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Three Dimensional Pressure Temperature Entropy Diagram

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Abstract. Three properties of carbon dioxide, namely, pressure, temperature, and entropy, are combined to produce three graphical plots: (1) Pressure vs. Temperature, (2) Entropy vs. Temperature, and (3) Entropy vs. Pressure. These three plots are, in actuality, the three projections of a three-dimensional surface depicting all the phases of carbon dioxide. The fluid must exist on the surface at all times, and any thermodynamic process will occur along the surface. The general configuration of the three-dimensional surface for carbon dioxide is shown, and the areas depicting structures are labeled.

Persons dealing with engineering fluids in research or the practice of engineering in industry must have information about the fluids so that their use may be applied properly. This information is normally made available in tabular or graphical form and establishes numerical values for the various fluid properties which include pressure, temperature, enthalpy, internal energy, entropy, specific heats at constant volume and constant pressure, and specific volume, or its reciprocal, density.

This paper deals with the graphical presentation of the properties (a) pressure, (b) temperature, and (c) entropy of carbon dioxide. Various devices have been used over the years to measure directly the pressure and temperature of a contained fluid. Entropy is a calculated property which depends upon the variable properties of temperature, pressure and specific heats for its numerical value. Entropy is regarded as having no absolute value. An arbitrary value for the entropy of a fluid is established at some chosen temperature and pressure of the fluid. The change in entropy of a fluid during a thermodynamic process is of great value, and this change can be calculated accurately regardless of the original arbitrary value chosen at the specified temperature and pressure.

A French mathematician named Caratheodory was the first to prove by rigorous mathematical analysis that the property, now called entropy, existed. This property enabled a thorough and accurate analysis and explanation of thermodynamic processes.

TEMPERATURE VS. PRESSURE

Probably the first type of graphical data introduced to the student

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is the familiar phase diagram plotting temperature as the abscissa and pressure as the ordinate, the plot appearing in the first quadrant. Figure 1 is a Temperature-Pressure plot for carbon dioxide but the usual presentation is rotated 90 degrees counterclockwise to the second quadrant for ease of future use.

There are four major zones or phases indicated on this type of diagram: (1) solid, (2) liquid, (3) vapor, and (4) fluid. The first three are separated by sharply defined lines since there is a comparatively easily discernable physical change in the fluid during the change from one phase to another as in solid to liquid, liquid to vapor, or solid to vapor. The boundaries of the fourth or fluid zone are usually defined by the critical temperature and pressure of the substance. Transition through the fluid zone from liquid to vapor or from vapor to liquid is difficult to establish by reason of any radical change in physical properties or appearance.

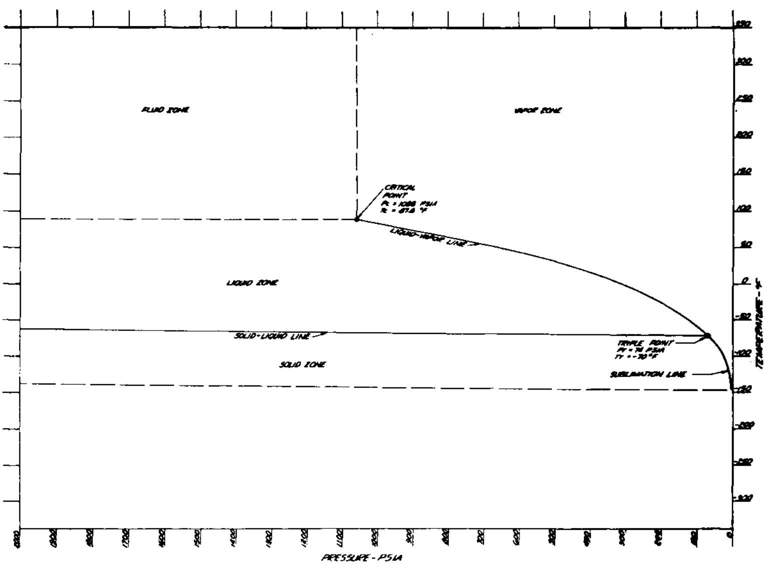

Figure 1. Phase diagram, carbon dioxide: Pressure vs. Temperature.

Temperature vs. Entropy

The second type of graphical data presentation to be used is the Temperature-Entropy plot of carbon dioxide. This type of plot usually includes lines of constant pressure, volume, and enthalpy. In addition, in the transition zones from liquid to vapor, the vaporization dome, and from solid to vapor, the sublimation zone, are lines of constant proportions of the two phases. Those which occur in the vaporization dome are termed constant quality lines. For clarity of this presentation nearly all of these lines have been omitted except those required to establish zone limits. Figure 2 depicts such a presentation, with the 1700 psia line in the solid and the solid to liquid transition zones being assumed, since the data in this area were incomplete.

Pressure vs. Entropy

Combining the pressure values of Figure 1 and the entropy values of Figure 2 resulted in a seldom used presentation of a Pressure-Entropy plot showing a few constant temperature lines as seen in Figure 3.

Three Dimensional Pressure-Temperature-Entropy Diagram

The combination of figures 1, 2, and 3 into a three dimensional presentation of the data of all three plots results in well defined surfaces as shown isometrically in figure 4. If carbon dioxide exists in any condition in the pure state it can be represented accurately

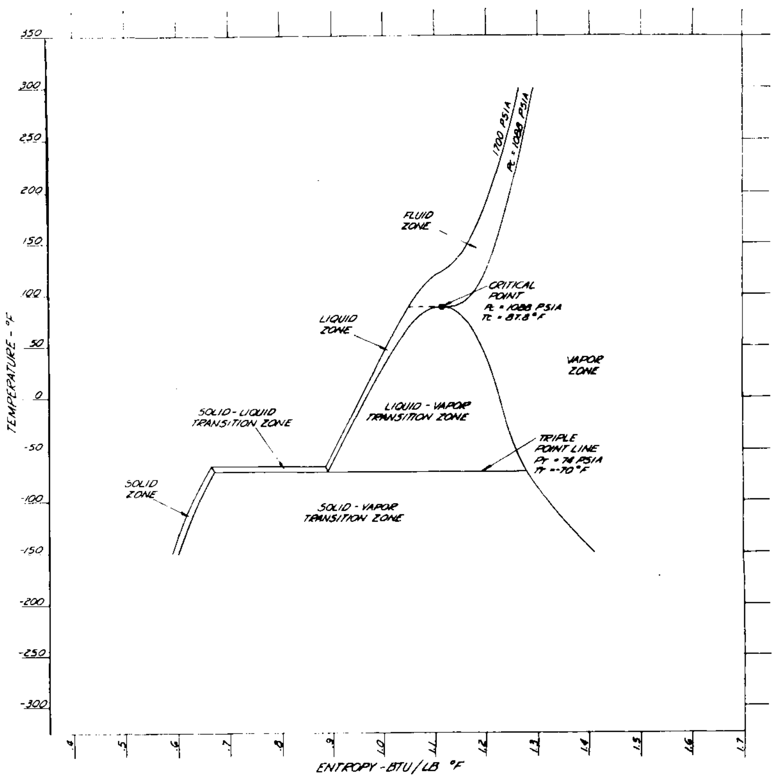

Figure 2. Phase diagram, carbon dioxide: Entropy vs. Temperature.

by a point on the surface shown or a continuation of the surface if it is beyond the present boundaries depicted. Transition from the initial condition to any final condition will take place along the surface regardless of the type of thermodynamic process involved, and the path of travel can be followed accurately if successive simultaneous values of pressure, temperature, and specific heat are known. Since entropy is calculable from pressure or temperature and specific heat, the value of the third coordinate is established.

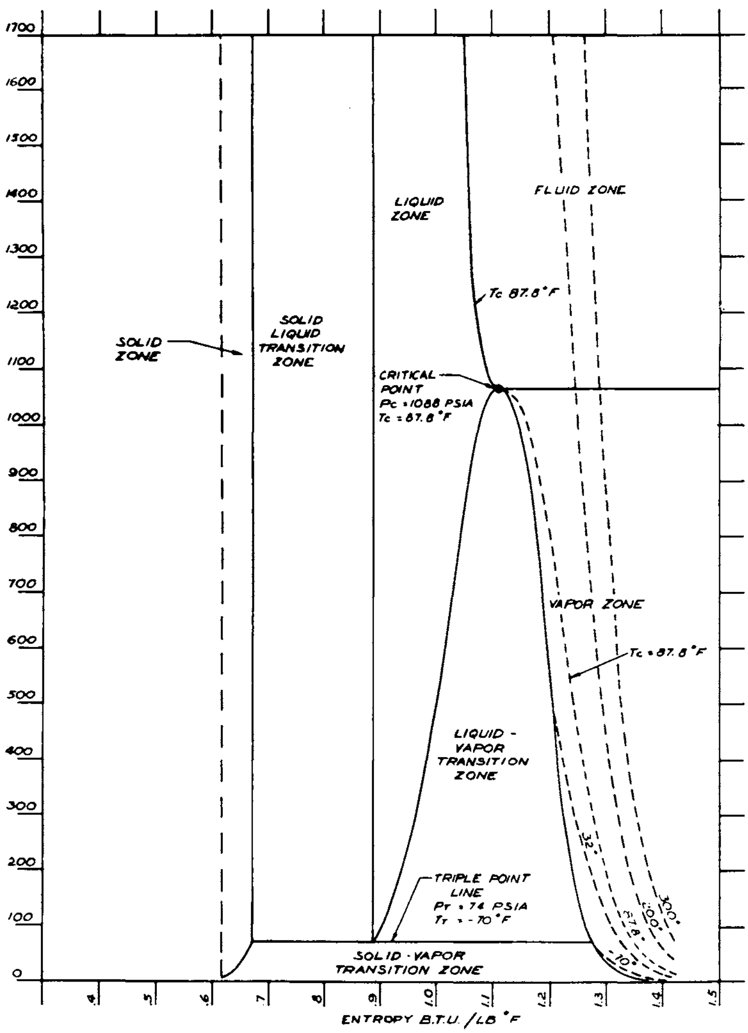

Figure 3. Phase diagram, carbon dioxide: Entropy vs. Pressure.

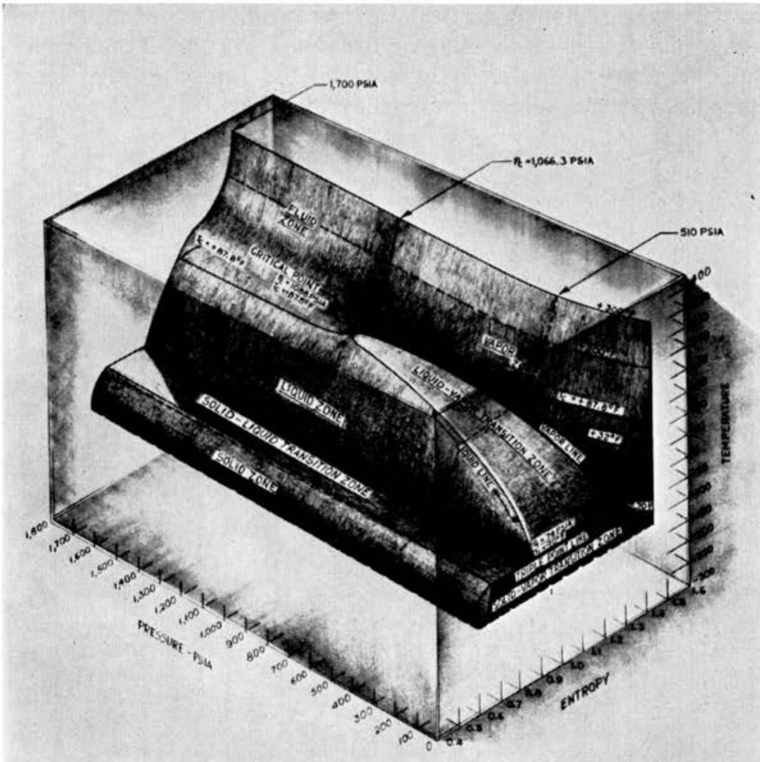

Figure 4. Phase diagram, carbon dioxide: Entropy vs. Temperature vs. Pressure.

Conclusion

It is quite often difficult for a student of thermodynamics to establish a mental picture of what transpires during a thermodynamic process particularly during a phase change, since the data are usually made available in the form of one diagram which quite often is an Enthalpy-Entropy or "Mollier" diagram. This diagram is extremely convenient to use in thermodynamic work, but it cannot be readily associated with the common Pressure-Temperature diagram.

The greatest utility, therefore, of a three dimensional Pressure-Temperature-Entropy diagram of any thermodynamic fluid would appear to be as an aid to an individual lacking relatively complete familiarity with changes occurring in thermodynamic processes to aid him in establishing a clear mental picture of process changes.

A second, but none the less valuable use, involves thermodynamic processes occurring near the critical and triple points of a fluid in engineering fields such as cryogenics, which deals with extremely low temperature liquefied gases. A clear mental picture of the general configuration of the three dimensional Pressure-Temperature-Entropy diagram has been of considerable utility in the design phases of systems using these engineering fluids.