MOLLIER DIAGRAM FOR NITROGEN

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ABSTRACT

Thermodynamic data for nitrogen are presented in Mollier diagram form covering the temperature range of 50 °K to 15,000 °K and the density range of $10^{-6}$ to $10^{3}$ atmospheres.

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NOMENCLATURE

$c_p$ Specific heat at constant pressure
$H$ Specific enthalpy
$^oK$ Degree Kelvin
$log$ Logarithm to the base 10
$P$ Pressure in relative atmospheres
$R$ Gas constant for nitrogen
$^oR$ Degree Rankine
$S$ Specific entropy
$T$ Temperature in $^oK$
$v$ Specific volume ($1/\rho$)
$\rho/\rho_o$ Density ratio
$\rho_o$ Reference density at one atmosphere pressure, 273.16 $^oK$

CONVERSION FACTORS

<table>
<thead>
<tr>
<th>Standard atmospheric pressure</th>
<th>Reference density</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P_o = 760$ mm Hg</td>
<td>$\rho_o = 1.25046 \times 10^{-3}$ g/cm$^3$</td>
</tr>
<tr>
<td>29.921 in. Hg</td>
<td>$4.46338 \times 10^{-5}$ moles/cm$^3$</td>
</tr>
<tr>
<td>10332 kg/m$^2$</td>
<td>$1.35050$ g/liter</td>
</tr>
<tr>
<td>14.656 psia</td>
<td>$4.51760 \times 10^{-5}$ lb/in.$^3$</td>
</tr>
<tr>
<td>2116 psfa</td>
<td>$7.80641 \times 10^{-2}$ lb/ft$^3$</td>
</tr>
<tr>
<td></td>
<td>$2.42435 \times 10^{-3}$ slugs/ft$^3$</td>
</tr>
</tbody>
</table>

Temperature

$T (^oK) \times 1.8 = T (^oR)$
$T (^oK) = T (^oC) + 273.15$
$T (^oR) = T (^F) + 459.69$
<table>
<thead>
<tr>
<th>To Change</th>
<th>To</th>
<th>With Units</th>
<th>Multiply by</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\frac{H}{R}$ (°K)</td>
<td>$\frac{H}{RT}$</td>
<td>none</td>
<td>$\frac{1}{T}$ (°K)</td>
</tr>
<tr>
<td>$\frac{H}{R}$</td>
<td>°R</td>
<td>1.8</td>
<td></td>
</tr>
<tr>
<td>$H$</td>
<td>$\frac{\text{ft}^2}{\text{sec}^2}$</td>
<td>3196.66</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>BTU</td>
<td>0.12768</td>
</tr>
<tr>
<td></td>
<td></td>
<td>cal</td>
<td>0.0709305</td>
</tr>
<tr>
<td>$\frac{S}{R}$</td>
<td>$S$</td>
<td>$\frac{\text{ft}^2}{\text{sec}^2}$ °K</td>
<td>3196.66</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$\frac{\text{ft}^2}{\text{sec}^2}$ °R</td>
<td>1775.92</td>
</tr>
<tr>
<td></td>
<td></td>
<td>BTU</td>
<td>0.07093</td>
</tr>
<tr>
<td></td>
<td></td>
<td>BTU</td>
<td>0.12768</td>
</tr>
<tr>
<td></td>
<td></td>
<td>cal</td>
<td>0.0709305</td>
</tr>
</tbody>
</table>
INTRODUCTION

This nitrogen Moller diagram includes all of the data available from the three sources listed in the references. It consists of an index sheet and 28 individual sections. The temperature ranges from 30°K to 15,000°K, and the diagram includes data for the solid and liquid nitrogen lines at very low temperatures. The density range extends from $10^{-6}$ to $10^3$ relative atmospheres.

DISCUSSION

EXTENT AND SOURCES OF THE NITROGEN MOLLER DIAGRAM

This Moller diagram covers the region between 30°K and 15,000°K. The following table demonstrates the scope of the diagram.

<table>
<thead>
<tr>
<th>T (°K)</th>
<th>$\rho$ atm</th>
<th>$P$ atm</th>
<th>S/R</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td>$10^5$</td>
<td>2 x $10^6$</td>
<td>21</td>
<td>Refs. 1 and 2</td>
</tr>
<tr>
<td>to 15k</td>
<td>to</td>
<td>to</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15000</td>
<td>$10^{-6}$</td>
<td>$10^{-5}$</td>
<td>121</td>
<td></td>
</tr>
<tr>
<td>to 100</td>
<td>$10^2$</td>
<td>$10^3$</td>
<td>19</td>
<td>Ref. 3</td>
</tr>
<tr>
<td>K</td>
<td>to</td>
<td>to</td>
<td></td>
<td></td>
</tr>
<tr>
<td>100</td>
<td>$10^{-2}$</td>
<td>$10^{-1}$</td>
<td>19</td>
<td>Perfect gas laws</td>
</tr>
<tr>
<td>K</td>
<td>to</td>
<td>to</td>
<td></td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>$1$</td>
<td>$10^{-2}$</td>
<td>24</td>
<td></td>
</tr>
<tr>
<td>K</td>
<td>to</td>
<td>to</td>
<td></td>
<td></td>
</tr>
<tr>
<td>100</td>
<td>$10^{-2}$</td>
<td>$10^{-1}$</td>
<td>21</td>
<td>Extrapolation (see text)</td>
</tr>
<tr>
<td>K</td>
<td>to</td>
<td>to</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2000</td>
<td>$10^{-6}$</td>
<td>$10^{-5}$</td>
<td>43</td>
<td></td>
</tr>
</tbody>
</table>

The sources used to compile this diagram were the recent preliminary nitrogen tables (Refs. 1 and 3) by Hilsenrath for temperatures above 2000°K and "Tables of Thermal Properties of Gases" (Ref. 3) for temperatures below 2000°K. The two sources differ by about two percent at 2000°K and pressures above 70 atmospheres. This difference is a result of van der Waal's forces being accounted for in the data of Ref. 3.

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and not in Refs. 1 and 2, but it is unnoticeable in the diagram where the two sources meet.

The Hilsenrath data (Refs. 1 and 2) above 2000°K give the properties of the equilibrium mixture treated as an ideal gas. Van der Waal's effects have not been accounted for in this region.

Reference 3 data below 2000°K are restricted to the pressure range of 100 to 0.01 atm, and no data below 100°K are given. Pressure and density data below 0.01 atm of pressure were obtained by extrapolation of the known data. This was done by plotting at constant temperature the logarithm of the pressure and density against dimensionless entropy (S/R). These extrapolations can be justified at low pressures and temperatures from perfect gas relationships. The three equations derived in the appendix using Bridgman's tables (Ref. 4) indicate that the extrapolations are straight lines. Plots of the available data indicate that these relationships are valid to about 100 atm of pressure.

Enthalpy-temperature data below 100°K were obtained by using the perfect gas relationship

\[
\frac{H}{R} = \left(\frac{c_p}{R}\right) T
\]

where \(c_p/R\) was taken to be 3.509. The liquefaction line, triple point, and the solidification line were plotted from data given in Ref. 1. Near this area caution should be used in the interpretation of the temperature, pressure, and density lines. These properties are based upon the perfect gas laws and may not accurately represent the true behavior of the gas in this region.

**THE FORMAT OF THE NITROGEN MOLLIER DIAGRAM**

For convenience and to obtain a scale that would allow accurate reading, the diagram was plotted in sections on 8 1/2 x 11 in. semilog paper. A master index sheet (Fig. 1) has been made which shows the regions covered by each section and the entire diagram.

Dimensionless numbers were used as much as possible to obtain a greater amount of flexibility in the use of the diagram. Entropy was plotted in the dimensionless form \(S/R\). Pressure was plotted in relative atmospheres, and the density in the logarithm to the base 10 of the density ratio \(p/p^*\). The enthalpy function \(H/R\) was used to give an appropriate scale and to simplify conversion. \(H/R\), as used here, has the units of °K so that \(H/RT\) is dimensionless since temperature is given in °K. The conversion tables show conversions of the enthalpy function \(H/R\) and the entropy function \(S/R\) to common engineering units.
Each of the individual sections was plotted with great care to maintain as much of the reliability of the sources as possible. The functions were plotted at close enough intervals so that interpolation on a linear basis should give satisfactory results.

REFERENCES


2. Hilsenrath, J., Addition to Ref. 1 covering the density range from 100 to 1000 relative atmospheres. Communication to Dr. Martin Grabau, December 1959.


APPENDIX

Derivation of the equations used as the basis for extrapolation at low pressures and temperatures.

1. Show that

\[
\frac{\partial H}{\partial S} = 0;
\]

\[
\left(\frac{\partial H}{\partial S}\right)_T = -v + T \left(\frac{\partial v}{\partial T}\right)_p
\]

\[
\left(\frac{\partial S}{\partial T}\right)_p = \left(\frac{\partial v}{\partial T}\right)_p
\]

from the equation of state

\[
v = -\frac{B_T}{P}
\]

\[
\left(\frac{\partial S}{\partial P}\right)_T = \frac{B}{P}
\]

\[
P = \frac{R_T}{v}
\]

\[
\left(\frac{\partial v}{\partial T}\right)_p = -\frac{R}{T_T/v} - \frac{v}{T}
\]

\[
\left(\frac{\partial H}{\partial S}\right)_T = -\frac{v}{v/T} + T = -T + T
\]

\[
\left(\frac{\partial H}{\partial S}\right)_T = 0
\]
2. Show that

\[ \left( \frac{\partial L S P}{\partial S} \right)_T = C \text{ (constant)} : \]

\[ P = v^{-1} R T \]

\[ \ln P = \ln R T - \ln v \]

\[ \left( \frac{\partial (L S P)}{\partial v} \right)_T = -\frac{1}{v} \]

\[ \left( \frac{\partial v}{\partial T} \right)_P = - \left( \frac{\partial v}{\partial P} \right)_T \]

\[ \left( \frac{\partial S}{\partial v} \right)_T = \left( \frac{\partial v}{\partial T} \right)_P \]

\[ \left( \frac{\partial S}{\partial P} \right)_T = \frac{-\left( \frac{\partial v}{\partial P} \right)_T}{\left( \frac{\partial v}{\partial T} \right)_P} \]

\[ \left( \frac{\partial L S P}{\partial T} \right)_P = \left( \frac{\partial L S P}{\partial S} \right)_T \left( \frac{\partial v}{\partial T} \right)_P - \frac{-\left( \frac{\partial v}{\partial P} \right)_T}{v \left( \frac{\partial v}{\partial T} \right)_P} \]

from the equation of state

\[ v = \frac{R T}{P} \]

\[ \left( \frac{\partial v}{\partial T} \right)_P = - \frac{R T}{P^2} \]

\[ \left( \frac{\partial v}{\partial P} \right)_T = - \frac{R}{P} \]

\[ \left( \frac{\partial L S P}{\partial S} \right)_T = - \frac{R T}{P^{\frac{1}{2}}} \left( \frac{\partial P}{\partial S} \right)_T \]

\[ \left( \frac{\partial L S P}{\partial S} \right)_T = - \frac{1}{R} \text{ constant} \]
3. Show that

\[ \left( \frac{\partial \ln \rho}{\partial S} \right)_T = C \text{ (constant):} \]

\[ \rho = \frac{p}{R T} \]

\[ \ln \rho = \ln p - \ln RT \]

\[ \left( \frac{\partial \ln \rho}{\partial p} \right)_T = \frac{1}{p} \]

\[ \begin{cases} \left( \frac{\partial p}{\partial T} \right)_T = -1 \\ \left( \frac{\partial S}{\partial T} \right)_p = \left( \frac{\partial S}{\partial T} \right)_p \end{cases} \]

\[ \left( \frac{\partial p}{\partial S} \right)_T = - \left( \frac{1}{\rho} \frac{\partial S}{\partial \rho} \right)_T \]

\[ \left( \frac{\partial \ln \rho}{\partial S} \right)_T = \left( \frac{\partial \ln \rho}{\partial p} \right)_T \left( \frac{\partial p}{\partial S} \right)_T \]

\[ = - \frac{1}{p} \left( \frac{\partial T}{\partial \rho} \right)_p \]

from the equation of state

\[ T = \frac{p v}{R} \]

\[ \left( \frac{\partial T}{\partial \rho} \right)_p = \frac{p v}{R} \]

\[ \left( \frac{\partial \ln \rho}{\partial \rho} \right)_T = - \frac{1}{\rho} \left( \frac{\partial p}{\partial \rho} \right)_T \]

\[ \left( \frac{\partial \ln \rho}{\partial \rho} \right)_T = - \frac{1}{\rho} \text{ (constant)} \]
Fig. 1 Index Sheet for Nitrogen Mollier Diagram
Figure 26
(4L)

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