A Bibliography of Sources of Thermodynamic Data for the Systems: \( \text{CO}_2 + \text{NH}_3 + \text{H}_2\text{O}, \text{CO}_2 + \text{H}_2\text{S} + \text{H}_2\text{O}, \text{H}_2\text{S} + \text{NH}_3 + \text{H}_2\text{O}, \text{and CO}_2 + \text{NH}_3 + \text{H}_2\text{S} + \text{H}_2\text{O} \)

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Sponsored by:
Design Institute for Physical Property Data
Project 811
American Institute of Chemical Engineers
New York, NY

May 1985
ABSTRACT

Contained herein is a bibliography of sources of experimental and correlated thermodynamic data for the systems \( \text{CO}_2 + \text{NH}_3 + \text{H}_2\text{O} \), \( \text{CO}_2 + \text{H}_2\text{S} + \text{H}_2\text{O} \), \( \text{H}_2\text{S} + \text{NH}_3 + \text{H}_2\text{O} \), and \( \text{CO}_2 + \text{NH}_3 + \text{H}_2\text{S} + \text{H}_2\text{O} \). The types of data in this bibliography include all types of equilibrium data, including both equilibria in solution and vapor-liquid equilibrium data, enthalpies, heat capacities, and densities. There are 215 references cited.

KEY WORDS: ammonia; ammonium carbamate; bibliography; carbon dioxide; enthalpy; equilibrium constants; heat capacity; hydrogen sulfide; sour water; thermodynamics; urea; vapor-liquid equilibria; water.
INTRODUCTION

The thermodynamics of mixtures of \( CO_2 + NH_3 + H_2O \), \( CO_2 + H_2S + H_2O \), \( NH_3 + H_2S + H_2O \), and \( CO_2 + NH_3 + H_2S + H_2O \) are of importance for a variety of industrial applications which include the synthesis of urea, the utilization of sour water systems, gas production, and environmental concerns. The purpose of this bibliography is to identify papers which contain either experimental thermodynamic data for these systems or reviews or correlations of this data. The thermodynamic properties of interest include all types of equilibrium data, including both equilibria in solution and vapor-liquid equilibrium data, enthalpies, heat capacities, and densities. The principal species in aqueous solutions are \( CO_2^0 \), \( CO_3^{2-} \), \( HCO_3^- \), \( H_2CO_3^0 \), \( NH_3^0 \), \( NH_4^+ \), \( HS^- \), \( S^{2-} \), \( CO(NH_2)_2 \), and ammonium carbamate, \( NH_2COONH_4 \). Our search of the literature was based upon a search of the following sources: a computer aided one of Chemical Abstracts from 1967 to 1983, the Bulletin of Chemical Thermodynamics [1] from 1960 to 1981, the files of the Chemical Thermodynamics Data Center at the National Bureau of Standards, and, finally, of the references found in the papers identified in the search itself. The authors would appreciate learning of any papers which we have missed in our search.

The papers are listed alphabetically by first author. Each bibliographic citation includes a brief reference citation (the year and three letters from the names of the first two authors), the authors names, the title of the article and the source. In one instance only an abstract was available and there we have also given the Chemical Abstracts citation. The last column contains a capital letter(s) which serves to identify which systems are found in the paper. The letter codes used are: (A) \( CO_2 + H_2S + H_2O \), (B) \( CO_2 + NH_3 + H_2O \), (C) \( H_2S + NH_3 + H_2O \), and (D) \( CO_2 + H_2S + NH_3 + H_2O \).
Each paper has been annotated to show the type of data, the temperature range and, if appropriate, the pressure, solution composition, and pH. The property codes which we have used are from the Bulletin of Chemical Thermodynamics [1]; they are reproduced in Table I. In specifying the compositions of ternary systems, we have frequently used the quantities $L$ and $W$, which are defined to be the mole ratios $\text{NH}_3/\text{CO}_2$ and $\text{H}_2\text{O}/\text{CO}_2$, respectively. Note that, using existing conventions, the value of $W$ can be negative [2]. We have attempted to adhere to the journal abbreviations used in the Chemical Abstracts Service Source Index [3].

The Japanese, Russian, and Polish titles have been translated into English. These translations come, by preference, from the papers themselves or from Chemical Abstracts. The titles from the latter source may be condensations of the originals.

This bibliography was sponsored by the Design Institute for Physical Property Data (DIPPR) of the American Institute of Chemical Engineers. Bibliographies on the binary systems $\text{CO}_2 + \text{H}_2\text{O}$, $\text{NH}_3 + \text{H}_2\text{O}$, and $\text{H}_2\text{S} + \text{H}_2\text{O}$ have also been compiled for DIPPR under the direction of Drs. David Garvin, David Smith-Magowan, and Bert R. Staples. These bibliographies have been used in developing the present listing, but those papers which treat only the binaries have not been repeated here. We thank Mr. T. B. Selover of the Standard Oil Company for bringing several references to our attention for inclusion in this bibliography, Dr. Hideo Okabe for his assistance with the papers written in Japanese, and Dr. Ewa Gajewski for her help with the papers in Polish.
REFERENCES


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<td>D</td>
<td>Da</td>
<td>Activity, fugacity</td>
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<tr>
<td></td>
<td>Dm</td>
<td>Partial molar quantities</td>
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<tr>
<td></td>
<td>Dx</td>
<td>Excess functions for mixtures</td>
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<tr>
<td>H</td>
<td>Hc</td>
<td>for combustion in O\textsubscript{2} or F\textsubscript{2}</td>
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<td></td>
<td>Hr</td>
<td>for other chemical reactions</td>
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<td></td>
<td>Hm</td>
<td>for mixing: solution, dilution, etc.</td>
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<td></td>
<td>Hp</td>
<td>for phase transitions, fusion, vaporization</td>
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<td></td>
<td>Hs</td>
<td>for surface processes: adsorption, desorption, etc.</td>
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<tr>
<td>K</td>
<td>Kd</td>
<td>Dissociation/decomposition pressures and derived enthalpy/entropy changes.</td>
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<td>Ke</td>
<td>Electrochemical cell potentials, etc. and derived enthalpy/entropy changes.</td>
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<td></td>
<td>Kk</td>
<td>Equilibrium constants for chemical reactions and derived enthalpy/entropy changes.</td>
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<tr>
<td>M</td>
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<td>Data (e.g., structural or spectroscopic) for molecular parameters; atomic energy levels; ionization potentials.</td>
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<td></td>
<td>Mi</td>
<td>Ideal gases: thermodynamic functions (e.g., tabulations).</td>
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<td></td>
<td>Mg</td>
<td>Real gases: intermolecular potentials, derived equations of state</td>
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<td></td>
<td>Mm</td>
<td>Mixtures</td>
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<td></td>
<td>Mx</td>
<td>Crystal, solid and liquid states.</td>
</tr>
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<td></td>
<td>Mb</td>
<td>Bond energies; non-bonded interactions.</td>
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</table>
**Phase Equilibria**

**Pt** Temperatures: freezing point, boiling point, triple point, other phase transitions.

**Pp** Vapor pressure and derived quantities for vaporization and/or sublimation, pure substances

**Pv** Vapor/liquid equilibria and related phase diagrams, mixtures

**Px** Condensed phase equilibria: solubility, freezing points, phase diagrams.

**Po** Osmotic pressure/membrane equilibria

**Ps** Surface phenomena: surface tension, surface energy, adsorption, etc.

**Thermal Properties for Non-Reacting Systems, by Calorimetry**

**Q1** Condensed phase, T \( \leq 400 \) K: heat capacity, enthalpy, entropy, etc.

**Qh** Condensed phase, T \( \geq 400 \) K: heat capacity, enthalpy, entropy, etc.

**Qg** Gas phase: heat capacity, enthalpy, entropy etc. as f(T,P).

**Volume as f(T,P): Empirical Equations of State**

**Vg** Gases: PVT, and related data

**Vc** Critical state properties

**Vx** Condensed phases: compressibility, thermal expansivity

**Vt** Tables and charts of data, e.g., Mollier diagrams.

**Physical Properties of a Single Phase**

**Xd** Density

**Xv** Viscosity

**Xr** Refractive index

**Compilations, Correlations and Reviews**

**Za** Analysis of experimental data and of errors

**Zc** Empirical Correlations

**Ze** Evaluations and compilations

**Zr** Reviews

**Physical States:** crystalline, solid

(aq)ueous

(amorp)hous (nonaq)ueous, includes fused salts, solid solutions

(liq)uid

(gas) (Ads)orbed
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<th>Reference</th>
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| Kk, Pv, 130-170 °C, 30 to 185 atm. | B |
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Zc, Kk, Pv, 25-80 °C.

Zc, Kk, Pv, 25-80 °C.

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Kk, Pv, 100-400 °F, CO, CH₄, N₂, and H₂ also added to mixture.
Pv, 200-500 °F.
Pv, 70-90 °C.
Pv, 100 and 150 °C, measurements also done in aqueous KNO₃ and K₂SO₄.
Zc, Kk, Pv, 80 °C
Pv, 20-90 °C.
Pv, 160 °C.


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Kk, Pv, 37.8 to 204 °C, 0.4 to 18.5 MPa, methane also present. A

Zc, Vt, 30-95 °C. B

Zc, Pv, 170-210 °C, L = 2 to 6, W = 0 to 1.2. B

Pv, 20-80 °C. B

Xd, 20-50 °C. B

Xd, 20-50 °C. B

Kk, Pv, 63-173 °C. B

Kk, Pv, 63-173 °C. B


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A Bibliography of Sources of Thermodynamic Data for the Systems: $\text{CO}_2 + \text{NH}_3 + \text{H}_2\text{O}$, $\text{CO}_2 + \text{H}_2\text{S} + \text{H}_2\text{O}$, $\text{H}_2\text{S} + \text{NH}_3 + \text{H}_2\text{O}$, and $\text{CO}_2 + \text{NH}_3 + \text{H}_2\text{S} + \text{H}_2\text{O}$

**BIBLIOGRAPHIC DATA**

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**TITLE AND SUBTITLE**

A Bibliography of Sources of Thermodynamic Data for the Systems: $\text{CO}_2 + \text{NH}_3 + \text{H}_2\text{O}$, $\text{CO}_2 + \text{H}_2\text{S} + \text{H}_2\text{O}$, $\text{H}_2\text{S} + \text{NH}_3 + \text{H}_2\text{O}$, and $\text{CO}_2 + \text{NH}_3 + \text{H}_2\text{S} + \text{H}_2\text{O}$

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Project 811
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New York, NY

**ABSTRACT**

Contained herein is a bibliography of sources of experimental and correlated thermodynamic data for the systems $\text{CO}_2 + \text{NH}_3 + \text{H}_2\text{O}$, $\text{CO}_2 + \text{H}_2\text{S} + \text{H}_2\text{O}$, $\text{H}_2\text{S} + \text{NH}_3 + \text{H}_2\text{O}$, and $\text{CO}_2 + \text{NH}_3 + \text{H}_2\text{S} + \text{H}_2\text{O}$. The types of data in this bibliography include all types of equilibrium data, including both equilibria in solution and vapor-liquid equilibrium data, enthalpies, heat capacities, and densities. There are 215 references cited.

**KEY WORDS**

ammonia; ammonium carbamate; bibliography; carbon dioxide; enthalpy; equilibrium constants; heat capacity; hydrogen sulfide; sour water; thermodynamics; urea; vapor-liquid equilibria; water

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