

*CHEMICAL ENGINEERING AND CHEMICAL PROCESS TECHNOLOGY - Transport Properties of Fluids - Konstantinos D. Antoniadis, Marc J. Assael and William A. Wakeham* ©Encyclopedia of Life Support Systems (EOLSS).

Nieto de Castro, W. Wakeham -- Dense fluids. Dymond ; Fluid mixtures at high density: Wakeham ; Fluid mixtures at high densities: Elhassan -- Computer calculation. Assael -- The corresponding-states principle: Uribe -- The corresponding-states principle: Poling -- Pure fluids. Sengers ; Diatomic fluids: Vesovic ; Polyatomic fluids: Millat ; Polar fluids: Dymond ; Polyatomic fluids: Stephan -- Binary mixtures: Hendl -- Reacting mixtures at low density: Nieto de Castro, J. Fareleira -- Data collection and dissemination systems. This book describes the most reliable methods available for evaluating the transport properties, such as viscosity, thermal conductivity and diffusion, of pure gases and fluid mixtures. Particular emphasis is placed on recent theoretical advances in our understanding of fluid transport properties for all temperatures and pressures. This book is a valuable addition to the literature on the transport of fluids, and will undoubtedly be useful to engineers who need to use such data. The volume will be especially useful to specialists in the area of property prediction and correlation. Lienhard, Applied Mechanics Review "This is a comprehensive and up-to-date account of the best methods at present for correlation, prediction and estimation It should find a wide range of users including both those working on the experimental determination and theoretical interpretation of transport properties and also those who need to use information on these properties in technological contexts. Add a review and share your thoughts with other readers.

*"Transport Properties of Fluids provides a thorough overview of current models of fluid transport properties. The volume will be especially useful to specialists in the area of property prediction and correlation."*

A catalytic reactor for the synthesis of methanol. Nieto de Castro Fig. The variation of the design heat-exchange area for the preheater in Figure 2. Subsequently, perturbations have been applied to the transport properties of the gases to examine the effect upon the heat-exchange area  $A$ . On the other hand, if the errors in the two properties were in the opposite sense then the preheater would be underdesigned, leading to a lower feed temperature to the catalytic beds and a subsequent reduction in the efficiency of the overall plant, with an increase in operating costs. For this last reason it is usual to overdesign the heat-transfer equipment and accept a larger capital cost that could be avoided if more accurate values for the transport properties of the fluids were available. In a nuclear reactor the energy produced by the self-sustaining fission of a material such as  $U$  is used to generate heat, which is transferred to a coolant circulating through the reactor. In turn, the heat absorbed by the coolant stream is transferred to a steam generator, which is then used to power a turbine for electricity generation. In the Magnox reactor the coolant is carbon dioxide at a pressure of 2 MPa, which leaves the reactor core at a temperature of K. The reactor core itself is typically 14 m in diameter and 8 m high and is contained in a steel or concrete pressure vessel. The safety of such reactors has, quite naturally, caused considerable public concern, and their design, as well as that of other nuclear installations, is the subject of national legislation and international regulation. In particular, the safety audit for such a reactor must consider the circumstances surrounding the failure of one or more components in the entire plant. A schematic diagram of a Magnox nuclear power plant. Nieto de Castro calculations for the heat-exchange processes, one must consider extreme conditions when, for example, there is a loss of pressure in the coolant cycle or a failure of circulation for some reason. Generally, these latter calculations form a part of the safety case for the installation, and quality assurance then dictates that every single numerical value for a physical property is validated and of an appropriate pedigree. Included in such validated data would be the transport properties of the coolant stream allowing for possible contaminants as a result of a variety of modes of failure. The implication of the need for validated data implies high accuracy and a degree of approval from an appropriate body. It seems likely that owing to the internationalization in the trade of plant designs of all kinds, such international approval will become increasingly important in satisfying the demands of national regulatory bodies for quality assurance. While the essential features of combustion processes are well-understood, the details are still the subject of active research. Indeed there is currently great interest in studies to reduce pollutant formation in combustion systems as well as studies of detonations in the area of safety. The principal feature of any combustion process is the chemical reaction of a fuel with oxygen which releases useful heat. Naturally, therefore, the process is dominated by the reaction kinetics involved, but the transport properties of the fuel and the products of combustion have some significance in its description. To illustrate the significance it is sufficient to consider the burning velocity in a laminar flame. If a quiescent, combustible gas mixture contained in an open tube is ignited by a spark at one end of the tube a combustion wave spreads through the gas. Provided that the tube is not too short the wave spreads at roughly constant speed which is the burning velocity or flame speed. A very simple analysis shows that the burning velocity,  $v$ , is related to the density of the gas,  $\rho$ , and to the reaction rate of the fuel and oxygen,  $r$ , by the equation  $r = 2v\rho$ . The thermal conductivity enters this equation because it controls the rate of heat transport away from the reaction zone while  $C_p$  determines the magnitude of the temperature gradient generated by the heat release in the reaction zone. Very much more detailed analyses of laminar and diffusion flames reveal that diffusion coefficients for the multicomponent mixtures present have an important effect upon the complete set of the products of combustion while even the viscosity of the system Technological Importance 15 can be important. Of course, in a particular combustion system it is not possible to alter the transport properties of the fluid so that data on such properties are of significance in the interpretation of combustion experiments and in modeling processes rather than in design. The most familiar examples are the continuous casting process for steels and the

float-glass process. However, there are more recent developments, such as the production of near-perfect crystals of semiconducting materials, where the degree of perfection of the crystal has a profound effect on the ultimate performance of electronic devices constructed from them. In the improvement of all of these processes a complete understanding of heat transfer by both conduction and convection is essential. Since the governing hydrodynamic equations are well known, the accuracy of models of such processes depends sensitively on, and is currently limited by, our knowledge of the constitutive equations of the molten materials and, in particular, upon the transport coefficients which enter them. Significant advances in the quality and uniformity of a number of materials might be attainable were accurate data for the thermal conductivity and viscosity of molten materials at high temperature available. The preparation of such internationally approved data standards is a timeconsuming and delicate activity that requires a critical evaluation of all the available measurements with a detailed assessment of the accuracy of each individual datum reported. For these reasons, only results obtained in instruments characterized by high quality and a complete working equation based upon a sound theory can be employed for the establishment of standard reference data. Whenever possible the results of measurements made with different experimental techniques should be included. These conditions on the establishment of standard reference data are satisfied by the results for relatively few fluids in the case of transport properties. Examples of cases where the conditions have been satisfied are provided by the standard reference values for the thermal conductivity of three liquids and the transport property correlations for carbon dioxide provided by the International Union of Pure and Applied Chemistry Nieto de Castro et al ; Vesovic et al. Nieto de Castro The absence of standard reference data of this kind for calibration or other purposes can cause some industrial activities to be impaired, legal disputes to arise between organizations and limit the assessment of the quality of measurements made in a relative manner. The effect of errors in the thermophysical properties of fluids upon plant design. Introduction to Nuclear Power. Their Origin and Determination. Nieto de Castro, C. Standard reference data for the thermal conductivity of liquids. An interpretation of intermolecular pair potentials obtained by inversion for non-spherical systems. The transport properties of carbon dioxide. For each pure fluid there are approximately 30 properties which are of technological significance of which twelve are functions of temperature and pressure. If just these twelve properties are considered and it is assumed that measurements at only ten pressures and ten temperatures are required then to provide the necessary information for only one pure fluid requires measurements. If all the pure species and all possible mixtures from among the set of bulk chemicals are included and composition is allowed as a variable then it is rather easy to estimate that, even for a generous estimate of the rate of experimental data acquisition in the world, the total effort required to fulfill the needs identified in Chapter 2 would exceed billion man-years. It is therefore necessary to replace a complete program of measurements by an alternative strategy designed to meet the same objective. The present chapter is, therefore, devoted to the methodology underlying the alternative strategy which the authors of this book believe to be appropriate. The chapter provides a definition of the levels of a hierarchy of correlation, prediction and estimation procedures that seek to generate the physical properties of fluids and their mixtures by means other than direct measurements. These different methods are then expanded in the subsequent sections of the book and examples of their application given. Nieto de Castro and W. Thus, for a particular fluid, a reasonable means to satisfy the need of industry for the transport properties of a fluid over a wide range of conditions is provided by the empirical correlation of available experimental data. In view of the comments made in the previous section this is evidently a route that will only ever be available for a small number of fluids. Moreover, the process of correlating the dependence of the transport property upon the independent state variables is not itself a straightforward one see Chapter 7. However, it should be recognized that although the theory of the transport properties of fluids is not completely developed, it can provide some guidance in the process of correlation. For example, all kinetic theories of transport reveal that it is the temperature and density that are the fundamental state variables and that pressure is of no direct significance. Since most measurements are carried out at specified pressures and not specified densities, this automatically means that a single, uniform equation of state must be used to convert any experimental data to  $p, T$  space from the experimental  $p, T$  space. Furthermore, the dilute-gas kinetic theory reveals a number of relationships between different

properties of a gas that are exact or nearly exact so that these relationships provide consistency tests for experimental data as well as constraints that must be satisfied by the final correlation of the properties. One point of significance in the process of correlation is the recognition that not all experimental values are of equal worth. The field of transport properties is littered with examples of quite erroneous measurements made, in good faith, with instruments whose theory was not completely understood. It is therefore always necessary to separate all of the experimental data collected during a literature search into primary and secondary data by means of a thorough study of each paper. The different contributions to the thermal conductivity of a fluid close to the critical point. Primary data are those to be used in the development of the correlation and they will satisfy the following conditions: Occasionally, experimental data that fail to satisfy these conditions may be included in the primary data set if they are unique in their coverage of a particular region of state and cannot be shown to be inconsistent with theoretical constraints. Their inclusion is encouraged if other measurements made in the same instrument are consistent with independent, nominally more accurate data. Secondary data, excluded by the above conditions, are used for comparison only. In association with the process of data selection an estimate of the accuracy must be made for each set of results on a basis which is independent of that of the original authors. This estimate of uncertainty usually refers to precision and not accuracy, and a statistical weight is then determined for each datum based upon that uncertainty. This process of weighting cannot be exact, and the relative weight among different data sets is the only relevant parameter; the process is important in cases where a number of data sets are available of different precision. Finally, the selected data are fitted to an appropriate functional form using least-squares procedures see Chapter 7. More frequently, the fitting is performed with an equation of fixed form with varying degrees of theoretical support. The fitting may be carried out to the entire body of data at once or to the data in different thermodynamic regions, such as the dilute-gas limit and the critical region, independently. The representations in these separated regions can then be connected through a bridging function for intermediate densities. The latter approach has the advantage that rather more theoretical guidance can be employed in the choice of appropriate functional forms, but it suffers from the defect that it is then necessary to be able to identify unequivocally the various regions of state, which is not simple particularly in the critical region. Completion of a preliminary fit to the data identifies outlying data which must be examined and, if appropriate, discarded. Generally, a satisfactory fit is deemed to have been achieved when all the primary data are reproduced within their estimated uncertainty and the correlation yields properties consistent with theoretical constraints. The estimated uncertainty in the fitted data is then used as a guide to the likely error in the property arising from the use of the correlation. Several examples of the use of this procedure for the transport properties of fluids will be found later in this book. Undoubtedly the most effective substitute for direct measurement of the transport properties of fluids would be a complete, rigorous statistical-mechanical theory that enabled the calculation of the properties of a macroscopic ensemble of molecules from a knowledge of molecular properties and of the forces between the molecules. Indeed, one might perceive this as the ultimate objective of statistical-mechanical theory. The impossibility of carrying through this program at present rests upon the fact that there exists no rigorous, applicable theory of transport properties except in the dilute-gas state, where only pair interaction potentials matter or, asymptotically close to the critical point, where the details of the intermolecular forces are irrelevant and effects depend upon the behavior of large clusters of molecules. Nevertheless, a procedure of this kind is defined as a prediction of the physical properties. It is thus defined because it is possible to evaluate the properties of pure fluids or mixtures without recourse to any measurements of the properties being evaluated. From the comments made above it should be clear that the number of occasions on which this route to properties will be available is exceedingly small. The theory may then be used to allow the available measurements on one property to be used to predict another for which no measurements are available. This may be done either directly through an explicit theoretical relationship between the properties, or through the intermediacy of an intermolecular potential derived from data on one property. In the first case it is unlikely that the temperature range of the prediction can exceed that of the original measurements, whereas in the latter case it is possible that new thermodynamic states may be treated. The scheme is predictive in the sense that no information on the property to be evaluated is required; an

example of such a procedure is the evaluation of the thermal conductivity of monatomic gases from the viscosity, which is discussed in Chapters 4 and 5. A further type of predictive method arises when mixtures are considered. Again, if a complete, rigorous theory for the properties of a fluid containing many components exists it is frequently the case that the mixture properties depend only upon well-defined quantities, characteristic of all of the various binary interactions in the system. In such circumstances, either of the predictive means set out above may be used to evaluate the quantities for each binary interaction, and their combination with theory then leads to values of the property of the multicomponent mixture without the need for data on that property. Such methods generally invoke a physical model of the interactions between the molecules in the system. Perhaps the best known of these methods, as well as that which departs the least from absolute rigor, is the Extended Law of Corresponding States, discussed in detail in Chapter 6. In this procedure, to the rigorous kinetic theory of dilute monatomic gases and gas mixtures is added the hypothesis that the spherical intermolecular pair potentials for interactions among the species can be rendered conformal by a suitable choice of scaling parameters for energy  $\epsilon$  and distance  $a$ . Thus, determinations of the functional form from measurements of a property for a variety of different species mean that the functional can be determined empirically for the complete set of species over a wider range of reduced temperature than can be investigated for any one species.

## Chapter 3 : Transport properties of fluids - PDF Free Download

*This comprehensive book describes the most soundly based methods currently available for evaluating the transport properties, particularly viscosity and thermal conductivity, of pure fluids and fluid mixtures.*

Steam engines with water as the working fluid were at the beginning of the industrial revolution. The rise of electrical energy is connected to hydroelectric and steam power plants. For conservation or for reaching desired properties, water must be removed from substances drying. In other cases water must be added humidification. Also, many chemical reactions take place in hydrous solutions. Thermodynamic, transport and other properties of water are known better than of any other substance. Accurate data are especially needed for the design of equipment in steam power plants boilers, turbines, condensers. Since IFC has been used for "official" calculations such as performance guarantee calculations of power cycles. The equations underlying IFC are published for example in [1]. The formulation is described in a paper by W. Gas Turbines and Power , Vol. The reference values of these constants are as follows. Regions 1, 2 and 5 are covered by fundamental equations for the Gibbs free energy  $g(T, p)$ , region 3 by a fundamental equation for the Helmholtz free energy  $f(T, v)$ . All thermodynamic properties can then be calculated from these fundamental equations by using the appropriate thermodynamic relations. For region 4 a saturation-pressure equation has been developed. In chemical engineering applications mainly regions 1, 2, 4, and to some extent also region 3 are of interest. The range of validity of these regions, the equations for calculating the thermodynamic properties, and references are summarized in Attachment 1. The equations of the high-temperature region 5 should be looked up in the references. For regions 1 and 2 the thermodynamic properties are given as a function of temperature and pressure, for region 3 as a function of temperature and density. For other independent variables an iterative calculation is usually required. So-called backward equations are provided in IAPWS-IF97 which allow direct calculation of properties as a function of some other sets of variables see references. Accuracy of the equations and consistency along the region boundaries are more than sufficient for engineering applications. Details can be found in the references. We have summarized the equations for calculating the transport properties dynamic viscosity and thermal conductivity as well as the surface tension of the interface between the liquid and the vapor phase of water in Attachment 2. IAPWS also gives equations for the static dielectric constant and the refractive index of water which are of less interest in chemical engineering applications. If required these equations can be found in the references [2, 3]. The equations for dynamic viscosity and thermal conductivity are given as a function of temperature and density. The use of density as an independent variable makes it possible to calculate properties of the liquid and vapor phase using one single equation. In most cases, however, temperature and pressure are the independent variables and the density must be determined first from the IAPWS-IF97 equations. Surface tension can be calculated over the whole range where a liquid-vapor interface exists, i. Accuracy of the equations is more than sufficient for engineering applications. Details can be found in the references []. Functions are available for calculating the following properties in the single-phase state for temperatures between

## Chapter 4 : Thermodynamic and Transport Properties of Fluids - G. F. C. Rogers, Yon R. Mayhew - Google

*The fifth edition of Thermodynamic and Transport Properties of Fluids incorporates two new tables: other material is being retained essentially as in the fourth edition, although tables beyond  $p$  will be on different pages.*

## Chapter 5 : Transport phenomena - Wikipedia

*The fifth edition of Thermodynamic and Transport Properties of Fluids incorporates two new tables: other material is being retained essentially as in the fourth edition, although tables beyond  $p$  will be on different pages. The new tables are as follows: Data of Refrigerant a (tetrafluoroethane).*

### Chapter 6 : Thermodynamic and Transport Properties of Fluids : G. F. C. Rogers :

*Transport Properties of Fluids: Their Correlation, Prediction and Estimation Transport Properties of Fluids Transport Properties of Fluids Their Correlation, Prediction and Estimation Edited by J Transport Properties of Foods.*

### Chapter 7 : File: THERMODYNAMIC AND TRANSPORT PROPERTIES OF FLUIDS - PDF

*The accurate computation of the thermodynamic and transport properties of fluids is a necessity for many engineering calculations. The FLUID program was developed to calculate the thermodynamic and transport properties of pure fluids in both the liquid and gas phases.*

### Chapter 8 : Fluid Properties

*Undoubtedly the most effective substitute for direct measurement of the transport properties of fluids would be a complete, rigorous statistical-mechanical theory that enabled the calculation of the properties of a macroscopic ensemble of molecules from a knowledge of molecular properties and of the forces between the molecules.*