Fuel 216 (2018) 870–889

Contents lists available at ScienceDirect

Fuel

journal homepage: www.elsevier.com/locate/fuel

Full Length Article

Thermophysical properties of Diesel fuel over a wide range of temperatures and pressures

Javid Safarov[a,b,*], Ulkar Ashurova[c], Bahruz Ahmadov[d], Elshan Abdullayev[b], Astan Shahverdiyev[b], Egon Hassel[a]

[a] Lehrstuhl für Technische Thermodynamik, Universität Rostock, Germany
[b] Department of Heat Energy, Azerbaijan Technical University, Baku, Azerbaijan
[c] Department of Power Engineering, Mingachevir State University, Azerbaijan
[d] Department of Engineering Drawing, Baku, Azerbaijan

ARTICLE INFO

Keywords:
Diesel fuel
Density
Vapor pressure
Heat capacity
Viscosity
Speed of sound
Equation of state
High pressure
High temperature
Thermal properties
Caloric properties

ABSTRACT

(p,ρ,T) data of two different Diesel fuel samples (Hallen DK B0) over a wide range of temperatures and pressures p up to 200 Pa [Hallen DK B0 from 2015 year (B0 2015) over a wide range of temperatures at T = (263.15 to 468.48) K and from 2016 year (B0 2016) at T = (263.15 to 468.40) K] are reported. The experimental measurements of Diesel fuel properties at high pressures and wide range of temperatures is of increasing interest in engine fuel injection. The measurements were carried out with an Anton Paar DMA HPM vibration tube densimeter. An equation of state (EOS) for fitting of the (p,ρ,T) data of Diesel fuels has been developed as a function of pressure and temperature. After a thorough analysis of literature values and validity of the constructed equation of state, various thermophysical properties such as isothermal compressibility, isobaric thermal expansibility, differences in isobaric and isochoric heat capacities, thermal pressure coefficient, internal pressure at temperatures [T = (263.15 to 468.48) K] and pressures p up to 200 Pa were calculated. The vapor pressure measurements of Diesel fuels were measured using the two high-accuracy static experimental set ups.

Additionally, heat capacity, viscosity and speed of sound of diesel fuels at ambient pressure p = 0.1 MPa and various temperature intervals were measured using an accuracy installations. Other thermophysical properties, like specific heat capacities at constant pressure $c_p(p,T)$ and volume $c_v(p,T)$, speed of sound $u(p,T)$ and isentropic expansibility $\kappa_s(p,T)$ at temperatures T = (263.15 to 468.48) K and pressures p up to 200 MPa have been evaluated.

1. Introduction

Diesel fuel is belong to light non-aqueous phase liquids (LNAPLs), is organic liquid such as gasoline and other petroleum hydrocarbon products. This group of liquids have no solubility in water and their density also smaller than water. Internal combustion engines driven with Diesel fuel are attractive in comparison to gasoline driven engines, because of relative low carbon-dioxide (CO_2) emissions, high power and reliable functionality. Engineering and environmental challenges with Diesel engines are the amount of emissions from the engines as acoustic noise, and gases like nitrogen oxides (NO_X), carbon monoxide (CO), unburned hydrocarbons (HC), soot and nanoparticles, and of course CO_2 emissions, the latter contributing to the climate warming experienced worldwide.

The legislation and public demands for lower emissions of noise and the above mentioned gases and particles from Diesel engine are currently politically very actual. It should be mentioned that the CO_2 emissions from human technologies are contributing for the so-called global warming and climate change, which today are in political focus worldwide.

The properties and performance of Diesel engines is close depending from the injection system design. The most notable advances achieved in Diesel engines resulted directly from superior fuel injection system designs. Because, the main purpose of the system is to supply the cylinders of a engine with fuel, the main actual problem is the fuel delivery process into cylinder and all changes in the engine performance, emissions, and noise characteristics. The stringent emission standards require advanced Diesel engines technology with improvement of the primary injection and combustion processes within the engine combustion chamber. One important development successfully applied to meet the stringent legal requirements for emissions of Diesel engine is the use of a common rail for fuel injection into the primary combustion

* Corresponding author at: Lehrstuhl für Technische Thermodynamik, Universität Rostock, Albert-Einstein-Str. 2, D-18059 Rostock, Germany.
E-mail address: javid.safarov@uni-rostock.de (J. Safarov).

https://doi.org/10.1016/j.fuel.2017.11.125
Received 17 August 2017; Received in revised form 10 October 2017; Accepted 28 November 2017

Nomenclature

List of symbols

B_T	isothermal bulk modulus
B_S	isentropic bulk modulus
c_p	Isobaric heat capacity
c_v	Isochoric heat capacity
p	Absolute pressure
p_{int}	Internal pressure
T	Absolute temperature
u	speed of sound

Greek letters

α_p	Isobaric thermal expansibility
γ	Thermal pressure coefficient
κ_s	Isentropic expansibility
κ_T	Isothermal compressibility
ρ	Density

chamber. This type of fuel supply uses a single fuel pump to feed fuel to a manifold, aka common rail from which the fuel is fed to the fuel injectors for each cylinder in the Diesel engine.

Injection rate shaping controlled by the engine management systems is another rather modern development found in many current diesel engines. The Diesel fuel injection system delivers fuel under extremely high injection pressures. Current fuel injection systems of compression-diesel engines reach pressures up to 200 MPa for transport systems. It is expected that in near future we will see injection systems with pressures up to 400 MPa in passenger cars. Rate shaping means, that the number of injections per cycle can be varied and the time duration of one single injection process can be changed. During such high pressure injection, fuel must be injected at the proper time, that is, the injection timing must be controlled and the correct amount of fuel must be delivered to meet power requirement, that is, injection metering must be controlled.

In this case, the system component designs and materials should be selected be carefully to higher stresses in order to perform for extended durations of the engine's. Upon injection of the fuel in a cylinder, large depressurization of the fuel results in a significant change of the thermophysical properties of the fluid. Because, upon injection of the fuel in a cylinder, large depressurization of the fuel results in a significant change of the thermophysical properties of the fluid. The differences in physical properties of fuels could change the injection mechanism, the fuel spray behavior, the combustion performance and consequently have an effect on pollutant emissions [1]. The most important injection parameters, which depend on the physical properties of the fuel, such as distillation range, cloud point, pour point, sulfur content, fuel stability, etc, are the inlet fuel pressure to the injector and the rate of injection which determine the spray penetration and atomization and finally the vaporization [2]. For optimal design of diesel engine combustion and high pressure fuel injection process with fuel mixtures concerning understanding, modeling and optimizing spray formation, vaporization, combustion and pollutant formation an accurate knowledge of basic fuel thermophysical properties, like density, vapor pressure, viscosity, speed of sound, surface tension, heat capacity, bulk modulus, etc. as a function of pressure, temperature and composition, is required [3]. Density, speed of sound and isentropic compressibilities have a strong influence on the injection process. Density is the main property that influences the conversion of volume flow rate into mass flow rate. Concerning the density influence, results reported by [4,5] concluded that fuels with higher density have little higher mass flow rate for the same injection conditions, so, the mass quantity in the combustion chamber would be higher [6].

The fluid properties depend on important state parameters such as pressure and temperature. In a Diesel engine the operating points involve strong pressure fluctuations and a wide range of temperatures, so it is expected that the fluid properties could change in terms of these two parameters [6]. The high pressure – high temperature thermophysical properties of Diesel fuel investigated by various research groups, but not in wide range of these state parameters. In the present times there are few installations to produce the thermophysical properties of fluids in extreme high pressures. There are some high pressure and wide range of temperature Diesel thermophysical properties investigated by various researchers [6–13]. Payri et al. [6] measured the speed of sound of winter Diesel sample of Spain in wide range of temperatures T = (298 to 343) K and pressures p = (15 to 180) MPa. The compressibility and density of sample were calculated using the thermodynamic relations. The other speed of sound measurements of biodiesel fuel at pressures up to p = 35 MPa using an ultrasonic pulse echo technique was presented by Tat et al. [7]. The isentropic bulk modulus was calculated from the measured density and speed of sound values. Boehman et al. [9] measured volume difference of ExxonMobil and BP Diesel fuel samples at pressures up to p = 27.6 MPa using a high pressure viscometer and calculated compressibility and bulk modulus. Kegl [10–11] investigated the density and speed of sound of various biodiesels: D2, B100 and their blends. The density of samples at ambient pressure was investigated using the vibration tube densimeter. The measurement of sound velocity in fuels and blends were carried out using the principle of pressure wave propagation on a specified length of the high pressure (HP) tube, instrumented by two piezoelectric based pressure transducers. Using the experimental results and the numerically determined dependencies, the density at pressures up to 40 MPa, temperatures at T = (253.15 to 313.15) K and the bulk modulus of elasticity was calculated. Schaschke et al. [13] reported the viscosity and density of various diesel fuels, obtained from British refineries, at elevated pressures up to 500 MPa and temperatures in the range T = (298 to 373) K using a thermostatically-controlled falling sinker-type high pressure viscometer and a micro-pVT device. There are also various literature works, dedicated to the thermophysical properties of different Diesel fuel samples in the small temperature or pressure intervals.

Analysis of the above discussed literature thermophysical properties of Diesel fuels shows the necessity of careful experimental (p,ρ,T) measurement of Diesel fuels at the wide range of temperature very high pressures and derived the thermophysical properties.

This work is a continuation of our investigations in the field of analysis of thermophysical properties of liquids at high pressures and over a wide range of temperatures [14–16]. The (p,ρ,T) properties of two different Diesel B0 fuel samples ("Winterdiesel", Shell Company, Sample description DK5037) - Hallen DK B0 from 2015 (B0 2015) and 2016 years (B0 2016) over a wide range of temperatures T = (263.15 to 468.48) K and pressures up to p = 200 MPa were studied using a high quality vibration tube densimeter method.

The calculation of the thermophysical properties [isothermal compressibility $\kappa_T(p,T)$, isobaric thermal expansibility $\alpha_p(p,T)$, thermal pressure coefficient $\gamma(p,T)$, internal pressure $p_{int}(p,T)$, specific heat capacities $c_p(p,T)$ and $c_v(p,T)$, speed of sound $u(p,T)$, isentropic expansibility $\kappa_s(p,T)$] were calculated at these high pressures and over a wide range of temperature, in which the density of Diesel fuels was studied. For such investigations very quality density values at high pressures and over a wide range of temperature, and also the heat capacity $c_p(p_0,T)$ of Diesel fuels at ambient pressure and over a wide range of temperatures are necessary.

The Diesel fuel is not pure chemical sample (is include various chemical compounds or bonding). The fuel sources in the various