CSC:PVJ
III-3

DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS
WASHINGTON

Letter
Circular
LC-419

INFORMATION ON REFRIGERATION

June 25, 1934
(Replaces LC-30)

The National Bureau of Standards receives numerous requests for general information on refrigeration. The Bureau's work in this field has been confined largely to the determination of the fundamental constants of refrigerating engineering, and it has, therefore, no publications dealing with refrigeration in general, and is not in a position to give consulting engineering service by correspondence. The following information, consisting largely of references, has been compiled for the purpose of answering inquiries of the kind referred to above.

Section I. Publications of the National Bureau of Standards

The following publications of the National Bureau of Standards dealing with refrigeration may be obtained from the Superintendent of Documents, Government Printing Office, Washington, D. C., at the prices stated (stamps not accepted). In ordering, give title, serial letter, and number of the publication desired.

S = Scientific Paper;
T = Technologic Paper;
C = Circular;
M = Miscellaneous Publication;
RP = Research Paper, reprint from the Journal of Research of the National Bureau of Standards.

In case price is not given the publication is no longer available for distribution but may be consulted in the "Government Depository Reference Libraries" listed in the Supplement to Circular 24, obtainable from the Superintendent of Documents, 15 ¢ per copy. Scientific Papers in bound form previous to Volume 15 were known as the "Bulletin".

Serial Letter and Number	Bound Volume Number	
S123	6	The Theory of the Hampson Liquefier (out of print).
S135	6	Specific Heat of Some Calcium Chloride Solutions between -35° and +20°C (out of print).
S209	10	Latent Heat of Fusion of Ice (out of print).
S248	12	Specific Heat and Heat of Fusion of Ice, 10¢.
S313	14	Specific Heat of Liquid Ammonia, 10¢.
S314	14	Latent Heat of Pressure Variation of Liquid Ammonia, 5¢.
S315	14	Latent Heat of Vaporization of Ammonia, 5¢.
S369	16	Vapor Pressure of Ammonia, 10¢.
S419	17	The Production of Liquid Air on a Laboratory Scale (out of print).
S420	17	Specific Volume of Liquid Ammonia, 5¢.
S465	18	Composition, Purification, and Certain Constants of Ammonia, 10¢.
S467	18	Specific Volume of Saturated Ammonia Vapor, 5¢.
S501	20	Specific Heat of Superheated Ammonia Vapor, 15¢.
S520	20	Nonflammable Liquids for Cryostats, 10¢.
T180	14	Causes and Prevention of the Formation of Non-condensible Gases in Ammonia Absorption Refrigerating Machines, 5¢.
RP538	10	Vapor Pressure of Liquid and Solid Carbon Dioxide, 5¢.
C142		Tables of Thermodynamic Properties of Ammonia, 15¢. (British units, also contains Mollier Chart, M52).
M52		Mollier Chart of Properties of Ammonia, 5¢. (Size 9x23 inches, British units.)
M57		Large Mollier Chart (Size 16x40 inches, British units.) (Out of print.)
M76		Large Mollier Chart of Properties of Ammonia, 10¢. (Size 39x107 cm, Metric units.)

Section II. Books on Thermodynamics and Refrigeration

The number of pages given for each book is not always the total number of pages, but the number devoted explicitly to refrigeration. The prices, where given, are the list prices.

1. Principles of Thermodynamics, by G. A. Goodenough, Henry Holt & Co., New York, 1920; 19 pages on refrigeration (College Textbook).
2. Thermodynamics for Engineers, by J. A. Ewing; Cambridge University Press, London, 1920; 58 pages on refrigeration; $12.00. (College Textbook.)
3. Engineering Thermodynamics, by C. E. Lucke; McGraw-Hill Book Co., New York, 1912; 34 pages on refrigeration, $8.00 (General Treatise.)
4. Elements of Engineering Thermodynamics, by Moyer, Calderwood and Potter; John Wiley and Sons, New York, 1920; 16 pages on refrigeration, $2.50. (College Textbook.)
5. Thermodynamics, by J. E. Emswiler, McGraw-Hill Book Co., New York, 1927; 11 pages on refrigeration, $3.00 (College Textbook.)
6. The Mechanical Production of Cold, by J. A. Ewing; Cambridge University Press, London, 1908; 201 pages. (Scientific Lectures.)
7. The Elements of Refrigeration, by A. M. Greene; John Wiley & Sons, New York, 1919; 472 pages, $4.50 (College Textbook.)
8. The Principles of Mechanical Refrigeration, by H. J. Macintire; McGraw-Hill Book Co., New York, 2nd Edition, 1928, 315 pages, $3.00 (for operating engineers).
9. Refrigeration, by J. A. Moyer and R. U. Fittz, McGraw-Hill Book Co., New York, 2nd Edition, 1932, 538 pages (General Treatise.)
10. Principles of Refrigeration, by W. H. Motz; Nickerson & Collins Co., Chicago, 3rd Edition, 1932, 1032 pages, $7.50 (General Treatise.)
11. Ammonia Compression Refrigerating System, by W. S. Doan, Nickerson & Collins Co., Chicago, 1922, 186 pages, $2.50, (for operating engineers).
12. The Absorption Refrigerating Machine - Elementary Theory and Practice, by Gardner T. Voorhees; Nickerson & Collins Co., Chicago, 158 pages, $2.50.
13. Practical Refrigerating Engineers Pocketbook, by John E. Starr, Nickerson & Collins Co., Chicago, 1922; 186 pages, $2.50 (for operating engineers).
14. Power's Practical Refrigeration, by L. H. Morrison; McGraw-Hill Book Co., New York, 2nd Edition, 1928; 259 pages, $2.50, (for operating engineers).

15. Handbook of Refrigerating Engineering, by W. R. Woolrich; D. Van Nostrand Co., New York, 1929; 329 pages, $4.00.
16. Kent's Mechanical Engineer's Handbook; John Wiley & Sons, New York; 10th Edition, 1923; 34 pages on refrigeration, $6.00.
17. Mechanical Engineers Handbook, Lionel S. Marks; McGraw-Hill Book Co., New York; 3rd Edition, 1930; 46 pages on refrigeration.
18. Handbook of Mechanical Refrigeration, by H. J. Macintire; John Wiley & Sons, New York, 1928; 724 pages.
19. Compend of Mechanical Refrigeration and Engineering, by J. E. Siebel; Nickerson & Collins Co., Chicago, 9th Edition, 1922; 550 pages, $10.00, (for operating engineers).
20. Ice and Refrigeration Blue Book and Buyers Guide, Nickerson & Collins Co., Chicago; 10th Edition, 1928; $12.00, (mainly statistical).
21. Instructions for the Operation, Care and Repair of Refrigerating Plants, U. S. Bureau of Engineering, Navy Department; 1926, 94 pages, purchasable from Superintendent of Documents, Washington, D. C., 25¢ (stamps not accepted).
22. Mechanical Equipment of Buildings, Vol. 2, Power plants and Refrigeration, by Harding and Willard; John Wiley & Sons, New York; 2nd Edition, 1929. (General treatise.)
23. Bibliography of American Literature Relating to Refrigeration, by The American Association of Ice and Refrigeration (3 volumes), Nickerson & Collins Co., Chicago.
24. Bibliography of Refrigeration, by Food Investigation Board of British Department of Scientific and Industrial Research, 16 Old Queen Street, Westminster, S. W., 1, London. Special Report No. 2.
25. Refrigerating Data Book and Catalog, American Society of Refrigerating Engineers, 37 West 39th St., New York, N. Y.; 1st Edition 1932-33; 435 pages, $3.50, (A comprehensive compilation, designed to provide a useful source of reference for general information on all phases of refrigeration, issued biennially.)

Section III. Domestic Refrigeration

Many of the books, listed in Section II above, contain some information on this subject, item 25 in particular. Other sources of information are:

1. Household Refrigeration, by H. B. Hull, Nickerson & Collins Co., Chicago; 4th Edition, 700 pages, $4.00.
2. Home Economics Bibliography 5 - Household Refrigeration. This booklet contains a list of references to articles, mostly non-technical, of interest to the householder. It is obtainable free from the Bureau of Home Economics, Department of Agriculture, Washington, D. C.

This subject is treated in a general manner from the standpoint of the prospective purchaser, in Letter Circular LC 412, entitled "Domestic Electric and Gas Refrigerators", single copies of which are obtainable from the National Bureau of Standards on request.

Section IV. Insulation and Heat Transmission

Most of the books listed in Section I contain some reference to insulation. The literature of this subject is very extensive and reference may be made to the bibliography (up to 1920) included in the publication "Heat Transmission of Insulating Materials" published by the American Society of Refrigerating Engineers and obtainable from the office of the Society, 37 West 39th St., New York, N. Y., at $2.00 per copy. A more complete bibliography, up to 1925 is included in Pennsylvania State College Engineering Experiment Station Bulletin No. 33, entitled "An Investigation of Certain Methods of Testing Heat Insulators", by E. F. Grundhofer, published June, 1925, and purchasable from the Engineering Experiment Station, State College, Pa., at twenty-five cents per copy.

Refrigerating Data Book (See Section II above, item 25) contains several tables giving data on thermal conductivity of insulating materials.

General information and data on various classes of insulating materials may be found in National Bureau of Standards Circular C376, entitled "Thermal Insulation of Buildings", obtainable only from the Superintendent of Documents, Washington, D. C., price 5¢.

Section V. Journals and Periodicals

The following journals and periodicals are devoted to the refrigeration and allied industries.

Name of Journal	Publisher	Address
1. Refrigerating Engineering	American Society of Refrigerating Engineers	37 West 39th St., New York, N. Y.
2. Refrigerating World	The Ice Trade Journal Co.	Woolworth Bldg., New York, N. Y.
3. Ice & Refrigeration	Nickerson & Collins Co.	5707 W. Lake St., Chicago, Ill.
4. Refrigeration	Refrigeration Publishing Co.	713 Glenn St., Atlanta, Ga.
5. The Ice Cream Review	The Olson Publishing Co.	5th & Cherry Sts., Milwaukee, Wis.
6. The Ice Cream Trade Journal	Thomas D. Cutler	171 Madison Ave., New York, N. Y.
7. Electric Refrigeration News	Business News Publishing Co.	550 Maccabees Bldg., Detroit, Mich.

Section VI. Properties of Refrigerants

Data on the thermodynamic properties of many refrigerants have been made conveniently available in the form of tables and charts. The publications listed below contain data on the properties of refrigerants.

1. National Bureau of Standards Circular C142, Thermodynamic Properties of Ammonia, (Tables and chart, see Section I above.)
2. Properties of Refrigerants, by H. D. Edwards, Refrigerating Engineering, 11, 95 (1924). (A general report containing tables of properties at saturation, effect on lubricants, etc.)
3. Thermodynamic Properties of Butane, Isobutane and Propane, by L. I. Dana, A. C. Jenkins, J. N. Burdick and R. C. Timm, Ref. Eng., 12, 387 (1926). (Saturation Tables).

4. Thermal Properties of Sulphur Dioxide, by David L. Fiske, Ref. Eng. 11, 235 (1924). (Saturation and superheat tables.)

5. New Tables of Refrigerant Gases, by J. B. Churchill, Ref. Eng., 26, 85 (1933). (Saturation Data on dichloromethane, dichloroethylene, trichloroethylene, and methyl formate.)

6. Thermodynamic Properties of Dichlorodifluoromethane, A New Refrigerant:
   I. The Equation of State of Superheated Vapor, by R. M. Buffington and W. K. Gilkey, Ind. Eng. Chem. 23, 254 (1931).
   II. Vapor Pressure, by W. K. Gilkey, F. W. Gerard, and M. E. Bixler, Ind. Eng. Chem., 23, 364 (1931).
   III. Critical Constants and Orthobaric Densities, by F. R. Bichowsky, and W. K. Gilkey, Ind. Eng. Chem. 23, 366 (1931).
   IV. Specific Heat of Liquid and Vapor and Latent Heat of Vaporization, by R. M. Buffington and J. Fleischer, Ind. Eng. Chem. 23, 1290 (1931).
   V. Correlation, Checks and Derived Quantities, by R. M. Buffington and W. K. Gilkey, Ind. Eng. Chem. 23, 1292 (1931).

7. Refrigeration and Refrigerants; Ind. Eng. Chem., 24, 601-630, June (1932). (A collection of papers containing information on various properties, including physical, chemical, toxicity, flammability, corrosion and effect on lubricants, of the following refrigerants:
   Anhydrous Ammonia, by R. J. Quinn
   Liquid Carbon Dioxide, by J. H. Pratt
   Solid Carbon Dioxide, by D. H. Killeffer
   Dichloromethane and Dichloroethylene, by R. W. Waterfill
   Freon, by R. J. Thompson
   Methyl Chloride, by J. B. Churchill
   Sulphur Dioxide, by C. W. Johnston.)

8. Refrigerating Data Book (See Section II above, item 25. Contains extensive tables on properties of steam, refrigerants, brines, insulating materials and foods.)

A list of the charts of the properties of various refrigerants, with references to the publications in which they may be found, is given in table 1. The chemical name, trade names, chemical formula, normal boiling point and vapor pressure at 86°F of sixteen refrigerants are given in table 2.

Recently several new refrigerants have been developed, which are intended to reduce the hazards involved in case the refrigerant escapes from the refrigerating system. The most important considerations from the standpoint of safety are the fire or explosion hazard and the toxic hazard. These hazards are usually small or negligible with single unit, domestic machines. With multiple apartment systems and the larger refrigerating or air conditioning systems, the safety qualities of the refrigerant are of great importance.

The relative hazards of different refrigerants may be estimated for a particular installation by means of two factors, namely, the amount of refrigerant in the system and the volume of the space into which it may be released. The ratio of these two factors gives, in general, the maximum concentration of the refrigerant vapor within the space, assuming, of course, complete escape of refrigerant and no ventilation. Comparison of this ratio for a particular installation with available data on flammability and toxicity yields information on the relative safety of different refrigerants.

Other factors should also be considered. For example, the working pressure influences the rate of escape. Even in the event of an open break in the system all of the refrigerant rarely escapes rapidly. In the course of time, normal ventilation tends to reduce materially the initial concentration of refrigerant vapor. The odor or irritating character of the refrigerant may serve as a warning. Refrigerants containing chlorine or fluorine decompose when passed through a flame yielding products of decomposition which are irritating and toxic.

All refrigerants may be considered as safe, for all practical purposes, if used under conditions such that the ratio of the amount of refrigerant in the system to the volume of the space into which it might readily escape and be confined, results in concentrations which are neither flammable nor harmful to human life or health.

Data on flammability and toxicity, as usually reported with concentrations in terms of percent by volume, are given in tables 3 and 4. Equivalent values in terms of pounds (weight) per 1000 cubic feet are also given since these values are more convenient for practical purposes. References to data on flammability and toxicity are as follows:

Public Health Bulletin No. 185, Physiological response attending exposure to vapors of methyl bromide, methyl chloride, ethyl bromide and ethyl chloride (March, 1929) (obtainable from Superintendent of Documents, Government Printing Office, Washington, D. C., 15 cents.)

Underwriters' Laboratories, Miscellaneous Hazard No. 2375, Report on the life, fire and explosion hazards of common refrigerants (November, 1933). (Obtainable from Kinetic Chemicals, Inc., 10th & Market Sts., Wilmington, Del., $2.25.)

Bureau of Mines, Reports of Investigations (R.I.):
(a) R.I. 3013, Toxicity of dichlorodifluoromethane, a new refrigerant (May, 1930).
(b) R.I. 3185, Toxicity of dichlorotetrafluoroethane (October, 1932).

American Chemical Society Monograph No. 35, Noxious Gases, by Henderson, Yandell and Haggard (1927).

Table 1. References to Charts of the Properties of Various Refrigerants.

Refrigerant	Coordinates of Chart	Author	Reference
NH_3	H-P	Nat.Bur.Standards	C142, M52, M57, M76 (See Section I for description)
CO_2	H-S H-P	Mollier	Zs.V.D.I., (I) 48, 271 (1904).
CO_2	H-P	Plank and Kuprianoff	Beiheft, Zs.K.I., Reihe, 1, Heft 1, 1929 (Metric units); also Ref.Eng., 20, 33 (1930) (British units).
CO_2	T-S H-S	Jenkin and Pye	Phil. Trans. 213A, 361 (1915).
SO_2	H-P	Fiske	Ref. Eng., 10, 200 (1923).
CH_3Cl	T-S H-S	Shorthose	Sp. Report No. 19 (1924); also Ref. Eng., 11, 76 (1924).
C_2H_5Cl	T-S H-S	Jenkin and Shorthose	Sp. Report No. 14 (1923); also Ref. Eng., 10, 316 (1924).
CCl_2F_2	H-P	Lawrence	Ref. Eng., 24, 287 (1932).

Notation ---- P = Absolute pressure
H = Heat content
T = Temperature
S = Entropy

Ref. Eng. = Refrigerating Engineering.
Sp. Report = Special Report of the Food Investigation Board of the Department of Scientific and Industrial Research of Great Britain, 16 Old Queen St., Westminster, S.W. 1, London.
Phil. Trans. = Philosophical Transactions of the Royal Society of London.
Zs.V.D.I. = Zeitschrift des Vereines Deutscher Ingenieure.
Zs.K.I. = Zeitschrift fur die gesamte Kalte-Industrie.

Table 2. Normal Boiling Point and Vapor Pressure at 86°F of Sixteen Refrigerants

Chemical Name	Trade Name	Chemical Formula	Approximate Normal Boiling Point °F	Approximate Vapor Pressure at 86°F Lb/in^2(abs.)
Carbon Dioxide[1]		CO_2	-109	1039
Ethane		C_2H_6	-128	681
Ammonia		NH_3	-28	169
Propane		C_3H_8	-44	155
Dichlorodifluoromethane	Freon[2]	CCl_2F_2	-22	108
Methyl chloride	Artic[3]	CH_3Cl	-11	95
Sulphur dioxide		SO_2	+14	66
Isobutane	Freezol	C_4H_{10}	+10	60
Butane		C_4H_{10}	+31	42
Dichlorotetrafluoroethane	Fl14	$C_2Cl_2F_4$	39	36
Ethyl chloride		C_2H_5Cl	54	27
Trichloromonofluoromethane[4]	Fl1	CCl_3F	76	18
Methyl formate		$C_2H_4O_2$	89	14
Dichloromethane[5]	Carrene	CH_2Cl_2	104	10
Dichloroethylene[6]	Dielina	$C_2H_2Cl_2$	122	7
Trichloroethylene	Trielene	C_2HCl_3	190	2

1. Also known as carbonic acid gas.
2. " " Fl2, Kl2 and Kinetic No. 12.
3. " " V-methyl.
4. " " Carrene No. 2.
5. " " methylene chloride.
6. " " acetylene dichloride.

Table 3. Flammable or Explosive Limits of Refrigerant Vapors Mixed with Air.*

Refrigerant	Formula	Explosive Range Percent by Volume		Explosive Range pounds per 1000 cu. ft.	
		Lower Limit	Upper Limit	Lower Limit	Upper Limit
Ammonia	NH_3	16.	25.	7.1	11.1
Butane	C_4H_{10}	1.6	6.5	2.4	9.8
Dichloroethylene	$C_2H_2Cl_2$	5.6	11.4	14.1	28.7
Ethane	C_2H_6	3.3	10.6	2.6	8.3
Ethyl chloride	C_2H_5Cl	3.7	12.0	6.2	20.1
Methyl chloride	CH_3Cl	8.1	17.2	10.6	22.6
Methyl formate	$C_2H_4O_2$	4.5	20.	7.0	31.
Propane	C_3H_8	2.3	7.3	2.6	8.4

The following refrigerants have been found to be non-flammable at ordinary temperatures:

Carbon dioxide	CO_2
Dichlorodifluoromethane	CCl_2F_2
Dichloromethane	CH_2Cl_2
Dichlorotetrafluoroethane	$C_2Cl_2F_4$
Sulphur dioxide	SO_2
Trichloroethylene	C_2HCl_3
Trichloromonofluoromethane	CCl_3F

* Based upon data given in Underwriters' Laboratories, Miscellaneous Hazard No. 2375.

Table 4. Toxicity of Refrigerant Vapors

Refrigerant	Reference	Kills Most Animals in Very Short Time	Dangerous in 1/2 to 1 Hour	Maximum Amount for 1 Hour Without Serious Disturbances	Slight Symptoms after Several Hours or Maximum Amount for Prolonged Exposure
		Concentration (Percent by volume)			
Sulphur dioxide	1	0.2	0.04-0.05	0.005-0.02	0.001
Ammonia	1	0.5-1.0	0.25-0.45	0.03	0.01
Methyl chloride	1	15-30	2-4	0.7	0.05-0.10
Ethyl chloride	1	15-30	6-10	4.0	2.0
Carbon dioxide	1	30	6-8	4-6	2-3
Methyl formate	2		2		
Dichloroethylene	2		2		
Dichloromethane	2		5		
Trichloromonofluoromethane	2		10		
Dichlorotetrafluoroethane	3		20		
Dichlorodifluoromethane	2		30		
		Concentration (pounds of refrigerant per 1000 cu. ft.)			
Sulphur dioxide	1	0.3	0.07-0.08	0.008-0.03	0.002
Ammonia	1	0.2-0.4	0.1-0.2	0.01	0.004
Methyl chloride	1	20-40	2.6-5.2	0.9	0.065-0.13
Ethyl chloride	1	25-50	10-17	6.6	3.3
Carbon dioxide	1	34	7-9	4.5-7	2.3-3.4
Methyl formate	2		3		
Dichloroethylene	2		5		
Dichloromethane	2		11		
Trichloromonofluoromethane	2		36		
Dichlorotetrafluoroethane	3		89		
Dichlorodifluoromethane	2		94		

Reference: (1) Public Health Bulletin No. 185
(2) Underwriters' Laboratories" Miscellaneous Hazard No. 2375.
(3) Bureau of Mines, Reports of Investigation R.I. 3185.