

# Thermophysical Properties Measurements of Rocket Propellants RP-1 and RP-2

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**The density, speed of sound, and viscosity of two rocket propellants (RP-1 and RP-2) have been measured. Densities were measured with two different instruments. Data at ambient atmospheric pressure were obtained with a rapid characterization instrument from 278.15 to 343.15 K that measured the speed of sound and density of the liquids in parallel. Adiabatic compressibilities derived from that data are included here. Densities of the compressed liquids were measured in an automated apparatus from 270 to 470 K and pressures to 40 MPa. Viscosities of the two liquids were measured in an open gravitational capillary viscometer at ambient atmospheric pressure from 293.15 to 373.15 K. The measurement results are consistent with compositional differences between the two samples. Correlations have been developed to represent the measured properties within the estimated uncertainties of the experimental data and to allow physically meaningful extrapolations beyond the range of the measurements.**

## Nomenclature

$C$	=	viscometer calibration constant
$E$	=	viscometer calibration constant
$p$	=	pressure
$p_{\text{ref}}$	=	reference pressure, 0.083 MPa
$T$	=	temperature
$T_r$	=	reduced temperature, $T/273.15$ K
$t$	=	efflux time
$V$	=	volume
$w$	=	speed of sound
$\alpha_p$	=	isobaric thermal expansivity
$\beta_i$	=	correlation coefficients
$\eta$	=	dynamic viscosity
$\kappa_s$	=	adiabatic compressibility at constant entropy
$\rho$	=	density
$\nu$	=	kinematic viscosity

## Introduction

EQUATIONS of state that accurately predict thermodynamic properties of fluids are often used to aid in the design of combustion machinery. These types of equations are the backbone of fluid properties databases such as the National Institute of Standards and Technology (NIST) software Reference Fluid Thermodynamic and Transport Properties (REFPROP) [1]. The formulation of accurate equations of state requires accurate thermophysical property data, in particular density and speed of sound over wide ranges of temperature and pressure. This is especially true when working with complex mixtures. Such data are presented here for the two rocket propellants RP-1 and RP-2. They were obtained using three different instruments to measure density, speed of sound, and viscosity at atmospheric pressure, and compressed liquid density in the combined range from 270 to 470 K with pressures to 40 MPa.

The measurements reported here were part of a larger effort at NIST to characterize two hydrocarbon rocket propellants, RP-1 and

RP-2. The studies were undertaken to provide the United States Air Force with the information and tools necessary to design new rocket propellants that would facilitate the ability to use rocket motors multiple times. This requirement dictates that the fuel be very low in sulfur components, aromatics, and alkenes. RP-1 is considered the traditional hydrocarbon rocket propellant, and is a kerosenelike, complex mixture which typically includes linear and branched paraffins, alkenes, and aromatics [2,3]. The RP-2 sample studied in this work was a reformulated grade of hydrocarbon rocket propellant. Properties investigated in this effort included distillation curves, thermal decomposition products, and thermophysical equilibrium and transport properties. These measurements facilitated the correlation of equations of state for each of the fluids, the ultimate tool to aid in efficient and effective design of advanced rocket engines.

## Test Samples

RP-1 and RP-2 samples were provided by the Fuels Branch of the United States Air Force Research Laboratory, Wright-Patterson Air Force Base, Ohio. Their compositions were analyzed at NIST with a gas chromatography, mass spectrometry, infrared spectrometry method [3], and compounds having chromatographic peak area counts in excess of 1% were reported. The differences between the two samples can be summarized as follows: the RP-1 sample contained alkanes up to C<sub>14</sub> (methyltridecane isomers) and approximately 1% (peak area) aromatic hydrocarbons (1-methylnaphthalene), whereas the RP-2 sample contained alkanes up to C<sub>16</sub> (hexadecane) and no reported aromatic hydrocarbons. Other major differences between the RP-1 and RP-2 samples include the fact that RP-2 contained less sulfur, whereas RP-1 contained a pink dye additive.

The composition of the RP-1 sample was detailed in the publication of Bruno and Smith [3]. The critical temperatures of the RP-1 constituents as listed in the NIST Chemistry WebBook [4] range from 639 K for n-decane to 772 K for 1-methylnaphthalene. This temperature range provides a rough estimate for the critical temperature of the RP-1 mixture.

The composition of the RP-2 sample is specified in the report of Ott et al. [5]. The content of different aromatic compounds and the higher content of alkanes in RP-2 results in a significantly different upper limit of the critical temperature and is given by the critical temperature of hexadecane at 722 K. Thus, a lower critical temperature is expected for RP-2 than for RP-1. The RP-2 sample contained a significantly higher fraction of larger alkane molecules

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