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Density and viscosity of propylene glycol at high temperatures and high pressures

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ABSTRACT

The density and viscosity of propylene glycol have been simultaneously measured over the temperature range from (298–452) K and at pressures up to 245 MPa using a combined method of hydrostatic weighing and falling-body techniques, respectively. The combined expanded uncertainty of the density, pressure, temperature, and viscosity measurements at the 95% confidence level with a coverage factor of $k = 2$ is estimated to be (0.15–0.30) %, 0.05%, 0.02 K, and (1.5–2.0) %, respectively. The measured high-temperature and high-pressure *PVT* data for propylene glycol were used to develop theoretically based Tait-type equation of state (EOS). The measured viscosities were used to develop theoretically based viscosity correlation models (Arrhenius-Andrade and VFT type models) with the pressure dependent parameters.

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1. Introduction

A new experimental apparatus [1] for simultaneously measurements of the density and viscosity of liquids and liquid mixtures at high temperatures (from room temperature to 500 K) and at high pressures (up to 250 MPa) was used to accurate measurements of the density and viscosity of propylene glycol. The method is based on combining of two well-known techniques for density (hydrostatic weighing) and viscosity (falling-body)measurements for liquids. Both techniques were combined into the same measuring cell [1]. The details of the construction of the measuring cell, procedure of measurements, and the uncertainty assessment has been detailed described in our previous publication [1]. The method and apparatus was tested and successfully used to accurate measure of the density and viscosity series of pure liquids and liquid mixtures at high temperatures and high pressures [2–9]. In this work we used the same technique and apparatus, without modification, to measure the density and viscosity of propylene glycol at high temperatures from (298–452) K and at high pressures (up to 245 MPa). The measured high-pressure and high-temperature *PVT* data were used to develop theoretically based Tait-type equation of state (EOS). Also we have developed Arrhenius-Andrade and VFT type theoretically based viscosity correlation model for propylene glycol with pressure depending parameters. The present results are considerably extending the available thermodynamic and transport property database for propylene glycol. This work is a part of a continuing program on the thermodynamic and transport property study of working fluids and fluid mixtures at high temperatures and high pressures.

A survey of the literature reveals that there are very limited data on density of propylene glycol at high temperatures and high pressures. The literature search was based on the TRC/NIST archive [10]. No reported data were found in the literature for the viscosity of propylene glycol under pressure. All previous reported measurements of the viscosity of propylene glycol were made at atmospheric pressure (see below). This work is the first report of viscosity measurements for propylene glycol under high pressures. Existing data cover only limiting range of temperature and pressure, and contain large uncertainties and inconsistencies. Tables 1 and 2 summarize the experimental measurements of the density [11–29] and viscosity [12,13,16,17,19–22,24,25,27–32] of liquid propylene glycol reported in the literature. 100 data sources were

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Table 1
Density measurements of propylene glycol (selected sources).

First author	Purity	Year	Method[a]	Uncertainty/ (% or kg·m^{-3})	Temperature range/K	Pressure range/MPa
Propylene glycol						
Bridgman [28]	NA	1932	PDM	0.25%	273–368	49–1177
Hamann [11]	99.0	1971	NA	NA	303	up to 100
Idriss-Ali [12]	98.0	1984	PYC	NA	298–358	0.101
Saleh [13]	99.0	1999	PYC	NA	303–323	0.101
Geyer [14]	99.0	2001	VTD	7×10^{-2} kg·m^{-3}	278–318	0.101
Geyer [15]	99.0	2001	VTD	(0.07 ± 0.21) kg·m^{-3}	288–308	60
George [16]	99.5	2003	VTD	1.7×10^{-2} kg·m^{-3}	298–338	0.101
Sun [17]	99.5	2004	PYC	0.2%	299–440	0.101
Zorębski [18]	99.5	2008	VTD, SS	5×10^{-2} kg·m^{-3}	293–313	up to 100[b]
Parsa [19]	99.0	2008	VTD	1×10^{-2} kg m^{-3}	293–323	0.101
Tsai [20]	99.0	2009	PYC	0.05%	303–343	0.101
Guignon [21]	99.5	2010	VTD, VVP	7.6×10^{-2} kg·m^{-3}	288	up to 349
Bajić [22,23]	99.5	2013	VTD	3×10^{-2} kg·m^{-3}	288–323	0.101
Kijevcanin [24]	99.5	2013	VTD	5×10^{-3} kg·m^{-3}	293–303	0.101
Zarei [25]	99.5	2013	VTD	1×10^{-2} kg·m^{-3}	293–333	0.101
Atilhan [26]	99.99	2013	VTD	1.2×10^{0} kg·m^{-3}	278–358	up to 60
Živković [27]	99.5	2014	VTD	2×10^{-2} kg·m^{-3}	288–323	0.101
Khattab [29]	NA	2017	30PXDM	1×10^{-2} kg·m^{-3}	293–323	0.101
This work	99.8	2017	HW	0.15–0.30%	293–452	up to 245

[a] VTD-vibrating tube densimeter; PYC –pycnometer; VVP–variable-volume piezometer; HW- hydrostatic weighing; 30PXDM- Portable Density Meter; SS-from speed of sound measurements; PDM –piston displacement method (Sylphon method).
[b] Calculated from acoustic measurements at high pressures.

Table 2
Viscosity measurements of propylene glycol.

First author	Purity	Year	Method[a]	Uncertainty/ (% or mPa·s)	Temperature range/K	Pressure range/MPa
Propylene glycol						
Thomas [30]	NA	1979	CV	0.5–3.0%	263–338	0.101
Idriss-Ali [12]	98.0	1984	CZ	NA	298–358	0.101
Saleh [13]	99.0	1999	OV	NA	303–323	0.101
Jadzyn [31]	99.5	2002	HV RV20	1.0%	284–302	0.101
George [16]	99.5	2003	UV	1×10^{-3} mPa·s	298–338	0.101
Sun [17]	99.5	2004	CV	2.0%	297–421	0.101
Nain [32]	99.3	2008	UV	5×10^{-3} mPa·s	293–318	0.101
Parsa [19]	99.0	2008	UV	NA	293–323	0.101
Tsai [20]	99.0	2009	CFRV	1.0%	303–343	0.101
Bajić [21,22]	99.5	2013	SV	0.4%	288–323	0.101
Kijevcanin [24]	99.5	2013	SV	3×10^{-3} mPa·s	298–313	0.101
Zarei [25]	99.5	2013	UV	NA	293–333	0.101
Živković [27]	99.5	2014	SV	0.8%	288–323	0.101
Khattab [29]	NA	2017	OV	1×10^{-3} mPa·s	293–323	0.101
This work	99.8	2017	FRB	1.5–2.0%	293–452	up to 245

[a] FRB-falling or rolling body; CFRV-Cannon-Fenske Routine Viscometer; UV-Ubbelohde viscometer; SV-Stabinger viscometer; CZ-Canon Zhukov viscometer 50 Z124; CV-capillary viscometer; OV- Ostwald viscometers.

found in the NIST SOURCED Data Archive for the density of propylene glycol at atmospheric pressure. In Table 1 are listed only 15 selected data sources for the density. Only 6 data sets for the high –pressure *PVT* data were found in the TRC/NIST Database for propylene glycol. 27 data sources were also found for the viscosity of propylene glycol at atmospheric pressure in TRC/NIST archive. Only selected 16 of them are listed in Table 2. No reported viscosity data of propylene glycol under pressure were found in the literature. Reported density measurements at atmospheric pressure [11–29] are cover temperature range from (278–440) K, while at high pressures [11,15,18,21,26,28] the measurements were made in the low temperature range (from 273 to 368) K only. Most reported density data at atmospheric pressure [14–16,18–27] were measured using VTD technique with an typical uncertainty of from $(1–7) \times 10^{-2}$ kg m^{-3} (or within 0.006–0.01%). Pycnometric method of measurements were used in the works [12,13,17,20] with typical uncertainty of (0.01–0.2) %. Most reported viscosity data of propylene glycol at atmospheric pressure were made using capillary method (see Table 2) with an uncertainty of from (0.4–2.0) %. There are only six density data sources [11,15,18,21,26,28] for propylene glycol in the liquid phase at high pressures (up to 100 MPa, except the data reported by Bridgman [28], up to 1177 MPa). High-pressure density data reported in Ref. [18] were derived by indirect (speed of sound) measurements. The temperature range of high-pressure density measurements is cover from (278–358) K. Uncertainty of the high-pressure density data is within from (0.02–0.10) %, except the data reported by Bridgman (uncertainty of 0.25%). High pressure density measurements (up to 349 MPa) by Guignon [21] were performed only at one temperature of 288 K. There are some data sources [10,11,18,20] where the authors reported densities and other derived thermodynamic properties of liquid propylene glycol, such as isothermal and isobaric thermal expansion, isothermal

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