book reviews

Correlational Aspects of the Viscosity-Temperature-Pressure Relationship of Lubricating Oils.

(Dr In dissertation at Technical University of Delft, 1966) by C J A Roelands

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THIS extensive work is of considerable importance to the lubrication community yet unfortunately until now has received very limited circulation. Much to the frustration of those who have not seen it, it has been referred to in the literature by the few who were able to get copies when it was first published. Because of the importance of the content and the thoroughness with which the author treats the subject, the ASME Research Committee on Lubrication has made arrangements so it is now readily available

This book is a valuable source book of data, and provides a critical review of correlation studies to the date of its publication Although primarily concerned with natural mineral oils (data on 357 mineral oils from many different researchers both in the U S and Europe), it also covers several groups of pure hydrocarbons, some polymer blended mineral oils, eight important groups of synthetic lubricating fluids (polyphenyl ether, chlorofluoro-carbon, polyglycol, dimethylsiloxanes, diesters, phosphate esters, and silicate esters), thirteen miscellaneous liquids including nine pure compounds (water, mercury, gallium, etc) and several gases All the fluids are included in the temperature-viscosity correlations but, because of lack of data, not all are included in the pressure-viscosity discussions

The object of the investigation was to improve the limited applicability of previous correlations while trying to cast the results into a form that will prove convenient in the theory and practice of hydrodynamic lubrication. The author has dealt almost exclusively with dynamic viscosity rather than kinematic viscosity. The former is more directly involved in hydrodynamic lubrication studies and thereby increases the usefulness of the investigation

The basic experimental data employed in the investigation are reviewed in Chapter II

Chapters III through V aim at describing the effects of temperature and pressure on the viscosity of liquids, notably those currently used as lubricating oils. In Chapter III, a new equation for the isobaric viscosity-temperature relationship is offered It is of wide general applicability, and seems to fairly well represent petroleum oils, nonhydrocarbon synthetics, metal, glass, etc. In detail, it does not give a truly straight line on the proposed generalized chart. The data plots as a slight sigmoid shape if the range is extended. The lower viscosity end of the chart (down to 0 2 cp) gives excessively curved lines for samples such as n-hexane, or jet fuels under operational pressure. Chap-

ter IV develops a new equation for the isothermal variation of viscosity with pressure. These new temperature and pressure equations for viscosity are combined in Chapter V to give a complete viscosity-temperature-pressure relationship

The resulting equations require a minimum of parameters for fully characterizing, in very wide ranges, the effects of temperature and/or pressure on the viscosity of a given liquid. They are shown to combine simplicity with wide applicability. Thus a minimum amount of experimental information is required for making the desired calculations and estimates. Though designed primarily for mineral oils (natural, hydrogenated, and polymer-blended) and various types of synthetic oils encountered in modern lubrication practice, the equations apply equally well to the other liquids investigated. Although both the viscosity-temperature and viscosity-pressure equations are empirically arrived he shows in each case the expressions can be obtained by starting with the Cohen-Turnbull free volume model of the liquid state and applying Weibull's function for describing the statistical distribution of the free volumes of individual molecules of a given liquid

The isothermal pressure-viscosity equation developed is much more accurate when compared to experimental data than the commonly used Barus equation (viscosity is an exponential function of pressure). Relatively few fluids actually follow the Barus expression which plots as a straight line on a log-viscosity versus pressure plot. Many fluids exhibit behavior which gives the isotherms a concave downward shape on such a plot. Roelands' pressure-viscosity equation adequately handles this curvature but does not predict the transition at higher pressure (about 70,000 psi for many mineral oils) where the isotherm has an inflection point and becomes concave upward according to the data of several investigators. This may not be a serious deficiency of the correlation depending on the application. In fact Roelands' correlation is more accurate than the Barus relation even above this inflection point as is seen when considering a dimethylsiloxane which has an inflection point as low as 45,000 psi. Roelands' equation agrees with the data quite well up to about 60,000 psi and even at 80,000 psi predicts a value one half of that measured. Whereas the Barus equation which predicts values higher than those measured, deviates by a factor of two at only 30,000 psi and a factor of five at 80,000 psi

Chapter IV introduces a convenient method for classifying, according to their atmospheric viscosity-temperature relationship, all the various kinds of oils encountered in current lubrication practice. The proposed method uses the "slope index" from the viscosity-temperature equation as a proposed solution to the "viscosity-index problem". In Chapter VII a similar method is presented for classifying lubricating oils according to their viscosity-pressure relationship. The use of a power term "Z" is suggested as a "Pressure Index" for classification. Both classification methods are based on the newly developed equations for the latter relationships

Further, the present equations have proved suitable as an analytical framework for correlations aiming at the prediction of

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the effects of temperature and pressure on the viscosity of liquids, either from their chemical consitutution or from easily assessable physical constants. The relevant correlational attempts have been concentrated upon mineral oils, which, notwithstanding their great variety and complexity, are interrelated in being essentially built up from hydrocarbon compounds.

Chapter VII presents convenient correlations for predicting, to a good approximation, the complete atmospheric viscosity-temperature relationship of mineral oils, either from their chemical constitution—characterized by their carbon-type composition according to the "Waterman analysis" in the form of the so-called n-d-M method—or from physical constants that are easily assessable at atmospheric pressure. In addition to the viscosity grade of the oils—defined as the viscosity at atmospheric pressure and at some standard reference temperature—the resulting correlations only require either their total percentage of carbon atoms in ring structure or one of the following atmospheric physical constants—density, refractive index, or molecular weight.

Chapter IX provides similar correlations for predicting, at any conventional reference temperature, the complete viscosity-pressure relationship of mineral oils. The correlations established employ, viscosity grade of the oils, either their total percentage of carbon atoms in ring structure or their atmospheric density and/or refractive index.

Finally, Chapter X discusses the direct correlation between the viscosity-pressure relationship of mineral oils and their atmospheric viscosity-temperature relationship. The significant conclusion has emerged that the complete family of viscosity-pressure isotherms of all the various kinds of mineral oils considered can indeed be predicted, to a good approximation, solely from their atmospheric viscosity-temperature isobars. The relevant correlation is unique in that it does not involve, in contradistinction to the aforementioned correlations, any additional physical or chemical data.

The correlations developed for mineral oils become substantially simplified when adapted to any particular homologous group of synthetic lubricating oils or pure compounds because of the well-known regularities observed within each such group. This has been demonstrated for various interesting homologous groups of synthetic lubricating oils included.

Chapter XI touches upon certain basic problems in the field of oil viscosities in being devoted to the correlation of viscosity grade of mineral oils and pure hydrocarbon both with their chemical constitution and with various easily assessable physical constants. Starting from a newly developed additive viscosity-density function, various significant correlations could be achieved. More particularly, these correlations have proved to permit a reliable statistical constitution analysis of the very complex mixtures represented by mineral oils.

Chapter XII introduces convenient methods—based on the viscosity-temperature equation developed in Chapter III—for predicting the viscosity grade as well as the complete atmospheric

viscosity temperature relationship of mixtures of mineral oils solely from those of the components. A worthwhile discussion is given on the comparison of previous methods of predicting viscosities of oil blends.

The concluding Chapter XIII elaborates several applications of the present findings in hydrodynamic lubrication, special attention being devoted to the isothermal viscosity-pressure effect which should be of interest to researchers in elastohydrodynamic lubrication. Because he has shown in Chapter X that the viscosity-pressure variation of mineral oils is correlated quantitatively with their atmospheric viscosity-temperature variation, he suggests that in problems where both the temperature and pressure variation of viscosity of mineral oils effect the hydrodynamic lubrication performance it cannot be unambiguously concluded which parts are played by the temperature and pressure variations. In other words, from the combined effects measured on the film profile or on the traction the influence on one variation cannot be separated experimentally from that of the other.

In Chapter XIII Roelands also discussed the importance of the asymptotic isoviscous pressure obtained from Weibulls' transformation, $P_{iv\ as} = \int_0^\infty \eta_0/\eta_{(p)}\ dP$. This is the pressure predicted in isoviscous hydrodynamic lubrication theory at which the actual pressure in a fluid for which the viscosity varies with pressure will tend to infinity. Blok and Roelands suggest that in elastohydrodynamic lubrication the reciprocal of $P_{iv\ as}$ should be used rather than the pressure-viscosity coefficient from the Barus equation which is currently used. Roelands also gives a table for determining the asymptotic isoviscous pressure given the atmospheric viscosity and the pressure-viscosity index used in Roeland's correlation.

In summary we believe the work is a significant contribution to the field of lubrication and belongs in the library of every serious lubrication research person or lubrication design engineer.

The book is now available ($20) in limited supply from the author

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