

Selected Properties of Water Substance 3-Dimensional Representation with Possible Applications

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ABSTRACT

Computer technology nowadays enables science and industry to evaluate thermodynamic properties of water substance and the derivatives within a few seconds from an equation of state. The aim of this representation is to enlarge the imagination for some properties in three dimensions in different relations, for example such potential function of enthalpy as a function of pressure and temperature or as a function of temperature and specific volume.

Extrema and anomalies can be seen quite easily and some imagination may help in regard with determining problems in the vicinity of the critical point and other areas.

A selection of some three-dimensional plots of properties in different dependencies should give impressions about the shape of the thermodynamic surface of properties of ordinary water substance.

KEYWORDS

thermodynamic properties; potential functions; equations of state; thermodynamic surface.

INTRODUCTION

The application of Gibb's phase rule on the one component system of water substance results in the relation that one property can be calculated from a set of maximal two independent variable properties. Therefore it is possible to define the properties of water substance by a three-dimensional thermodynamic surface.

THREE-DIMENSIONAL THERMODYNAMIC SURFACE

Most of the equations of state for scientific and industrial use for the calculation of properties of water substance are deduced from the Helmholtz potential function which has temperature and specific volume as a set of independent input variables. In the course of technical engineering's practice this relationship satisfies only very few occasions of use because in the first steps of cycle processes or similar problems commonly another set of input is available, that is pressure and temperature. In the working field of power and chemical engineering with water substance as working medium additional some other dependencies are of interest, e. g. temperature and entropy or temperature and enthalpy as pair of input variables.

For the scaling of the axes of the three-dimensional plots SI-units have been used with the exception of pressure given in bar and temperature given in degree Celsius. For the reason of proper visibility the properties of the specific volume, the isobaric heat capacity and the Rayleigh-number are used in logarithmic scale with logarithmic values for the axis legend respectively.

To facilitate the handling with the three-dimensional models the well-known Clausius-Rankine process is shown on its way on all represented surfaces. Fig. 1 shows the process running on three isobars p_1 , p_2 , p_3 within the region of subcritical pressure in the usually used temperature-entropy-diagram and it is transferred to the represented surfaces in bold lines. The dashed lines in the three-dimensional plots show the saturation lines and enclose the two-phase region in which the isogrid-lines are calculated by means of the steam fraction because of some computer graphic necessity but the graph lines need not to be physically reliable.

The numbers given in the outline of the Clausius-Rankine process, which is slightly modified in the way that the perfect reversible expansion is changed to the realistic irreversible expansion in the turbine with additional reheating, refer to Fig. 1.

The feedwater pump increases the pressure to the isobar p_1 (1-2), the absorbed heat from the heat exchanger, from the boiler or by internal combustion (2-3) leads to the turbine's entry (3) where the fluid expands irreversibly (3-4) to the isobar p_2 (4). After removing the liquid parts and reheating (4-5) a second turbine expansion follows (5-6) and the condensing steam is lead on the isobar p_3 to the feedwater pump (6-1).

Tracking the process on the surface of the different models one can imagine how an optimization of such a process may work or in which areas improvements seem to be economical.

Another type of help is offered for the question which type of simple equation of state should fit possibly a certain restricted region on the surface or which will not match the conditions.

The following figures show the technical most important thermodynamic and transport properties:

Fig. 2: entropy	$s(p, T)$	
Fig. 3: specific volume	$v(p, T)$	$p_{\max} = 250 \text{ bar}$
Fig. 4: enthalpy	$h(p, T)$	
Fig. 5: entropy	$s(p, T)$	
Fig. 6: specific volume	$v(p, T)$	$p_{\max} = 1000 \text{ bar}$
Fig. 7: enthalpy	$h(p, T)$	
Fig. 8: entropy	$s(T, v)$	
Fig. 9: enthalpy	$h(T, v)$	
Fig. 10: heat capacity at constant pressure	$c_p(p, T)$	
Fig. 11: heat capacity at constant volume	$c_v(p, T)$	
Fig. 12: isothermal compressibility	$\chi_T(p, T)$	
Fig. 13: viscosity	$\eta(p, T)$	
Fig. 14: thermal conductivity	$\lambda(p, T)$	
Fig. 15: Rayleigh-number	$Ra(p, T)$	
Fig. 16: viscosity	$\eta(T, v)$	
Fig. 17: thermal conductivity	$\lambda(T, v)$	

The plots of the transport properties may warn to take these properties over a wide range of validity as constant values, especially in the area of the critical point. Problems may arise actually to be seen at the Rayleigh-number which has been calculated with temperature difference and characteristic length to be equal to one, so that different conditions influence only the ordinate's scale.

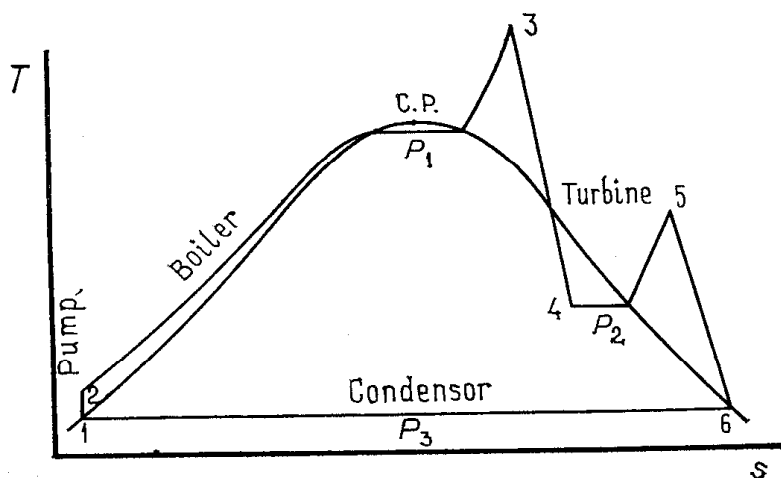


Fig. 1. Modified Clausius-Rankine process

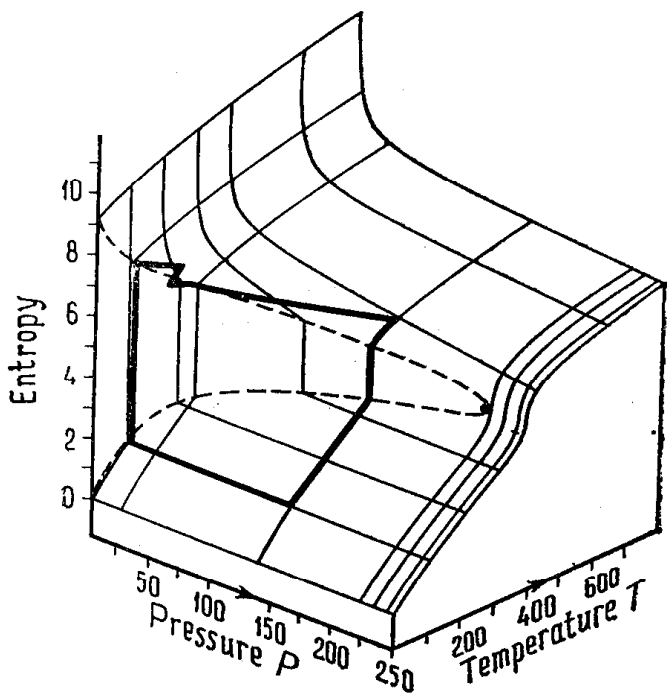


Fig. 2. Entropy as a function of pressure and temperature

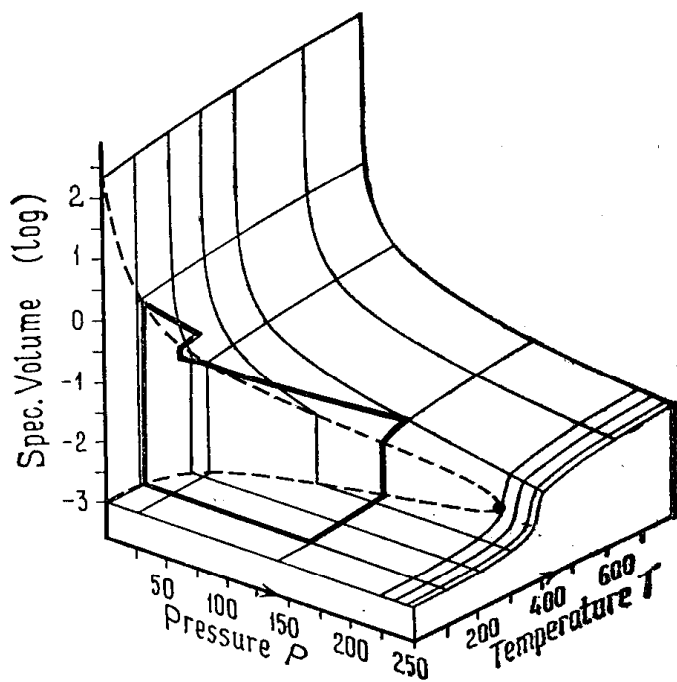


Fig. 3. Specific volume as a function of pressure and temperature

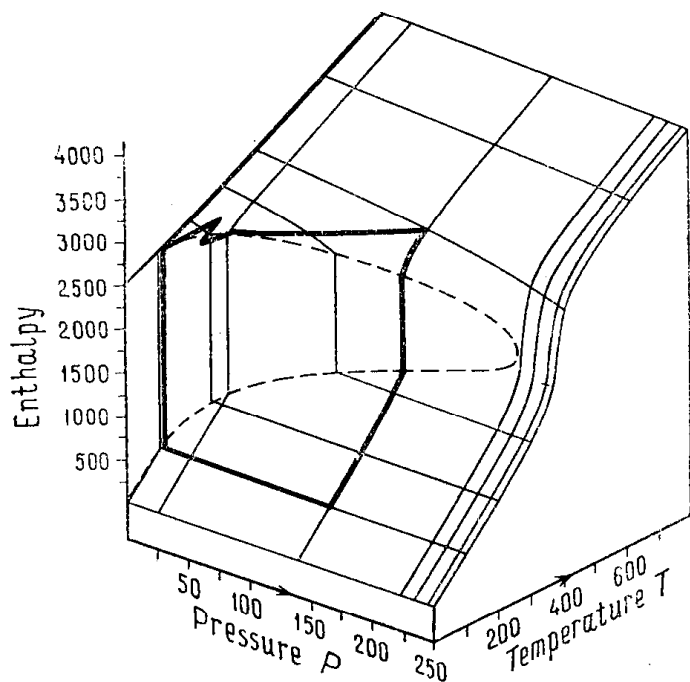


Fig. 4. Enthalpy as a function of pressure and temperature

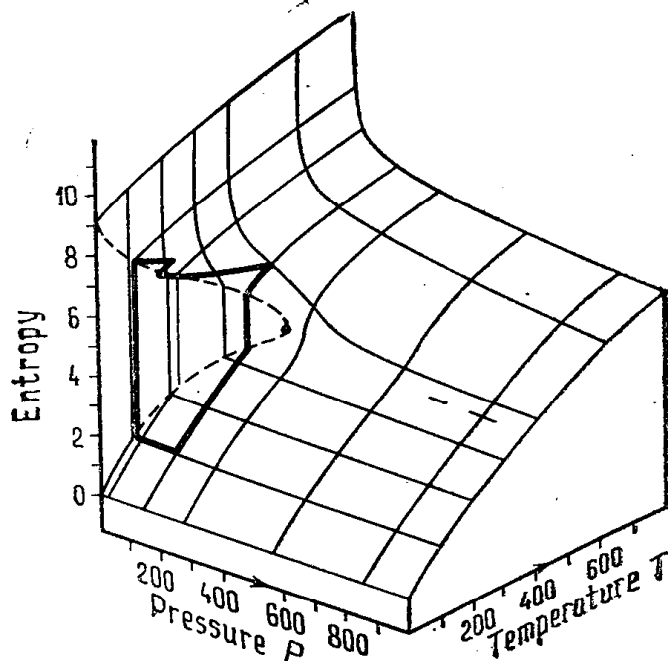


Fig. 5. Entropy as a function of pressure and temperature

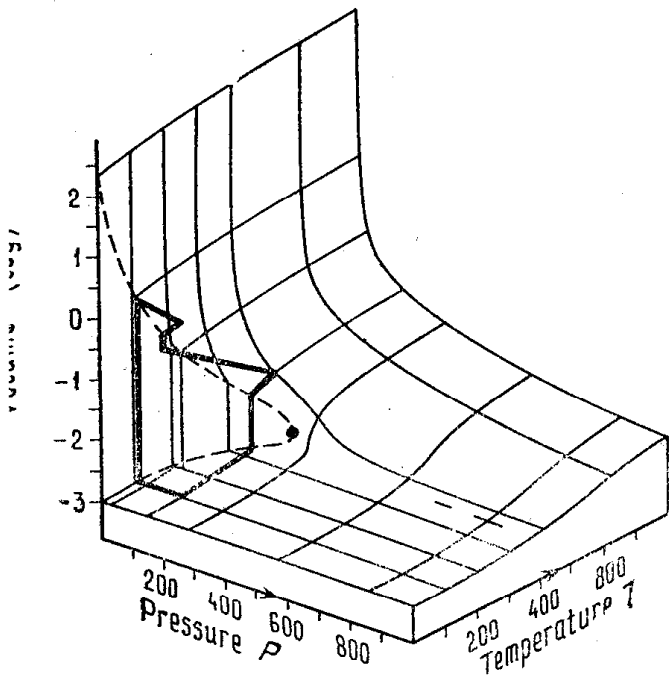


Fig. 6. Specific volume as a function of pressure and temperature

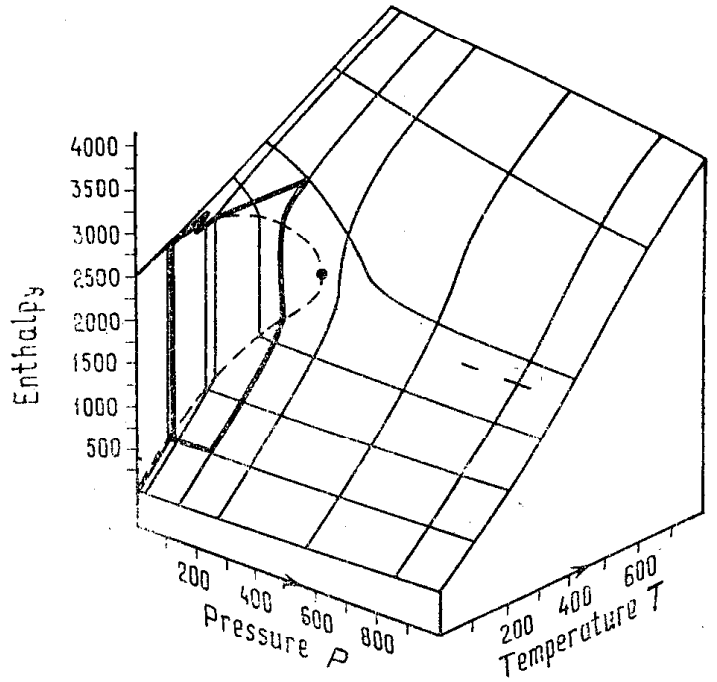


Fig. 7. Enthalpy as a function of pressure and temperature

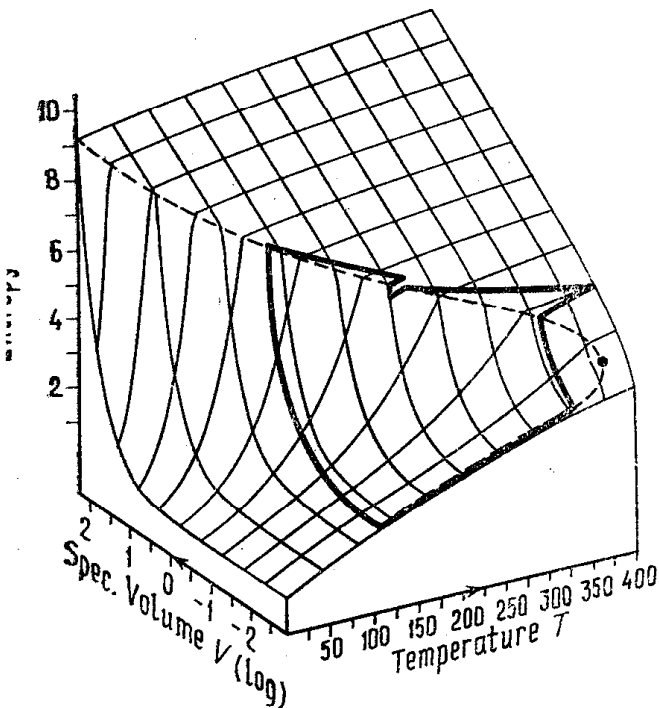


Fig. 8. Entropy as a function of temperature and specific volume

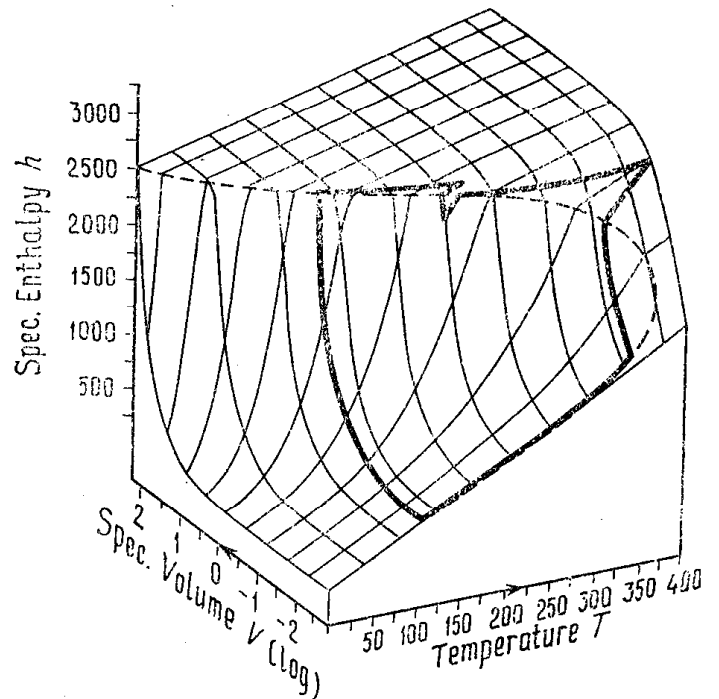


Fig. 9. Enthalpy as a function of temperature and specific volume

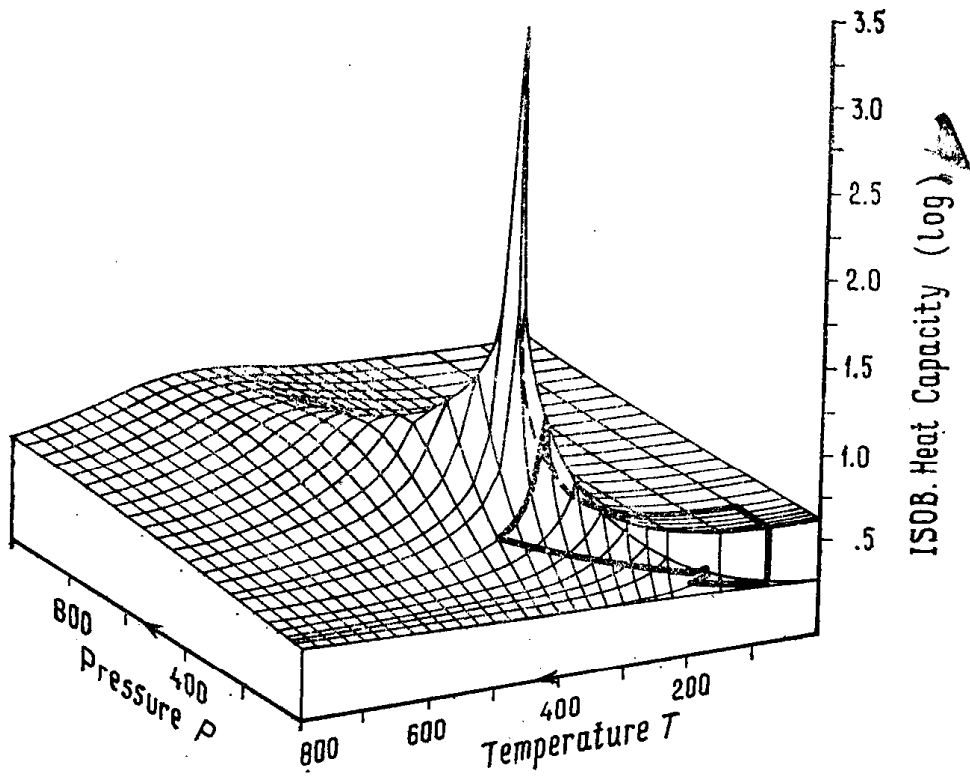


Fig. 10. Heat capacity at constant pressure $c_p(p, T)$

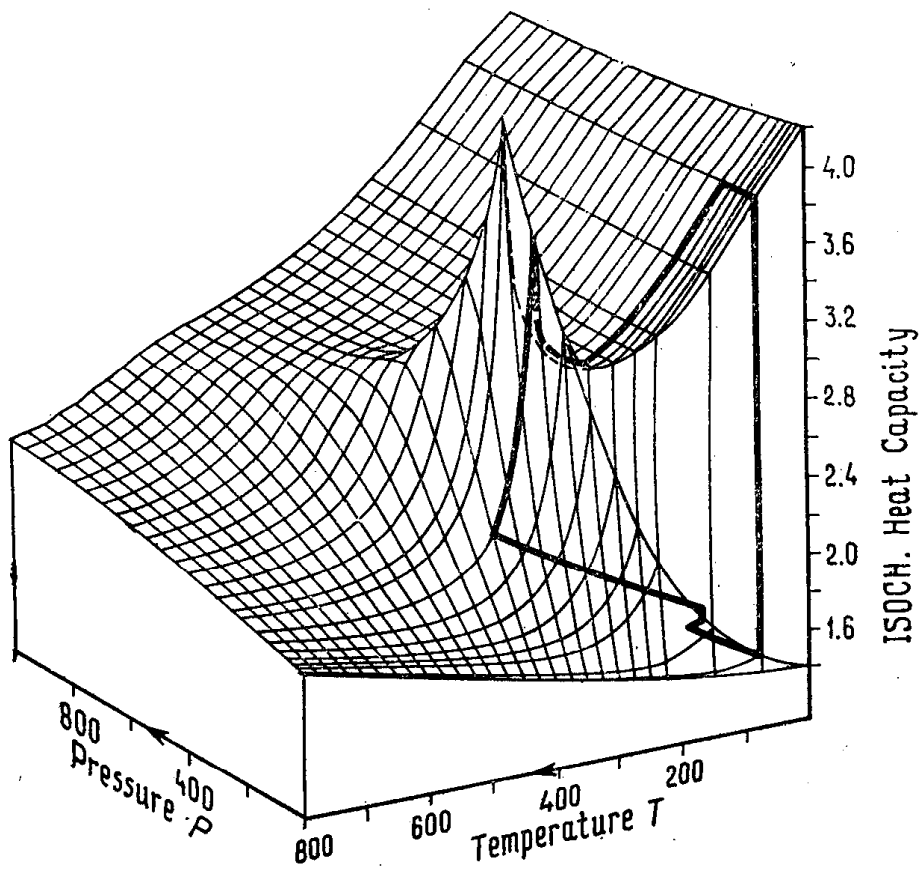


Fig. 11. Heat capacity at constant volume $c_v(p, T)$

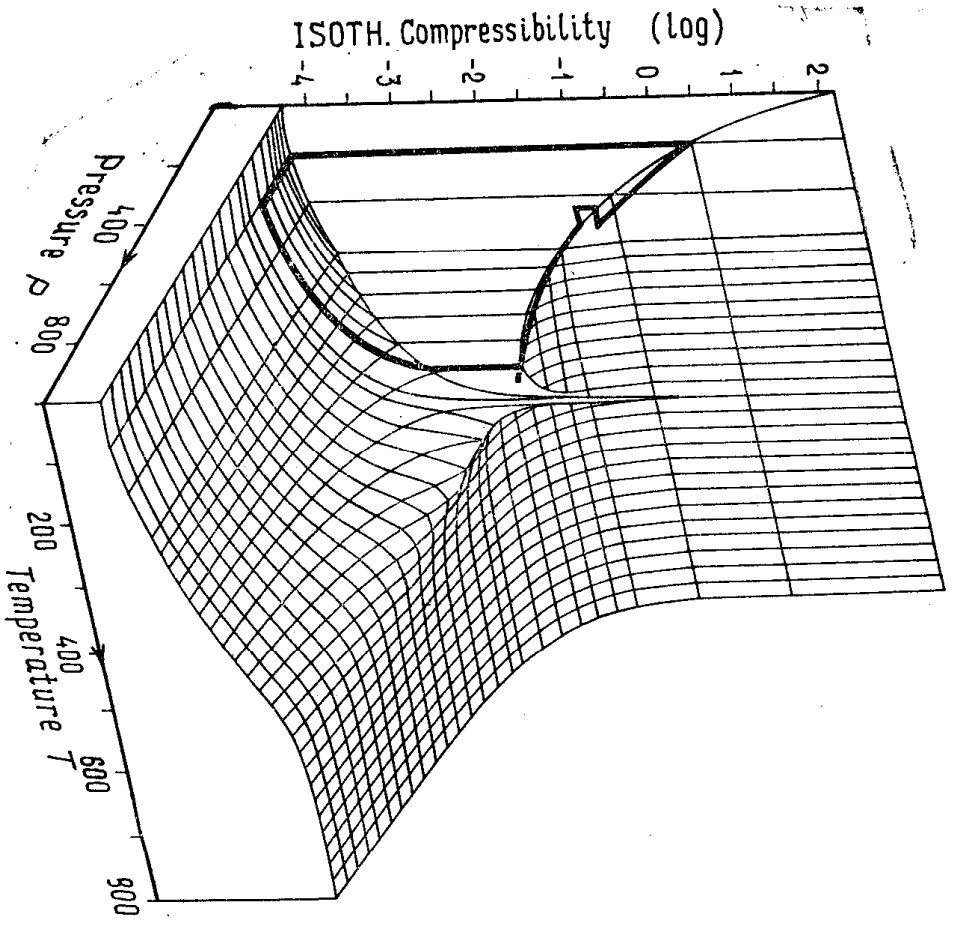


Fig. 12. Isothermal compressibility as a function of pressure and temperature

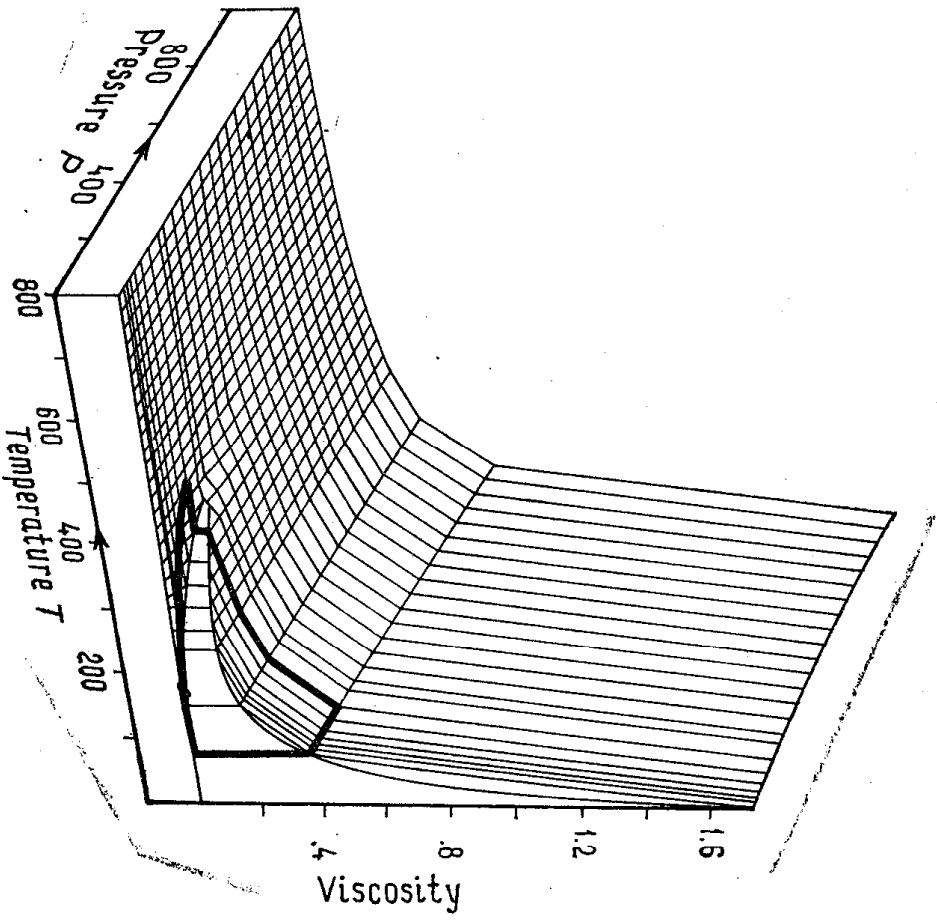


Fig. 13. Viscosity as a function of pressure and temperature

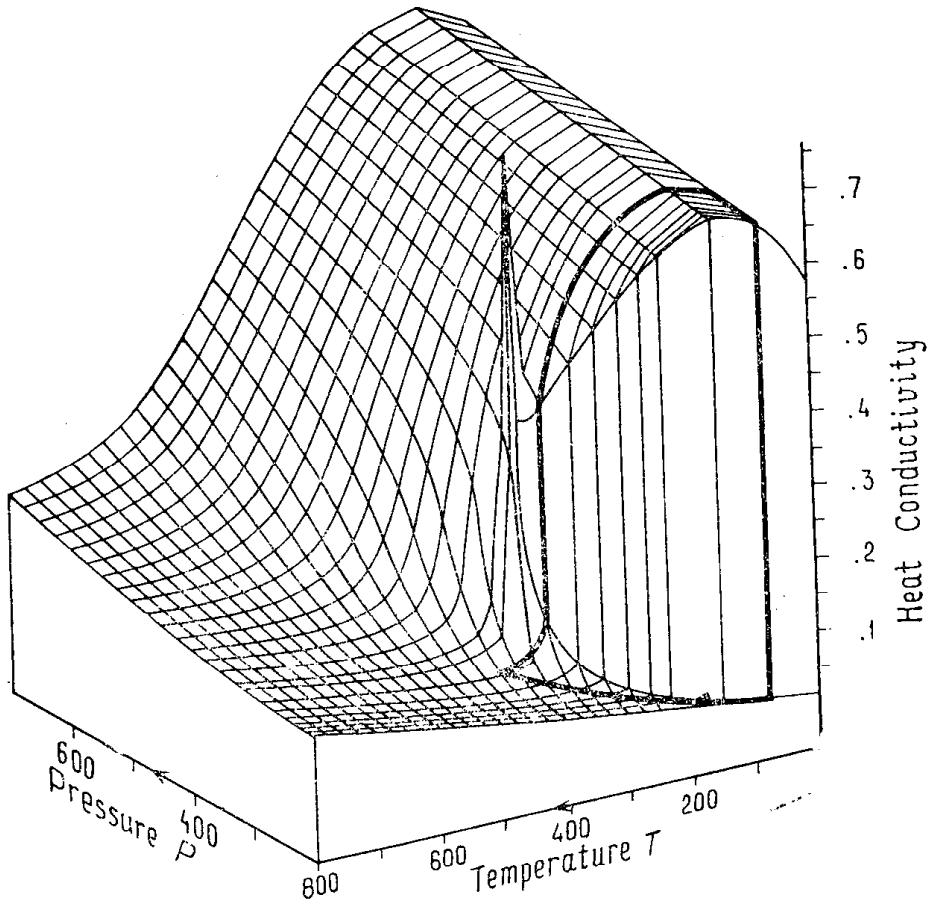


Fig. 14. Thermal conductivity as a function of pressure and temperature

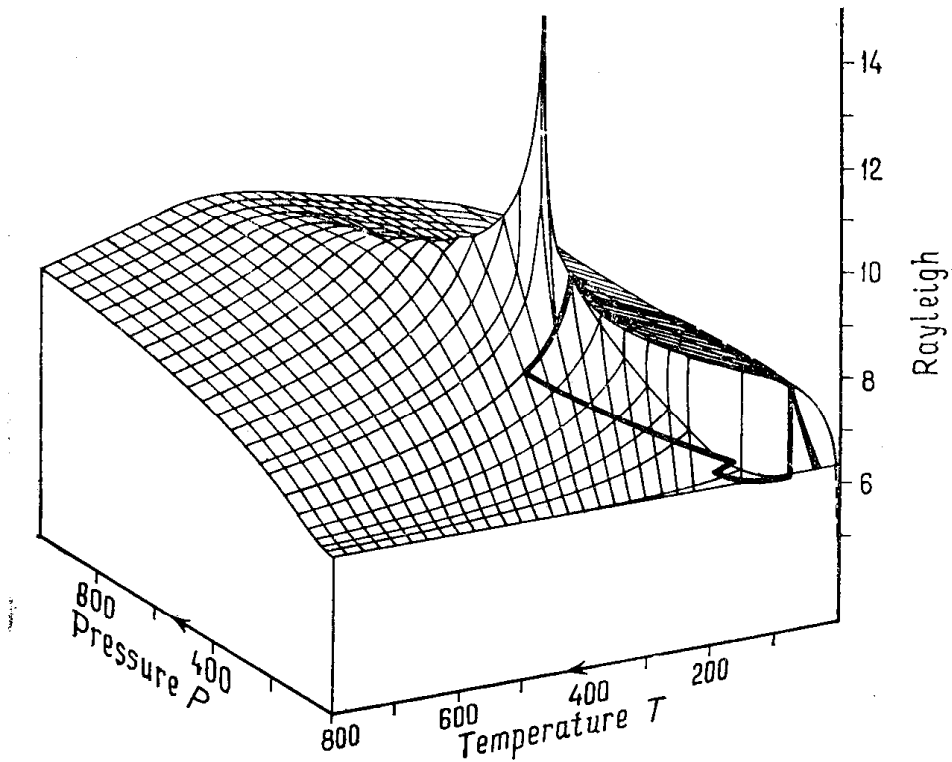


Fig. 15. Rayleigh-number as a function of pressure and temperature

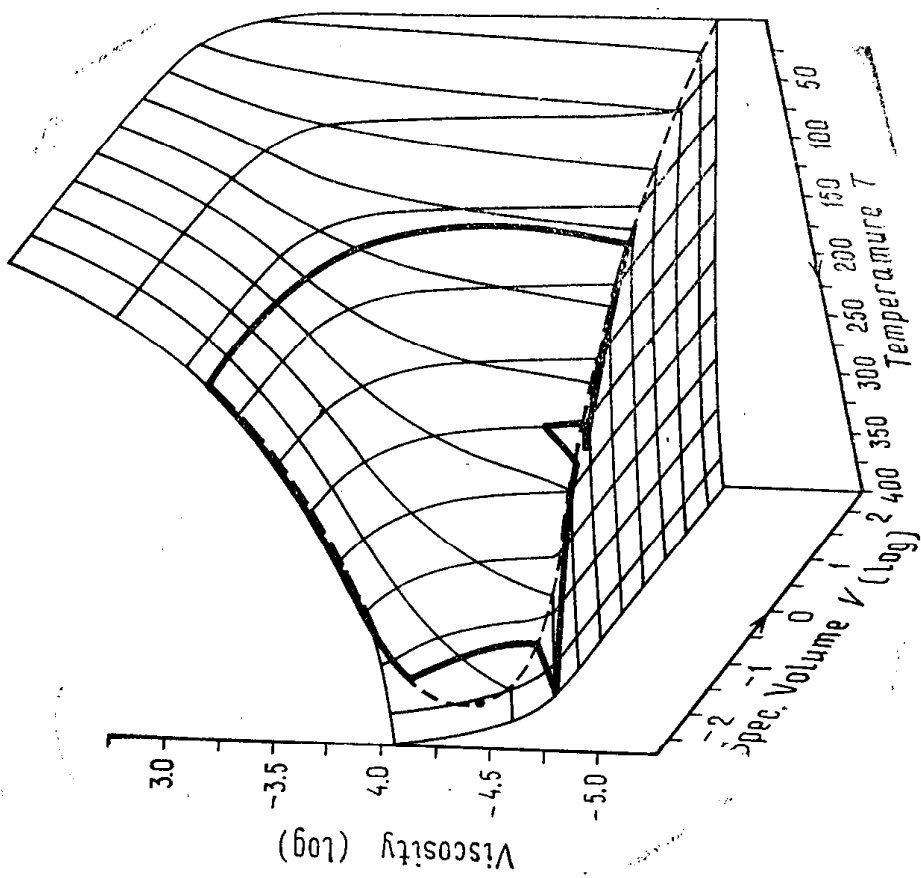


Fig. 16. Viscosity as a function of temperature and specific volume

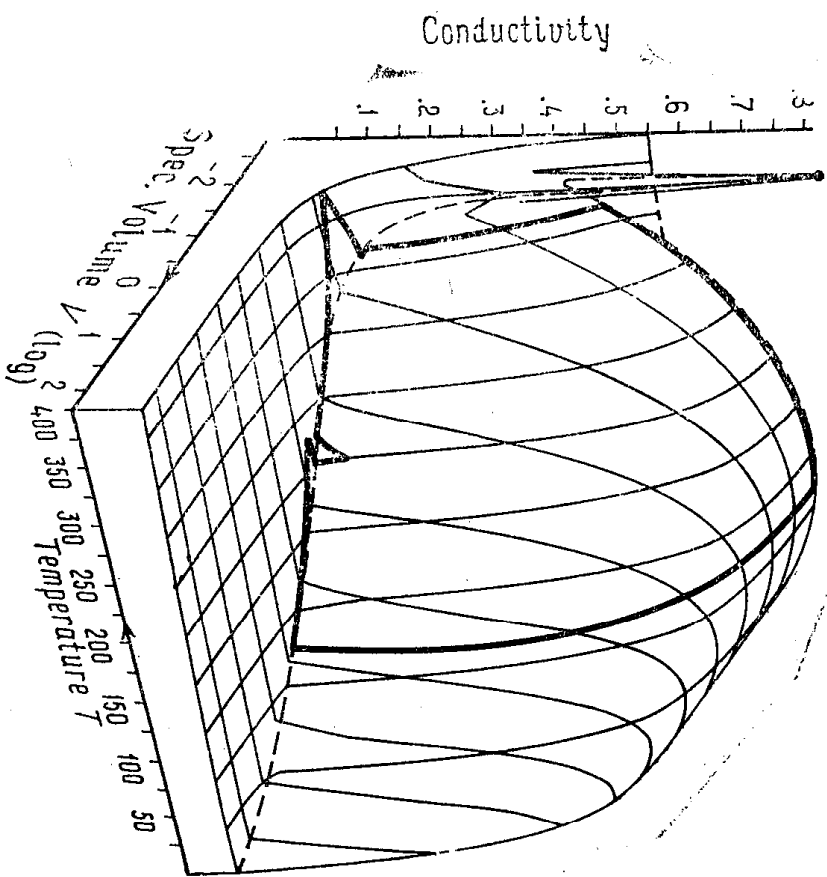


Fig. 17. Thermal conductivity as a function of temperature and specific volume

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