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# ABSORPTION FLUIDS DATA SURVEY

## 1989 UPDATE

R. A. Macriss
T. S. Zawacki

Prepared by

INSTITUTE OF GAS TECHNOLOGY
3424 South State Street
Chicago, Illinois 60616

under
Subcontract 88X-47989C

for the

ENERGY DIVISION
OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37831

operated by
MARTIN MARIETTA ENERGY SYSTEMS, INC.

for the
U.S. DEPARTMENT OF ENERGY
under Contract DE-AC05-84OR21400

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NTIS price codes—Printed Copy: A03 Microfiche: A01

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# ABSORPTION FLUIDS DATA SURVEY: 1989 UPDATE

Topical Report
(First Update of Final Report
on Worldwide Data)

R. A. Macriss
T. S. Zawacki

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## SUMMARY OF RESULTS

This is an update of a series of prior reports on absorption fluids and data, ORNL/Sub/84-47989/1,2,&3. It covers additional data developed and published mainly during 1985-88, and cites 44 additional references.

Seventy-four different worldwide publications containing data relating to properties of binary, ternary, and multicomponent absorption fluids were identified. Of these, 30 manuscripts include applications of absorption fluid properties data toward evaluation, assessment, or design of chillers or heat pumps but do not include actual fluid properties data. The remaining 44 publications date as far back as 1929, but over 50% of these documents were published between 1985 and 1988. The texts of the 44 manuscripts are in English, German, Japanese, Russian, or French.

The absorption fluids discussed in the 44 documents are combinations of 9 different "refrigerant" compounds and 30 single, 7 binary, and 1 ternary "absorbent" compounds. Generally, the refrigerants are divided among the following categories of chemical compounds:

<u>Refrigerants</u>

| | |
|---|---|
| Inorganic | 2 |
| Organic | 7 |
| • Amines | 1 |
| • Alcohols | 4 |
| • Halogenated hydrocarbons | 2 |

The 30 single absorbent compounds generally are subdivided as follows:

<u>Absorbents</u>

| | |
|---|---|
| Inorganic | 13 |
| Organic | 17 |
| • Ethers | 3 |
| • Amides | 3 |
| • Amines | 1 |
| • Esters | 1 |
| • Ketones | 3 |
| • Others | 6 |

The binary and ternary absorbents are various mixtures of two or more single absorbent compounds.

In terms of absorption fluid properties, for which data are available in the 44 primary documents, the list below shows that vapor-liquid equilibrium is the predominant property, which is reported in almost 60% of the documents. Toxicity or flammability of fluids, on the other hand, have not been found in any of the references.

Thermodynamic, Transport, and Other Data

| Fluid Property | Number of References* |
|---|---|
| Vapor-liquid equilibrium | 26 |
| Enthalpy | 13 |
| Specific heat | 3 |
| Viscosity | 8 |
| Heat of mixing | 6 |
| Density | 7 |
| Crystallization | 4 |
| Surface tension | 4 |
| Corrosion (and inhibitors) | 4 |
| Thermal conductivity | 4 |
| Entropy | 0 |
| Stability | 2 |
| Refractive index | 0 |
| Heat and mass transfer | 3 |
| Toxicity | 0 |
| Flammability | 0 |

A list of several key absorption fluids identified in earlier publications are of interest to researchers of advanced absorption heat pumps and are shown below:

---

* A given document may contain data relating to more than one property; therefore, the sum of the references is larger than 44.

## Key Fluids
(see Table 3 for abbreviations)

| | |
|---|---|
| $NH_3$-$H_2O$ | $CH_3OH$-LiBr-$ZnBr_2$ |
| $NH_3$-$H_2O$-LiBr | TFE-NMP |
| $NH_3$-$H_2O$-$LiNO_3$ | TFE-DMEDEG |
| $NH_3$-NaSCN | TFE-DMETEG |
| $H_2O$-LiBr | $CH_3NH_2$-$H_2O$-LiBr |
| $H_2O$-LiBr-LiCl | R21-DMETEG |
| $H_2O$-LiBr-LiSCN | R22-DMEDEG |
| $H_2O$-LiBr-$ZnBr_2$ | R22-DMETEG |
| $H_2O$-NaOH-KOH-CsOH | R22-DMF |
| $H_2O$-$LiNO_3$-$NaNO_3$-$KNO_3$ | R123a-ETFE |
| $CH_3OH$-LiBr | R124-ETFE |
| $CH_3OH$-$ZnBr_2$ | R133a-NMP |

During 1988, these additional key fluids were identified and included in this report:

| | |
|---|---|
| $H_2O$-LiBr-$ZnCl_2$ | R22-DMA |
| $H_2O$-LiBr-4.BLN | R22-DMETrEG |
| $CH_3OH$-LiBr-$H_2O$ | R22-DMMP |
| $C_2H_5OH$-LiI | R22-NMC |
| TFE-DBP | R22-NMMNO |
| TFE-HMPT | R22-PYR |
| TFE-PYR | HFIP-DMETEG |
| TFE-QUN | HFIP-SL |

ABSTRACT

This is an update of a series of prior reports on absorption fluids and data, ORNL/Sub/84-47989/1,2,&3. It covers additional data developed and published mainly during 1985-88, and cites 44 additional references.

Fluids discussed include combinations of 9 different refrigerant compounds, as well as of 30 single, 7 binary, and 1 ternary absorbent compounds. Generally, the 9 refrigerants are divided among the following categories of chemical compounds: inorganic, 2 and organic, 7 (amines, 1; alcohols, 4; halogenated hydrocarbons, 2). The single absorbent compounds generally are subdivided as follows: inorganic, 13 and organic, 17 (ethers, 3; amides, 3; amines, 1; esters, 1; ketones, 3; and others, 6). The binary and ternary absorbents are various mixtures of two or more single absorbent compounds.

# 1. INTRODUCTION

In an effort to define the availability and quality of existing data and, thereby, to assist in the determination of needs for new data useful to advanced concepts, the Institute of Gas Technology (IGT) has performed an extensive literature search and a coarse screening of existing U.S. and foreign literature data to identify potential conflicts or gaps in the data for certain key fluid systems.

A detailed account of IGT's findings has been contained in three earlier reports (ORNL/Sub/84-4798/1,2,&3) that covered, in part, absorption fluids and data developed, respectively, in the United States, Western Europe, Japan, and internationally. This report is the first update of this series of reports and covers additional data developed and published mainly during the 1985-88 period.

## 2. METHOD AND SCOPE

Literature searches and site visits were undertaken to identify and obtain available publications – several dating back to 1901 – on pertinent physical, thermodynamic, and transport properties of absorption fluids. The bulk of references identified contain data developed mainly in the United States, West Germany, France, Britain, Japan, and the USSR. Cross-checks of literature searches were also made, using available published bibliographies and literature review articles, to eliminate secondary sources for the data and, thus, include only original sources and manuscripts.

### 2.1. FLUID PROPERTIES AND DATA

The properties of these fluids relate to the liquid and/or vapor state encountered in normal operation of absorption equipment employing such fluids and to the crystallization boundary of the liquid phase, where applicable. The actual data were systematically classified according to type of fluid and property as well as to temperature, pressure, and concentration ranges over which data were available. Data were sought for at least 17 different properties as follows:

Mixture Properties

1. Vapor-liquid equilibria
2. Crystallization temperature
3. Corrosion characteristics
4. Heat of mixing
5. Liquid-phase densities
6. Vapor-liquid-phase enthalpies
7. Specific heat
8. Stability
9. Viscosity
10. Mass transfer rate
11. Heat transfer rate
12. Thermal conductivity
13. Refractive index
14. Entropy
15. Surface tension
16. Toxicity
17. Flammability

The type of available data was of importance, with raw experimental data considered to be highly desirable for use in actual process and equipment design and sizing and for process design correlation development. For this reason, raw tabulated experimental data were given the highest possible ranking, with other forms of data following in importance as shown below:

| Form of Data | Symbol |
|---|---|
| Raw experimental | (E) |
| • Tabular | (T) |
| • Graphical | (G) |
| Smoothed experimental | (S) |
| • Tabular | (T) |
| • Graphical | (G) |
| Empirical polynomial | (P) |
| Equations of state | (C) |

Empirical polynomial relationships based on raw or smoothed experimental data are often reported. At best, such correlations are as good as the experimental data, and they can help facilitate the use of the data in performance and design calculations through automation (computer software and terminals). In the absence of data, reliable methods of prediction have been sought (equations of state, generalized correlations) but are expected to produce greater uncertainties than the previous forms of data.

# 3. DETAILED PRESENTATIONS AND TABULATIONS

This report is organized to cover the various work elements of this study in their natural sequence. This portion of the report contains a listing of the refrigerants and absorbents of the absorption fluids of this study. The details of the range of conditions over which property data exist for each fluid are given in the Appendix.

## 3.1. REFRIGERANTS AND ABSORBENTS

Table 1 lists the 9 refrigerants grouped into 4 distinct chemical compound categories: inorganics, amines, alcohols, and halogenated hydrocarbons. For each refrigerant, Table 1 contains the chemical formula and name, molecular weight, and normal boiling point (in dual units).

Table 2 lists the chemical formula and name, and molecular weight for 13 single inorganic absorbents. Table 3 lists 17 single organic absorbents grouped into 6 distinct chemical compound categories: ethers, amides, amines, esters, ketones, and an undefined catch-all category. For each organic absorbent, Table 3 contains an arbitrary abbreviation of convenience, chemical formula and name, molecular weight, and normal boiling point (in dual units). Table 4 lists 8 multicomponent (binary and ternary) absorbents with access number and chemical formula.

Table 1. Refrigerants

| | Chemical Formula | Name | MW* | NBP** (°F) | NBP** (°C) |
|---|---|---|---|---|---|
| Inorganics | | | | | |
| | $NH_3$ | Ammonia | 17.0 | -28 | -33.3 |
| | $H_2O$ | Water | 18.0 | 212 | 100.0 |
| Organics | | | | | |
| Amines | $CH_3NH_2$ | Methylamine | 31.1 | 21 | -6.1 |
| Alcohols | $CH_3OH$ | Methanol | 32.0 | 149 | 65.0 |
| | $C_2H_5OH$ | Ethanol | 46.1 | 173 | 78.3 |
| | $CF_3CH_2OH$ | Trifluoroethanol | 100.0 | 164 | 73.6 |
| | $(CF_3)_2CHOH$ | Hexafluoroisopropanol | 168.0 | 138 | 59.0 |
| Halogenated Hydrocarbons | $CHF_2Cl$ | Refrigerant 22 | 86.5 | -41 | -40.6 |
| | $CHClFCClF_2$ | Refrigerant 123a | 152.9 | 85 | 29.4 |

*Molecular weight.
**Normal boiling point.

Table 2. Absorbents (inorganic)

| Chemical Formula | Name | Molecular Weight |
|---|---|---|
| $CaCl_2$ | Calcium chloride | 111.0 |
| LiBr | Lithium bromide | 86.8 |
| LiI | Lithium iodide | 133.8 |
| $LiNO_3$ | Lithium nitrate | 68.9 |
| KOH | Potassium hydroxide | 56.1 |
| $KNO_3$ | Potassium nitrate | 101.1 |
| NaOH | Sodium hydroxide | 40.0 |
| $NaNO_3$ | Sodium nitrate | 85.0 |
| NaSCN | Sodium thiocyanate | 81.1 |
| $H_2SO_4$ | Sulfuric acid | 98.0 |
| $H_2O$ | Water | 18.0 |
| $ZnBr_2$ | Zinc bromide | 225.2 |
| $ZnCl_2$ | Zinc chloride | 136.3 |

Table 3. Absorbents (organic)

| Abbrev. | Chemical Formula | Name | MW[a] | NBP[b] (°F) | NBP[b] (°C) |
|---|---|---|---|---|---|
| Ethers | | | | | |
| DMEDEG | $CH_3(OC_2H_4)_2OCH_3$ | Dimethylether diethylene glycol | 134.2 | 324 | 162.2 |
| DMETrEG | $CH_3(OC_2H_4)_3OCH_3$ | Dimethylether triethylene glycol | 178.2 | 421 | 216.1 |
| DMETEG | $CH_3(OC_2H_4)_4OCH_3$ | Dimethylether tetraethylene glycol | 222.3 | 528 | 275.6 |
| Amides | | | | | |
| DMF | $CHON\ (CH_3)_2$ | N, N-Dimethyl formamide | 73.1 | 302 | 150.0 |
| DMA | $CH_3CON(CH_3)_2$ | N, N-Dimethyl acetamide | 87.1 | 329 | 165.0 |
| HMPT | $[(CH_3)_2N]_3PO$ | Hexamethylphosphoric acid triamide | 179.2 | ND[c] | ND |
| Amines | | | | | |
| QUN | $C_9H_7N$ | Quinoline | 129.2 | 465 | 240.5 |
| Esters | | | | | |
| DBP | $C_6H_4(CO_2C_4H_9)_2$ | Dibutyl phthalate | 278.3 | 644 | 340.0 |
| Ketones | | | | | |
| BLN | $(CH_2)_3CO_2$ | 4-Butyrolactone | 86.1 | 403 | 206.1 |
| NMP | $C_5H_9NO$ | N-Methyl-2-pyrrolidone | 99.1 | 394 | 201.1 |
| PYR | $C_4H_7NO$ | 2-Pyrrolidinone 2-Pyrrolidone | 85.1 | 473 | 245.0 |
| Others | | | | | |
| DMMP | $CH_3PO(OCH_3)_2$ | Dimethyl methyl phosphonate | 124.1 | 175 | 79.5 |
| DMPU | $C_6H_{12}N_2O$ | 1,3 Dimethyl-3,4,5,6 tetra-hydro-2 (1H)-pyrimidinone "Dimethylpropylenurea" | 128.2 | 450 | 232.0 |
| NMC | $C_7H_{13}NO$ | N-Methyl-E-caprolactam | 101.1 | ND | ND |
| NMMNO | ND | N-Methylmorpholine-N-oxide | ND | ND | ND |
| SL | $C_4H_8SO_2$ | Sulfolane | 120.2 | 549 | 287.0 |
| CCH | $C_6H_{12}$ | Cyclohexane | 84.2 | 177 | 80.7 |

[a]Molecular weight.
[b]Normal boiling point.
[c]ND – Not determined.

Table 4. Absorbents (multicomponent)

| Binary | | Ternary | |
|---|---|---|---|
| Abbrev. | Chemical Formula | Abbrev. | Chemical Formula |
| Bi-1 | KOH:NaOH | Te-1 | $KNO_3:LiNO_3:NaNO_3$ |
| Bi-2 | LiBr:4,BLN | | |
| Bi-3 | $LiBr:H_2O$ | | |
| Bi-4 | $LiBr:ZnBr_2$ | | |
| Bi-5 | $LiBr:ZnCl_2$ | | |
| Bi-6 | $LiNO_3:H_2O$ | | |
| Bi-7 | $NMC:CaCl_2$ | | |

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# APPENDIX

FLUID PROPERTY DATA

A.1.1. Vapor-Liquid Equilibrium

| Fluid System | Data Type | Temperature Range, °C | Pressure Range, atm | Weight, % X (R) Y (R) | Reference No. | Author | Year | Country | Text |
|---|---|---|---|---|---|---|---|---|---|
| $NH_3 + H_2O$ | TEGC | 130–230 | 3.2–113.3 | 0–100<br>0–100 | 22 | Guillevic et al. | 1985 | France | English |
| $NH_3 + H_2O$ | TE | 80 | 0.47–0.91 | 0.001–5 | 44 | Wilson et al. | 1978 | USA | English |
| $NH_3 + H_2O$ | TE | 120 | 1.96–3.16 | 0.001–5 | 44 | Wilson et al. | 1978 | USA | English |
| $NH_3 + LiNO_3$: $H_2O$ | SG | -20–200 | 0.5–30 | 16–100 | 8 | Bokelmann et al. | 1985 | FRG | German |

A.2.1. Vapor-Liquid Equilibrium

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| $H_2O + LiBr$ | P | 4–182 | NA | 30–100 | 35 | Patterson et al. | 1988 | USA | English |
| $H_2O + LiI$ | GES | 60–150 | 4–100(1) | 15–35 | 5 | Bach et al. | 1967 | USA | English |
| $H_2O + H_2SO_4$ | GS | -20–200 | 0.1–100(1) | 5–100 | 36 | Plank | 1959 | FRG | German |
| $H_2O + KOH$: NaOH | GS | -10–130 | 20–10,000(1) | 30–100 | 36 | Plank | 1959 | FRG | German |

X – Liquid Phase (R) – Refrigerant NA – Not Available
Y – Vapor Phase (1) – mm Hg

## A.2.1. Vapor-Liquid Equilibrium

| Fluid System | Data Type | Temperature Range, °C | Pressure Range, atm | Weight, % X (R) Y (R) | Reference No. | Author | Year | Country | Text |
|---|---|---|---|---|---|---|---|---|---|
| $H_2O$ + NMC | SG | 40–120 | 0.02–0.85 | 18–100 | 37 | Rakette et al. | 1987 | DDR | English |
| $H_2O$ + NMMNO | GE | 40–120 | 0.01–1.0 | 7–100 | 37 | Rakette et al. | 1987 | DDR | English |
| $H_2O$ + LiBr: $ZnCl_2$ | SG | 0–200 | 0.0103–1.03 | 28–100 | 34 | Ouchi et al. | 1982 | Japan | Japanese |
| $H_2O$ + LiBr: $ZnCl_2$ | SG | -16–20 | 0.0055–0.238 | 29.7–89.8 | 43 | Uemura et al. | 1982b | Japan | Japanese |
| $H_2O$ + NMC: $CaCl_2$ | SG | 42–120 | <0.01–0.65 | 7–10 | 37 | Rakette et al. | 1987 | DDR | English |
| $H_2O$ + $LiNO_3$: $KNO_3$:$NaNO_3$ | GS | 54.4–260 | 40–10,000(1) | 7.5–30 | 3 | Ally | 1988b | USA | English |
| $H_2O$ + $LiNO_3$: $KNO_3$:$NaNO_3$ | TEG | 75–275 | 0.1–14 | 7.5–30 | 2 | Ally | 1988a | USA | English |

X – Liquid Phase (R) – Refrigerant
Y – Vapor Phase (1) – mm Hg

FLUID PROPERTY DATA

A.3.1. Vapor-Liquid Equilibrium

| Fluid System | Data Type | Temperature Range, °C | Pressure Range, atm | Weight, % X (R) Y (R) | Reference No. | Author | Year | Country | Text |
|---|---|---|---|---|---|---|---|---|---|
| $CH_3OH$ + LiBr | SG | -10–52 | NA | 4.0–100 | 9 | Bokelmnn et al. | 1982 | FRG | English |
| $CH_3OH$ + LiBr | GE | 9.5–67.3 | 14–840(2) | 59.64–83.08 | 20 | Eichholz | 1980 | FRG | English |
| $CH_3OH$ + LiBr | TEG | -10–170.5 | 1.4–3070(2) | 39.66–74.72 | 39 | Renz et al. | 1980 | FRG | English |
| $CH_3OH$ + LiSCN | GE | -10–68 | NA | 40–100 | 9 | Bokelmann et al. | 1982 | FRG | English |
| $CH_3OH$ + $ZnBr_2$ | GE | -10–70 | NA | 24–100 | 9 | Bokelmann et al. | 1982 | FRG | English |
| $CH_3OH$ + LiBr: $ZnBr_2$ (1:1) (W) | GE | -10–34 | NA | 24–100 | 9 | Bokelmann et al. | 1982 | FRG | English |
| $CH_3OH$ + $LiBr_3$: $ZnBr_2$ (1:1) (W) | SG | -20–120 | 1–1000(2) | 20–100 | 9 | Bokelmann et al. | 1982 | FRG | German |
| $C_2H_5OH$ + LiI | EG | -17–30 | 0.0185–0.268 | 50.7–94.7 | 42 | Uemura et al. | 1982a | Japan | Japanese |

X – Liquid Phase (R) – Refrigerant (M) – Mole, (W) – Weight
Y – Vapor Phase (2) – mbar NA – Not Available

FLUID PROPERTY DATA

A.4.1. Vapor-Liquid Equilibrium

| Fluid System | Data Type | Temperature Range, °C | Pressure Range, atm | Weight, % X (R) Y (R) | Reference No. | Author | Year | Country | Text |
|---|---|---|---|---|---|---|---|---|---|
| $CH_3NH_2 + H_2O$ | TE | 1–90 | 7–4871(1) | 1.7–48.6 | 21 | Felsing et al. | 1929 | USA | English |
| $CH_3NH_2 + H_2O$ | GE | -40–180 | 0.2–10 | 0–100 | 36 | Plank | 1959 | Germany | English |

X – Liquid Phase
Y – Vapor Phase

(R) – Refrigerant
(1) – mm Hg

FLUID PROPERTY DATA

A.6.1. Vapor-Liquid Equilibrium

| Fluid System | Data Type | Temperature Range, °C | Pressure Range, atm | Weight, % X (R) Y (R) | Reference No. | Author | Year | Country | Text |
|---|---|---|---|---|---|---|---|---|---|
| R22 + DMF | TEGC | -43–260 | 1–20 | 0–100 | 1 | Agarwal et al. | 1985 | India | English |
| R22 + DMF | GEP | 22–100 | 0.008–203(1) | 22.8–91.4 | 18 | Chen et al. | 1985 | China | English |
| R22 + DMEDEG | GESP | -20–200 | 0.1–50 | 10–100 | 4 | Ando et al. | 1984 | Japan | English |
| R22 - DMF | GC | 37.8–107.2 | 1.3–13.7 | 0–70 | 7 | Bhaduri et al. | 1987 | India | English |
| R22 - DMA | GC | 0–100 | 1–25 | 8–95 | 7 | Bhaduri et al. | 1987 | India | English |
| R22 + DMA | TEP | 26–93 | 1.7–12.5 | 16.0–49.2 | 6 | Bhaduri et al. | 1985 | India | English |
| R22 + CCH | TE | 28–89 | 1.9–13.9 | 17.2–45.2 | 6 | Bhaduri et al. | 1985 | India | English |
| R22 - PYR | GE | 0–150 | 0–30 | 0–100 | 13 | Borde | 1988 | Israel | English |
| R22 + NMP | GS | 0–140 | 1–26 | 0–100 | 16 | Borde et al. | 1987c | Israel | English |
| R22 + DMETEG | GS | 0–120 | 0.1–30 | 0–100 | 27 | Jelinek et al. | 1980 | Israel | English |
| R22 + DMA | GS | 0–150 | 1–25 | 0–100 | 15 | Borde | 1987b | Israel | English |
| R22 + DMMP | GS | 0–140 | 1–24 | 0–100 | 14 | Borde | 1987a | Israel | English |

X – Liquid Phase  Y – Vapor Phase  (R) – Refrigerant  (1) – mm Hg

A.12.1. Vapor-Liquid Equilibrium

| Fluid System | Data Type | Temperature Range, °C | Pressure Range, atm | Weight, % X (R) Y (R) | Reference No. | Author | Year | Country | Text |
|---|---|---|---|---|---|---|---|---|---|
| TFE + QUN | SG | -18–165 | 1–1000(2) | 10–50 | 10 | Bokelmann et al. | 1986 | FRG | English |
| TFE + QUN | SG | -16–180 | 1–1000(2) | 5–35 | 9 | Bokelmann et al. | 1982 | FRG | English |
| TFE + HMPT | SG | -20–170 | 1–1000(2) | 36–60 | 9 | Bokelmann et al. | 1982 | FRG | English |
| TFE + DMETEG | SG | -16–180 | 1–1000(2) | 5–50 | 10 | Bokelmann et al. | 1986 | FRG | English |
| TFE + PYR | SG | -16–190 | 1–1000(2) | 15–60 | 10 | Bokelmann et al. | 1986 | FRG | English |
| TFE + NMP | SG | -20–200 | 1–1000(2) | 0–100 | 10 | Bokelmann et al. | 1986 | FRG | English |
| TFE + NMP | SG | -23–177 | 0.0031–1.03 | 0–100 | 33 | Nakayama et al. | 1987 | Japan | English |
| TFE + DMETEG | GP | 120–200 | NA | 0–100<br>0–100 | 40 | Rockenfeller et al. | 1986 | USA | English |
| TFE + DBP | GE | 190–220 | 6–9.3 | 20.1 | 40 | Rockenfeller et al. | 1986 | USA | English |
| TFE - DMETEG | GP | 80–240 | 1–20 | 10–100 | 40 | Rockenfeller et al. | 1986 | USA | English |
| HFIP + DMPU | GE | 0–200 | 0.004–40<br>350(2) | 0–100<br>0–100 | 17 | Bothe et al. | 1988 | USA | English |

X – Liquid Phase (R) – Refrigerant NA – Not Available
Y – Vapor Phase (2) – mbar

A.X.2. Crystallization Temperature

| Fluid System | Data Type | Temperature Range, °C | Pressure Range, atm | Weight, % X (R) Y (R) | Reference No. | Author | Year | Country | Text |
|---|---|---|---|---|---|---|---|---|---|
| $H_2O$ + LiBr: $ZnCl_2$ | GE | -4–130 | NA | 13–26 | 43 | Uemura et al. | 1982 | Japan | Japanese |
| $H_2O$ + $LiNO_3$: $KNO_3$:$NaNO_3$ | GS | 60.0–193.3 | 32–155(1) | 1–25 | 3 | Ally | 1988b | USA | English |
| $CH_3OH$ + LiBr | GS | -12–60 | NA | 40–70 | 28 | Knoche et al. | 1988 | FRG | English |
| $CH_3OH$ + LiBr (5.9:1) (W) | GS | -20–60 | NA | 34–70 | 28 | Knoche et al. | 1988 | FRG | English |
| $C_2H_5OH$ + LiI | EG | -17–245 | NA | 26–68 | 42 | Uemura et al. | 1982 | Japan | Japanese |
| $H_2O$ + $H_2SO_4$ | GS | -70–100 | NA | 0–100 | 36 | Plank | 1959 | FRG | German |
| $H_2O$ + KOH | GS | -70–100 | NA | 0–100 | 36 | Plank | 1959 | FRG | German |
| $H_2O$ + NaOH | GS | -70–100 | NA | 0–100 | 36 | Plank | 1959 | FRG | German |

X – Liquid Phase (R) – Refrigerant (M) – Mole, (W) – Weight
Y – Vapor Phase (1) – mm Hg NA – Not Available

A.X.3. Corrosion

| Fluid System | Data Type | Temperature Range, °C | Corrosion Inhibitor, wt % | Weight, % X (R) Y (R) | Reference No. | Author | Year | Country | Text |
|---|---|---|---|---|---|---|---|---|---|
| $H_2O$ + LiBr: 4-BLN (20:1) (M) | GE | 120–160 | Benzatriazole 0.1–0.8 | 42–63 | 24 | Iyoki et al. | 1982 | Japan | Japanese |
| $H_2O$ + LiBr: 4-BLN (20:1) (M) | GE | 120–160 | Tolyltriazole 0.1–0.8 Li-Molybdate 0.1–0.8 | 42–63 | 24 | Iyoki et al. | 1982 | Japan | Japanese |
| TFE + DMETEG | TE | 260 | NA | NA | 40 | Rockenfeller et al. | 1986 | USA | English |
| $NH_3$ + LiBr: $H_2O$ | TE | 21–218 | Chromate Arsenite | NA | 31 | Modahl et al. | 1988 | USA | English |
| $H_2O$ + LiBr | GE | 143–227 | Carrene DL-16 | 25–46 | 38 | Reimann et al. | 1988 | USA | English |

X – Liquid Phase (M) – Mole, (W) – Weight NA – Not Available
Y – Vapor Phase (R) – Refrigerant

A.X.4. Heat of Mixing

| Fluid System | Data Type | Temperature Range, °C | Pressure Range, atm | Weight, % X (R) Y (R) | Reference No. | Author | Year | Country | Text |
|---|---|---|---|---|---|---|---|---|---|
| $H_2O$ + LiBr: $ZnCl_2$ | GE | 25 | NA | 24.55–100 | 43 | Uemura et al. | 1982 | Japan | Japanese |
| $CH_3OH$ + LiBr | GEP | 25–60 | NA | 1–36 | 20 | Eichholz | 1980 | FRG | English |
| $C_2H_5OH$ + LiI | TEG | 35 | NA | 44–100 | 42 | Uemura et al. | 1982 | Japan | Japanese |
| R22 + DMEDEG | GE | 10 | NA | 0–100 | 4 | Ando et al. | 1984 | Japan | English |
| R22 + DMF | GC | 30–50 | NA | 0–100 | 7 | Bhaduri et al. | 1987 | India | English |
| R22 + DMA | GC | 10–70 | NA | 0–100 | 7 | Bhaduri et al. | 1987 | India | English |
| R22 + PYR | GP | 0–150 | NA | 0–100 | 13 | Borde | 1988 | Israel | English |
| R22 + DMF | P | 10–90 | 1–20 | 10–75 | 26 | Jelinek et al. | 1978 | Israel | English |
| R22 + DMA | GP | 0–150 | NA | 0–100 | 15 | Borde | 1987b | Israel | English |

X – Liquid Phase (R) – Refrigerant
Y – Vapor Phase NA – Not Available

## A.X.5. Liquid-Phase Densities

| Fluid System | Data Type | Temperature Range, °C | Pressure Range, atm | Weight, % X (R) Y (R) | Reference No. | Author | Year | Country | Text |
|---|---|---|---|---|---|---|---|---|---|
| $H_2O$ + LiBr | C | 100–200 | NA | 40 | 2 | Ally | 1988a | USA | English |
| $H_2O$ + LiBr | P | NA | NA | NA | 35 | Patterson et al. | 1988 | USA | English |
| $H_2O$ + LiBr: $ZnCl_2$ | TE | 20–90 | NA | 24.8–67.6 | 43 | Nemura et al. | 1982 | Japan | Japanese |
| $CH_3OH$ + LiBr | TEG | 5–90 | NA | 40–100 | 39 | Renz et al. | 1980 | FRG | English |
| TFE + DMETEG | EP | 25–180 | NA | 20.08–30.02 | 40 | Rockenfeller et al. | 1986 | USA | English |
| HFIP + DMETEG | GE | 20–90 | NA | 0–100 | 17 | Bothe et al. | 1988 | FRG | English |
| R22 + DMF | PGS | -3–87 | NA | 0–100 | 19 | Dorairaj et al. | 1987 | India | English |

X – Liquid Phase
Y – Vapor Phase
(R) – Refrigerant
NA – Not Available

A.X.6. Vapor-Liquid Phase Enthalpies

| Fluid System | Data Type | Temperature Range, °C | Pressure Range, atm | Weight, % X (R) Y (R) | Reference No. | Author | Year | Country | Text |
|---|---|---|---|---|---|---|---|---|---|
| $NH_3 + H_2O$ | CG | -50–300 | 0.2–50 | NA | 29 | Kouremenos et al. | 1987 | Greece | English |
| $NH_3$ + NaSCN | P | 0–60 | NA | 35.05–91.14 | 12 | Bonauguri et al. | 1980a | Italy | English |
| $H_2O$ + LiBr | P | 0–180 | NA | 30–100 | 35 | Patterson et al. | 1988 | USA | English |
| $H_2O$ + LiBr: $ZnCl_2$ | SG | 0–300 | NA | 20–40 | 34 | Ouchi et al. | 1982 | Japan | Japanese |
| $H_2O$ + LiBr: $ZNCl_2$ | GE | 0–200 | 0.0014–4.12 | 7–100 | 43 | Uemura et al. | 1982 | Japan | Japanese |
| $H_2O + LiNO_3$: $KNO_3$:$NaNO_3$ | GS | 125–275 | NA | 8–30 | 3 | Ally | 1988b | USA | English |
| $H_2O + LiNO_3$: $KNO_3$:$NaNO_3$ | TS | 125–275 | NA | 7.5–30 | 2 | Ally | 1988a | USA | English |

X – Liquid Phase (R) – Refrigerant
Y – Vapor Phase NA – Not Available

## A.X.6. Vapor-Liquid Phase Enthalpies

| Fluid System | Data Type | Temperature Range, °C | Pressure Range, atm | Weight, % X (R) Y (R) | Reference No. | Author | Year | Country | Text |
|---|---|---|---|---|---|---|---|---|---|
| $C_2H_5OH$ + LiI | TE | -30–130 | 0.00515–4.12 | 29–100 | 42 | Uemura et al. | 1982 | Japan | Japanese |
| TFE + NMP | SG | 0–200 | 1–1000(2) | 0–100 | 8 | Bokelmann et al. | 1985 | FRG | German |
| TFE + NMP | SG | -40–180 | 0.00137–1.37 | 0–100 | 33 | Nakayama et al. | 1987 | Japan | English |
| TFE + DMETEG | G | 80–260 | 0.4–14 | 10–60 | 40 | Rockenfeller et al. | 1986 | USA | English |

X – Liquid Phase (R) – Refrigerant
Y – Vapor Phase (2) – mbar

A.X.6. Vapor-Liquid Phase Enthalpies

| Fluid System | Data Type | Temperature Range, °C | Pressure Range, atm | Weight, % X (R) Y (R) | Reference No. | Author | Year | Country | Text |
|---|---|---|---|---|---|---|---|---|---|
| R22 + DMEDEG | GS | -40–200 | 0.1–50 | 0–100 | 4 | Ando et al. | 1984 | Japan | English |
| R22 + NMP | SC | 0–140 | 1–26 | 0–100 | 16 | Borde et al. | 1987c | Israel | English |
| R22 + NMP | GS | 0–140 | 1–26 | 0–100 | 16 | Borde et al. | 1987c | Israel | English |
| R22 + PYR | GP | 0–150 | 1–26 | 0–100 | 13 | Borde | 1988 | Israel | English |
| R22 + DMETrEG | GS | 0–200 | 0.5–25 | 0–100 | 8 | Bokelmann et al. | 1985 | FRG | German |
| R22 + DMF | GS | 10–90 | 1–20 | 10–75 | 26 | Jelinek et al. | 1978 | Israel | English |
| R123a + DMETEG | | 0–200 | 100–5000(2) | 0–100 | 8 | Bokelmann et al. | 1985 | FRG | German |
| R22 + DMA | GS | 0–150 | 1–26 | 0–100 | 15 | Borde | 1987b | Israel | English |
| R22 + DMMP | GS | 0–140 | 1–24 | 0–100 | 14 | Borde | 1987a | Israel | English |

X – Liquid Phase (R) – Refrigerant
Y – Vapor Phase (2) – mbar

FLUID PROPERTY DATA

A.X.7. Specific Heat

| Fluid System | Data Type | Temperature Range, °C | Pressure Range, atm | Weight, % X (R) Y (R) | Reference No. | Author | Year | Country | Text |
|---|---|---|---|---|---|---|---|---|---|
| $C_2H_5OH$ + LiI | TE | 15–65 | NA | 44.3–92 | 42 | Uemura et al. | 1982 | Japan | Japanese |
| TFE + DMETEG | GE | 60–170 | NA | 24.5 | 40 | Rockenfeller et al. | 1986 | USA | English |
| R22 + DMEDEG | GE | -40–120 | NA | 0–100 | 4 | Ando et al. | 1984 | Japan | English |

X – Liquid Phase (R) – Refrigerant
Y – Vapor Phase NA – Not Available

A.X.8. Stability

| Fluid System | Data Type | Temperature Range, °C | Pressure Range, atm | Weight, % X (R) Y (R) | Reference No. | Author | Year | Country | Text |
|---|---|---|---|---|---|---|---|---|---|
| $CH_3OH$ + LiBr | GE | 130–215 | NA | 45.4–59.2 | 28 | Knoche et al. | 1988 | FRG | English |
| $CH_3OH$ + LiBr | GE | 145–218 | 0.05 | 45.4–59.2 | 28 | Knoche et al. | 1988 | FRG | English |
| $CH_3OH$ + LiBr: $H_2O$ (5.9:1) (W) | GE | 160–150 | NA | 43.9 | 28 | Knoche et al. | 1988 | FRG | English |
| $CH_3OH$ + LiBr: $H_2O$ (5.9:1) (W) | GE | 170–190 | 0.18 | 44.1 | 28 | Knoche et al. | 1988 | FRG | English |
| $CH_3OH$ + LiBr: $H_2O$ (5.9:1) (W) | GE | 137–180 | 0.45 | 44.1 | 28 | Knoche et al. | 1988 | FRG | English |
| TFE + DBP | E | 220–225 | NA | 20.1 | 40 | Rockenfeller et al. | 1986 | USA | English |
| TFE + DMETEG | GE | 150–250 | NA | 0–100 | 40 | Rockenfeller et al. | 1986 | USA | English |
| TFE + DMETEG | GE | 235 | NA | >20 | 40 | Rockenfeller et al. | 1986 | USA | English |
| TFE + DMETEG | GE | 180 | NA | 0–100 | 40 | Rockenfeller et al. | 1986 | USA | English |

X – Liquid Phase (M) – Mole, (W) – Weight NA – Not Available
Y – Vapor Phase (R) – Refrigerant

A.X.9. Viscosity

| Fluid System | Data Type | Temperature Range, °C | Pressure Range, atm | Weight, % X (R) Y (R) | Reference No. | Author | Year | Country | Text |
|---|---|---|---|---|---|---|---|---|---|
| $H_2O$ + LiBr | C | 105–190 | NA | 40 | 2 | Ally | 1988a | USA | English |
| $H_2O$ + LiBr | P | 0–90 | NA | 40–95 | 35 | Patterson et al. | 1988 | USA | English |
| $H_2O$ + LiBr: $ZnCL_2$ | TEG | 20 | NA | 24.8–67.6 | 43 | Nemura et al. | 1982 | Japan | Japanese |
| $H_2O$ + $LiNO_3$: $KNO_3$:$NaNO_3$ | GS | 95–180 | NA | 20 | 2 | Ally | 1988a | USA | English |
| $CH_3OH$ + LiBr | TEG | 5–90 | NA | 40–80 | 39 | Renz et al. | 1980 | FRG | English |
| TFE + DMETEG | GE | 79.7–120.2 | NA | 20.1–30.0 | 40 | Rockenfeller et al. | 1986 | USA | English |
| HFIP + DMETEG | GE | 20–90 | NA | 0–100 | 17 | Bothe et al. | 1988 | FRG | English |
| HFIP + SL | GE | 20–70 | NA | 0–90 | 17 | Bothe et al. | 1988 | FRG | English |
| R22 + DMETEG | TEG | -40–105 | NA | 10–50 | 11 | Bonauguri et al. | 1980 | Italy | French |
| R22 + DMF | PGS | -3–87 | NA | 0–100 | 19 | Dorairaj et al. | 1987 | India | English |

X – Liquid Phase (R) – Refrigerant
Y – Vapor Phase NA – Not Available

FLUID PROPERTY DATA

A.X.10 and 11. Mass and Heat Transfer Rates

| Fluid System | Data Type | Temperature Range, °C | Pressure Range, atm | Weight, % X (R) Y (R) | Reference No. | Author | Year | Country | Text |
|---|---|---|---|---|---|---|---|---|---|
| $H_2O$ + LiBr | GE | 40 | 9.3(1) | NA | 32 | Nagaoka et al. | 1987 | Japan | English |
| $H_2O$ + LiBr | GE | 25.5 | NA | 40–90 | 23 | Isshiki et al. | 1988 | Japan | English |
| $NH_3$ + $H_2O$ | GE | NA | NA | 31 | 31 | Modahl et al. | 1988 | USA | English |

X – Liquid Phase (R) – Refrigerant NA – Not Available
Y – Vapor Phase (1) – mm Hg

FLUID PROPERTY DATA

A.X.12. Thermal Conductivity

| Fluid System | Data Type | Temperature Range, °C | Pressure Range, atm | Weight, % X (R) Y (R) | Reference No. | Author | Year | Country | Text |
|---|---|---|---|---|---|---|---|---|---|
| $H_2O$ + LiBr | CE | 100–195 | NA | 40 | 2 | Ally | 1988a | USA | English |
| $H_2O$ + LiBr | P | NA | NA | NA | 35 | Patterson et al. | 1988 | USA | English |
| TFE + DMETEG | E | 120 | NA | 24.5 | 40 | Rockenfeller et al. | 1986 | USA | English |
| R22 + DMF | PGS | -3–87 | NA | 0–100 | 19 | Dorairaj et al. | 1987 | India | English |

X – Liquid Phase (R) – Refrigerant
Y – Vapor Phase NA – Not Available

A.X.15. Surface Tension

| Fluid System | Data Type | Temperature Range, °C | Pressure Range, atm | Weight, % X (R) Y (R) | Reference No. | Author | Year | Country | Text |
|---|---|---|---|---|---|---|---|---|---|
| $NH_3 + H_2O$ | TE | 29–167 | 10.2 | 24–92 | 30 | Miller | 1988 | USA | English |
| $NH_3 + H_2O$ | TE | 55.6 | 17.0 | 77 | 30 | Miller | 1988 | USA | English |
| $H_2O$ + LiBr | P | NA | NA | NA | 35 | Patterson et al. | 1988 | USA | English |
| $H_2O$ + LiBr | GE | 20–80 | NA | NA | 41 | Uemura | 1982 | Japan | Japanese |
| R22 + DMF | PGS | -3–87 | NA | 0–100 | 19 | Dorairaj et al. | 1987 | India | English |

X – Liquid Phase (R) – Refrigerant
Y – Vapor Phase NA – Not Available