0.00339	1.50937	2.5047
175	73.42823	207.87	11.082	102178.65	0.0018264	0.09382	16.315	0.00337	1.50412	2.3766
180	72.75707	205.28	10.864	97259.86	0.0018468	0.09219	15.272	0.00334	1.49887	2.2669
185	72.08448	202.63	10.654	92548.09	0.0018683	0.09156	14.324	0.00332	1.49363	2.1557
190	71.41020	199.92	10.452	88035.65	0.0018911	0.08892	13.460	0.00329	1.48836	2.0602
195	70.73393	197.13	10.261	83715.07	0.0019153	0.08729	12.673	0.00327	1.48313	1.9734
200	70.05536	194.28	10.081	79579.10	0.0019409	0.08566	11.955	0.00324	1.47786	1.8946
205	69.37414	191.33	9.914	75620.70	0.0019681	0.08403	11.301	0.00322	1.47262	1.8230
210	68.68991	188.30	9.760	71833.08	0.0019970	0.08241	10.703	0.00319	1.46734	1.7581
215	68.00228	185.16	9.623	68209.69	0.0020278	0.08080	10.157	0.00315	1.46206	1.6992
220	67.31082	181.92	9.502	64744.24	0.0020606	0.07919	9.658	0.00314	1.45675	1.6453
225	66.61509	178.56	9.401	61430.68	0.0020957	0.07760	9.201	0.00311	1.45145	1.5974
230	65.91461	175.10	9.319	58263.22	0.0021331	0.07601	8.783	0.00309	1.44606	1.5530
235	65.20898	175.51	8.895	55607.62	0.0021475	0.07444	8.399	0.00303	1.44071	1.5309
240	64.49079	173.09	9.110	53317.99	0.0022587	0.07287	8.044	0.00289	1.43527	1.5592
245	63.78531	171.38	8.510	50284.57	0.0022031	0.07135	7.727	0.00295	1.42991	1.4727
250	63.07645	168.36	8.362	47352.01	0.0022628	0.06986	7.436	0.00291	1.42459	1.4599
255	62.35220	165.79	8.329	44447.35	0.0023404	0.06836	7.165	0.00283	1.41969	1.4542
260	61.64795	162.78	7.863	42033.29	0.0023189	0.06694	6.925	0.00288	1.41379	1.4058
265	60.91420	159.82	7.986	39059.46	0.0024525	0.06548	6.695	0.00274	1.40829	1.4427
270	60.17397	157.60	7.737	37058.52	0.0024602	0.06405	6.483	0.00275	1.40279	1.4128
275	59.43532	155.14	7.629	35583.75	0.0025162	0.06266	6.290	0.00273	1.39724	1.4106
280	58.70712	151.14	7.113	32923.64	0.0024882	0.06132	6.115	0.00278	1.39182	1.3506
285	57.94593	150.93	6.700	31876.57	0.0023724	0.05996	5.958	0.00289	1.38617	1.2609
290	57.22107	148.05	6.903	29574.41	0.0026385	0.05870	5.843	0.00263	1.38080	1.3991
295	56.45265	145.77	6.843	28055.17	0.0026971	0.05741	5.719	0.00259	1.37522	1.4097
300	55.69902	144.06	6.746	26714.40	0.0027404	0.05616	5.549	0.00255	1.35956	1.4170
310	54.17574	140.64	6.441	24005.91	0.0028124	0.05377	5.369	0.00251	1.35841	1.4219
320	52.66463	136.69	6.046	21472.53	0.0028684	0.05155	5.153	0.00250	1.34739	1.4197
330	51.13449	133.80	5.905	19451.93	0.0029864	0.04945	4.943	0.00242	1.33629	1.4379
340	49.61541	130.57	5.660	17571.70	0.0030516	0.04750	4.745	0.00240	1.32534	1.4329
350	48.10370	127.50	5.466	15919.15	0.0031238	0.04570	4.558	0.00239	1.31449	1.4301
360	46.62166	123.87	5.234	14314.75	0.0031876	0.04406	4.344	0.00234	1.30392	1.4146
370	45.15354	120.96	5.065	13016.44	0.0032454	0.04254	4.221	0.00240	1.29351	1.4023
380	43.67885	120.27	5.298	12115.04	0.0034819	0.04112	4.065	0.00225	1.28316	1.4963
390	42.23714	119.34	4.951	11499.81	0.0032749	0.03982	3.920	0.00241	1.27298	1.3651
400	40.90227	117.14	4.596	10583.71	0.0031761	0.03872	3.795	0.00254	1.26366	1.3127
410	39.60409	115.41	4.516	9749.97	0.0032604	0.03771	3.679	0.00253	1.25463	1.3215
420	38.35047	113.79	4.304	9332.27	0.0032269	0.03680	3.573	0.00261	1.24597	1.2533
430	37.12212	113.63	4.282	8534.64	0.0032622	0.03596	3.475	0.00261	1.23751	1.2892
440	35.89784	116.26	4.402	8483.62	0.0032517	0.03517	3.381	0.00259	1.22912	1.3082
450	34.78353	117.34	4.205	8262.91	0.0030759	0.03450	3.301	0.00275	1.22152	1.2432
460	33.75686	117.41	4.029	7898.62	0.0029792	0.03393	3.232	0.00287	1.21455	1.1997
470	32.77384	117.83	3.933	7598.00	0.0029203	0.03341	3.170	0.00295	1.20789	1.1754
480	31.83830	118.51	3.869	7349.69	0.0028703	0.03294	3.114	0.00304	1.20156	1.1575
490	30.94678	119.40	3.808	7142.37	0.0028091	0.03252	3.063	0.00313	1.19559	1.1372
500	30.09838	120.49	3.761	6971.32	0.0027489	0.03215	3.018	0.00322	1.18992	1.1193
510	29.27605	122.31	3.643	6895.15	0.0027450	0.03180	2.975	0.00324	1.18442	1.1313
520	28.50220	124.23	3.753	6829.22	0.0026193	0.03149	2.939	0.00340	1.17927	1.0931
530	27.78387	125.48	3.655	6693.27	0.0025211	0.03123	2.907	0.00355	1.1745	1.0599
540	27.03959	126.89	3.626	6587.67	0.0024641	0.03100	2.878	0.00365	1.16997	1.0452
550	26.45847	128.49	3.540	6492.35	0.0023693	0.03079	2.854	0.00382	1.16574	1.0155
560	25.84578	130.08	3.521	6416.02	0.0023160	0.03062	2.831	0.00393	1.15172	1.0033
570	25.26109	131.78	3.503	6354.12	0.0022632	0.03046	2.812	0.00405	1.15786	0.9899
580	24.70351	133.56	3.485	6303.12	0.0022038	0.03032	2.795	0.00417	1.15421	0.9766
590	24.17185	135.39	3.469	6260.33	0.0021477	0.03020	2.779	0.00430	1.15073	0.9634
600	23.66478	137.26	3.454	6223.71	0.0020928	0.03010	2.765	0.00443	1.14742	0.9504

Figure 2b. Thermodynamic Properties of Oxygen

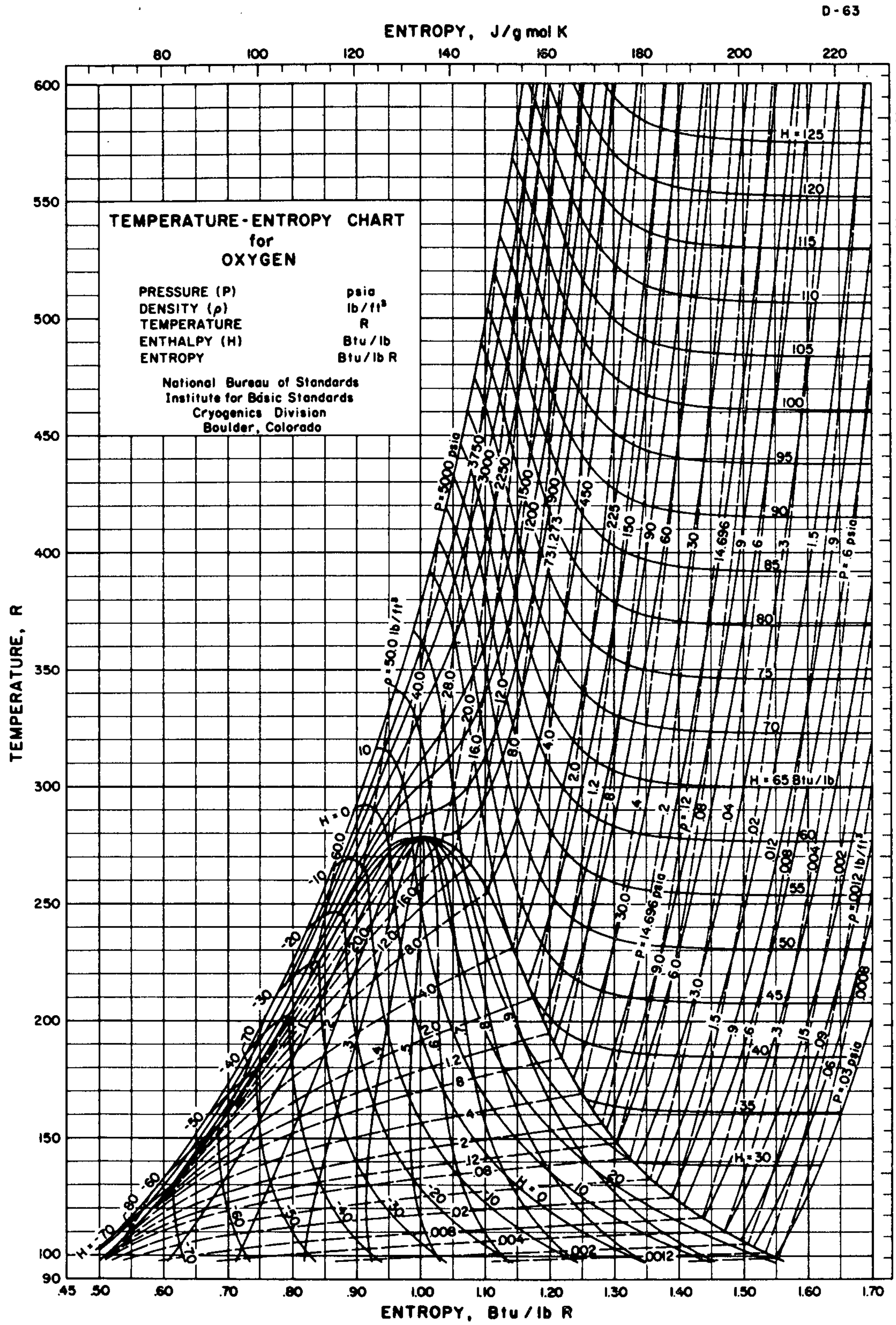

Figure 3. Temperature-Entropy Chart for Oxygen