Article

Temperature Dependence of Density and Viscosity of Biobutanol-Gasoline Blends

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Featured Application: The results are applicable in industrial practice. The models with the coefficients could be used to set a car control unit, which would be able to evaluate the exact amount of fuel needed for injection into the combustion chamber according to the current concentration of the biobutanol in the gasoline and current temperature of the fuel, because, as this paper stated, these can affect the fuel volumetric mass density and the dynamic/kinematic viscosity.

Abstract: Butanol seems to be an eligible fuel for compensating for the increasing fuel consumption. Biobutanol could be produced from local sources in the place of use. Its properties show similar results to gasoline, so biobutanol could be added as a biocomponent into fuels. Important properties, in the case of blending biobutanol into gasoline, are its fluid properties and their dependence on the temperature. Therefore, in this paper, the volumetric mass density and viscosity of the selected ratios between biobutanol and gasoline (0, 5, 10, 85, 100 vol.%) were tested over the temperature range from -10°C up to 40°C . Gasolines with a 95 Research Octane Number (RON 95) and with a 98 Research Octane Number (RON 98) were used. It was observed that as the temperature increased, the viscosity and volumetric mass density of the samples decreased nonlinearly. Four mathematical models were used for modelling the viscosity. The accuracy of models was evaluated and compared according to the coefficient of determination R^2 and sum of squared estimate of errors (SSE). The results show that blends with 5 vol.% and 10 vol.% of biobutanol promise very similar fluid properties to pure gasoline. In contrast, a blend with 85 vol.% of biobutanol shows different fluid properties from gasoline, especially in negative temperatures, a lot. For practical applications, mathematical polynomial multivariate models were created. Using these models, three-dimensional graphs were constructed.

Keywords: biobutanol; gasoline; viscosity; density; low temperature; mathematical model

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1. Introduction

In the current consumer society, characterised by an increase in the population, a corresponding increase in the consumption of resources, especially fuels, are required. Unless significant changes are made in the energy sector, fuel needs could increase up to 48% from 2012 to 2040 [1]. Furthermore, it is assumed that by 2030 fossil fuels will become the most expensive energy source. With consideration to the depleting oil resources, market volatility, greenhouse gas (GHG) emissions and required mitigation strategies, and the environmentally unfriendly character of processing crude oils, it would be appropriate to develop other ecological and sustainable sources [2]. Another successful approach is the in situ gasoline upgrade into strong anti-knocking alcohol mixtures [3]. Therefore, many studies have been concentrated on this topic nowadays in order to find suitable renewable sources that can replace or supplement fossil fuels, e.g., [4–6].

A promising solution seems to be the processing of biofuels. Two of the main advantages of using biofuels is its good availability and the abundance of local raw materials for production—directly at the place of consumption. Biofuels can replace petroleum fuels mainly in the transportation sector and, in many cases, without the replacement of the existing powertrain design. Of the various biofuels, biobutanol (especially produced from lignocellulosic raw materials [7]) seems to be one of the most appealing because biobutanol has attractive properties such as a higher heating value/specific energy, cetane number, hydrophobicity, and low vapour pressure [8,9]. Furthermore, it is less corrosive and volatile [10]. Currently, in the US and Europe, biofuels are blended with commonly used fuels, referred to as E5, E7, and E10 per Directive 2008/50/EC in Europe. The former and latter express the type of fuel used as the bio-component (bioethanol or fatty acid methyl ester, respectively) as well as the quantity of the biofuel (5, 7, or 10 vol.%, respectively) that have been incorporated into the fossil fuel. Biobutanol can be produced similarly to bioethanol by fermentation of the directly fermentable simple sugars, called the ABE (Acetone-Butanol-Ethanol) process under the action of the microorganism (*Clostridium acetobutylicum*) [11]. Starch crops (cereals, maize, and potatoes) and molasses from the sugar cane or sugar beet are the traditional raw materials used to produce biobutanol [12,13]. On the other hand, microalgae strains are also gaining attention as an advanced energy feedstock for biofuel production [14,15]. Due to the similar properties to common use fuels, it is possible to add larger amounts of biobutanol into a fuel, which would result in a bigger fossil fuel savings. Although many science papers have been published about biobutanol as a promising biofuel, (e.g., [16–18]) only a couple of them have investigated the temperature effect on the rheological properties (kinematic and dynamic viscosity) of the fuel, and only for bioethanol [19]. The temperature dependent properties are crucial for understanding the performance of the fuel and, subsequently, the engine over a given period of time [20,21].

Therefore, the objective of this work is to survey the fluid behaviour of biobutanol-gasoline blends (volumetric mass density, dynamic viscosity, kinematic viscosity) through the whole year's temperature range that normally occur for most European countries (from $-10\text{ }^{\circ}\text{C}$ up to $40\text{ }^{\circ}\text{C}$) and the subsequent modelling of this behaviour.

2. Materials and Methods

2.1. Material

In this study, automobile gasolines with a 95 Research Octane Number (RON 95) and with a 98 Research Octane Number (RON 98), both without a biocomponent (Čepro, Czech Republic) and biobutanol (Penta, Czech Republic) were used. Five samples with various volume concentrations of gasoline and biobutanol were prepared, see Table 1. The sample identification is according to the volume ratio of the biobutanol in the whole blend (e.g., B10 contains 10 vol.% of biobutanol and 90 vol.% of gasoline).

Table 1. Composition of samples.

Sample	Volume of Biobutanol	Volume of Gasoline
B0	0%	100%
B5	5%	95%
B10	10%	90%
B85	85%	15%
B100	100%	0%

The typical physical and chemical properties of the fuels (gasoline, bioethanol, and biobutanol) are shown in Table 2.

2.2. Volumetric Mass Density Measuring

The values of the volumetric mass density of the biobutanol-gasoline samples were measured by a digital Densito 30 PX densitometer (Mettler Toledo, Columbus, OH, USA)

operating on an oscillating tube principle. All the samples were measured in temperature range from -10 to 40 °C (~ 263 – 313 K). The ASTM D4052 standard was followed throughout the whole experiment.

Table 2. Comparison of selected properties of fuels [22,23].

Property	Unit	Gasoline	Bioethanol	Biobutanol
Chemical formula		C ₄ to C ₁₂	C ₂ H ₅ OH	C ₄ H ₉ OH
Molecular mass	kg·mol ^{−1}	109	46	74
Volumetric mass density (15 °C)	kg·m ^{−3}	720–775	789	814
Calorific value	MJ·kg ^{−1}	43.3	29	33
Heat of vaporization	kJ·kg ^{−1}	349	918	583
Octane number ROM	-	91–99	107	96
Boiling point	°C	27–225	78	104
Flash point	°C	−45	13	35
Auto ignition Temp.	°C	258	420	415
Stoichiometric AFR	-	14.7	9.01	11.12

2.3. Viscosity Measuring

To determine the dynamic viscosity, a DV2T rotary viscometer (Brookfield, Middleboro, MA, USA) with standard spindle 18 (according the Brookfield) was used. The shear strain rate was set to a constant 200 s^{-1} . During the experiment, the similar procedure that was already used for gasoline-bioethanol and diesel-biobutanol blends in the papers [19,24,25] was followed. All the samples were measured in a temperature range from -10 to 40 °C (~ 263 – 313 K). Each sample was cooled down to -10 °C and gradually heated by 5 °C steps and after 2 min of stabilising the temperature, the viscosity was measured. A closed measuring cuvette was used to prevent evaporation of the sample during the measurement.

The kinematic viscosity was calculated from the dynamic viscosity and volumetric mass density using the equation:

$$\nu = \frac{\eta}{\rho} \quad (1)$$

where ν is the kinematic viscosity, η is the dynamic viscosity, and ρ is the volumetric mass density.

2.4. Mathematical Models for the Density, Dynamic, and Kinematic Viscosity

In this paper, four mathematical models were used for the temperature dependence of the volumetric mass density and both viscosities. These models are used for nonlinear (frequently exponential) dependences, which is also observed in the temperature dependence of the volumetric mass density and the viscosity of the fuels.

Some of models below were used also in papers [26–30]. The details and formulas of the used mathematical models are shown below.

Exponential model:

$$\eta = \eta_0 \cdot e^{b \cdot T} \text{ for dynamic viscosity} \quad (2)$$

$$\eta = \eta_0 \cdot e^{b \cdot T} \text{ for dynamic viscosity} \quad (3)$$

$$\rho = \rho_0 \cdot e^{b \cdot T} \text{ for volumetric mass density} \quad (4)$$

Arrhenius model:

$$\eta = \eta_0 \cdot e^{\frac{E_a}{R \cdot T}} \text{ for dynamic viscosity} \quad (5)$$

$$\nu = \nu_0 \cdot e^{\frac{E_a}{R \cdot T}} \text{ for kinematic viscosity} \quad (6)$$

Newton model:

$$\eta = \eta_0 \cdot e^{\frac{b}{T}} \text{ for dynamic viscosity} \quad (7)$$

$$\nu = \nu_0 \cdot e^{\frac{b}{T}} \text{ for kinematic viscosity} \quad (8)$$

Vogel model:

$$\eta = \eta_0 \cdot e^{\frac{b}{c+T}} \text{ for dynamic viscosity} \quad (9)$$

$$\nu = \nu_0 \cdot e^{\frac{b}{c+T}} \text{ for kinematic viscosity} \quad (10)$$

where η is the dynamic viscosity, η_0 is the reference value of the dynamic viscosity, ν is the kinematic viscosity, ν_0 is the reference value of the kinematic viscosity, ρ is the volumetric mass density, ρ_0 is the reference value of the volumetric mass density, T is the absolute temperature, R is the Universal gas constant, E_a is the Arrhenius activation energy, and b and c are coefficients.

Furthermore, mathematical polynomial multivariate models were created. These models describe the behaviour of the volumetric mass density or kinematic viscosity of the biobutanol-gasoline blends depending on their temperature and concentration. The models were created for both the RON 95 and RON 98 gasolines. The equations of the multivariate models are given below based on polynomial functions.

The volumetric mass density:

$$\rho(T, C) = x_0 + x_1 \cdot T + x_2 \cdot C + x_3 \cdot T^2 + x_4 \cdot T \cdot C \quad (11)$$

The kinematic viscosity:

$$\nu(T, C) = y_0 + y_1 \cdot T + y_2 \cdot C + y_3 \cdot T^2 + y_4 \cdot T \cdot C. \quad (12)$$

In Equations (11) and (12), ρ is the volumetric mass density, ν is the kinematic viscosity, T is the absolute temperature, C is the concentration, and x_i , y_i are coefficients.

2.5. Statistical Data Processing

All the measurements were repeated five times for volumetric mass density and 20 times for viscosity to obtain a higher accuracy and relevance of the results, and the values in the tables are displayed as the mean value including the standard deviation.

The experimental data were processed by Matlab® and Statistica®. To determine a statistically significant difference between the measured values of the volumetric mass density, dynamic viscosity and kinematic viscosity at the selected temperatures at the individual gasoline (RON 95, RON 98) and biobutanol concentrations, an ANOVA (analysis of variance) test was performed followed by multiple comparisons using Tukey's HSD (honestly significant difference) test (at the significance level of $p < 0.05$).

The normality and homogeneity of the data were evaluated according to a critique of the regression triplet data, which examines the quality of the data for the proposed model. The evaluation was performed by means of graphical (using rankit Q-Q graphs of residues and index graphs) and numerical statistical analysis of residues.

3. Results and Discussion

The following section comprehensively shows the values obtained during the experiments.

3.1. Volumetric Mass Density

Tables A1 and A2 (in Appendix A) shows the mean values of the volumetric mass density of the biobutanol-gasoline blends at the selected temperature range and concentration.

It can be seen that volumetric mass density of the blends decreases with an increasing temperature. Furthermore, the blends with a higher biobutanol content reach a higher volumetric mass density value and the RON 98 gasoline also has a higher volumetric mass density value than the RON 95 gasoline, similar to the bioethanol and gasoline blends [19,25,31].

3.2. Dynamic Viscosity

Tables A3 and A4 show the mean values of the dynamic viscosity of the biobutanol-gasoline blends at the selected temperature range and concentration.

It is evident that the dynamic viscosity of the blends decreases with an increasing temperature. Furthermore, the blends with a higher concentration of biobutanol reach a higher dynamic viscosity value and the RON 98 gasoline also has a lower dynamic viscosity value than the RON 95 gasoline, similar to the viscosity values of the bioethanol-gasoline blends [18,32].

3.3. Kinematic Viscosity

The mean values of the kinematic viscosity of the biobutanol-gasoline blends for the selected temperature range and concentrations are shown in Tables A5 and A6. The tables also show the results of the ANOVA test with respect to the multiple comparisons using Tukey's HSD test in the similar indices (a, b, c, etc.). The same indices indicate that no statistically significant difference was demonstrated between the respective kinematic viscosity at the significance level of $p = 0.95$.

From Tables A5 and A6, it can be seen that the kinematic viscosity values of the biobutanol-gasoline blends decrease with an increasing temperature. Also, the blends with a higher biobutanol content have higher kinematic viscosity values, and the RON 98 gasoline also has lower kinematic viscosity values than the RON 95 gasoline, similar to the bioethanol-gasoline blends [25]. The dependence of the kinematic viscosity on the concentration of the biocomponent in the fuel was also observed and described [8,33].

3.4. Mathematical Models

Finally, the most important part of this paper is devoted to the mathematical modelling of the volumetric mass density and viscosity behaviour of the biobutanol-gasoline blends. This part mainly contains tables with the coefficients of used mathematical models which are listed in Section 2.4. The obtained coefficients of the models are valid for the thermodynamic temperatures with Kelvin units.

The mentioned coefficients, especially the coefficient of determination R^2 and sum of squared estimate of errors (SSE), express the degree of accuracy and suitability of using these mathematical models to model the dependence of the volumetric mass density and both viscosities on the temperature of the biobutanol-gasoline blends. Some of the used temperature-viscosity models were described and also used in the papers, e.g., [26–28].

3.4.1. Mathematical Model for Volumetric Mass Density

The values of the coefficients for the exponential volumetric mass density model are shown in Table 3. The reference value of the volumetric mass density ρ_0 numerically determines the increase in the volumetric mass density of the blends with an increasing biobutanol volume concentration. The values of coefficient b are close to 0, so the temperature impact on the volumetric mass density approaches a linear dependence. The minus operator for the coefficient b means a decreasing trend in the exponential model, respectively, a decreasing volumetric mass density of the biobutanol-gasoline blends with an increasing temperature [8,24,34]. The above statement is graphically confirmed by Figures 1 and 2. The average value of the coefficient of determination R^2 for the exponential volumetric mass density model was 0.9676, which indicates the high accuracy of the models.

Table 3. Coefficients of exponential volumetric mass density model and statistical indicators (R^2 —coefficient of determination, SSE—sum of squared estimate of errors).

Exponential	ρ_0 (kg·m ^{−3})	b (K ^{−1})	R^2	SSE
B0-95	842.7	−0.0003653	0.9675	7.094
B5-95	918.5	−0.0006602	0.9108	67.90
B10-95	939.7	−0.0007296	0.9800	17.37
B85-95	1054	−0.0009530	0.9793	33.96
B0-98	950.2	−0.0007528	0.9705	27.75
B5-98	989.9	−0.0008632	0.9720	35.31
B10-98	973.6	−0.0007975	0.9710	31.33
B85-98	1057	−0.0009501	0.9824	28.75
B100	1074	−0.0009863	0.9745	45.80

Figure 1. Exponential model for volumetric mass density of biobutanol-gasoline (RON 95) blends. **Figure 2.** Exponential model for volumetric mass density of biobutanol-gasoline (RON 98) blends.

3.4.2. Mathematical Models for Dynamic Viscosity

The temperature dependence of the dynamic viscosity of the biobutanol-gasoline blends were modelled using four mathematical models, see Section 2.4 for more details. The coefficients of these models are shown in Tables 4–7. Thus, it was shown that with an increasing temperature, the dynamic viscosity of the biobutanol-gasoline blends decreases [32]. The difference between the Arrhenius model and Newtonian model is only in the use of the Universal gas constant R , so it holds that the coefficient b (Newton model) multiplied by the Universal gas constant R equals the Arrhenius activation energy E_a . However, knowledge of the Arrhenius activation energy E_a of the biobutanol-gasoline

blends is important and can be used for further calculations and applications [27–29]. In Table 7 (the coefficients of the Vogel model), several statistically insignificant coefficients can be seen, despite the Vogel model being the most accurate according to the highest average value of the coefficient of determination R^2 (0.9784) and average value of sum of squared estimate of errors SSE (0.0067). The Newton and Arrhenius models are in the next rows, which have an identical average value of R^2 (0.9234) and SSE (0.0514) and the exponential model has the lowest accuracy (but still very high), according to the results of the average value R^2 (0.8991) and SSE (0.0168).

Table 4. Coefficients of Exponential dynamic viscosity model and statistical indicators (R^2 —coefficient of determination, SSE—sum of squared estimate of errors).

Exponential	η_0 (mPa·s)	b (K ^{−1})	R^2	SSE
B0-95	2.785	−0.005277	0.8904	0.003453
B5-95	2.291	−0.004474	0.8800	0.002957
B10-95	3.753	−0.005958	0.8234	0.009255
B85-95	2.785	−0.005277	0.8904	0.003453
B0-98	2.855	−0.005526	0.9412	0.001755
B5-98	1.318	−0.002481	0.8729	0.001026
B10-98	2.040	−0.003918	0.7008	0.007626
B85-98	2926	−0.024320	0.9974	0.033080
B100	1.141×10^4	−0.028090	0.9971	0.088950

Table 5. Coefficients of Arrhenius dynamic viscosity model and statistical indicators (R^2 —coefficient of determination, SSE—sum of squared estimate of errors).

Arrhenius	η_0 (mPa·s)	E_a (J·mol ^{−1})	R^2	SSE
B0-95	0.1329	3634	0.9101	0.002831
B5-95	0.1735	3085	0.8994	0.002481
B10-95	0.1194	4134	0.8563	0.007531
B85-95	0.003794	1.576×10^4	0.9996	0.005149
B0-98	0.118700	3793	0.9566	0.001295
B5-98	0.316800	1698	0.8742	0.001015
B10-98	0.208800	2747	0.7397	0.006637
B85-98	0.003084	1.615×10^4	0.9989	0.013940
B100	0.001479	1.856×10^4	0.9997	0.010480

Table 6. Coefficients of Newton dynamic viscosity model and statistical indicators (R^2 —coefficient of determination, SSE—sum of squared estimate of errors).

Newton	η_0 (mPa·s)	b (K ^{−1})	R^2	SSE
B0-95	0.132900	437.1	0.9101	0.002831
B5-95	0.173500	371	0.8994	0.002481
B10-95	0.119400	497.3	0.8563	0.007531
B85-95	0.003794	1896	0.9996	0.005149
B0-98	0.118700	456.2	0.9566	0.001295
B5-98	0.316800	204.3	0.8742	0.001015
B10-98	0.208800	330.4	0.7397	0.006637
B85-98	0.003084	1942	0.9989	0.013940
B100	0.001479	2233	0.9997	0.010480

3.4.3. Mathematical Models for Kinematic Viscosity

For practical use, modelling the temperature dependence of the kinematic viscosity of the biobutanol-gasoline blends is the most suitable, because the kinematic viscosity contains information about the values of both the dynamic viscosity and the volumetric mass density of the blends [35]. Therefore, in the industrial and petrochemical fields, this viscosity is preferred, especially for temperature-dependent fluids.

Table 7. Coefficients of Vogel dynamic viscosity model and statistical indicators (R^2 —coefficient of determination, SSE—sum of squared estimate of errors).

Vogel	η_0 (mPa·s)	b (K)	c (K)	R^2	SSE
B0-95	0.47170000	12.59 *	−233.8	0.9572	0.0013480
B5-95	0.51300000	9.758 *	−235.9	0.9493	0.0012490
B10-95	0.54120000	8.194	−244.4	0.9700	0.0015740
B85-95	0.0079680 *	1500	−31.16 *	0.9996	0.0047340
B0-98	0.40190000	25.06 *	−216.5	0.9782	0.0006507
B5-98	0.0008957 *	2703 *	50.67 *	0.9989	0.0133100
B10-98	0.58500000	3.513 *	−250.8	0.9321	0.0147100
B85-98	0.0008959 *	2703 *	50.66 *	0.9989	0.0133100
B100	0.0037680 *	1737	−33.16 *	0.9997	0.0093950

* coefficient is not statistically significant for confidence level $p < 0.05$.

The temperature dependence of the kinematic viscosity of the biobutanol-gasoline blends were also modelled using four mathematical models (see Section 2.4). The coefficients of these models are shown in Tables 8–11. Again, it has been proven that with an increasing temperature, the kinematic viscosity of the gasolines (RON 95 and RON 98) and biobutanol nonlinearly decreases [36], which is confirmed by the coefficients of the mathematical models in Figures 3–5. In Table 11 (the coefficients of the Vogel model), several statistically insignificant coefficients can be seen, despite the Vogel model being the most accurate according to the highest average value of the coefficient of determination R^2 (0.9411) and average value of sum of squared estimate of errors SSE (0.0040) without SSE of B100. The Newton and Arrhenius models followed with an average R^2 value 0.8621 and SSE value 0.0353, and the exponential model has the lowest accuracy (but still very high), according to the results of the average value R^2 (0.8440) and SSE (0.0387).

Table 8. Coefficients of Exponential kinematic viscosity model and statistical indicators (R^2 —coefficient of determination, SSE—sum of squared estimate of errors).

Exponential	ν_0 (mm ² ·s ^{−1})	b (K ^{−1})	R^2	SSE
B0-95	3.2970	−0.004905	0.8745	0.006032
B5-95	0.8766	−0.003729	0.7472	0.008742
B10-95	4.1030	−0.005324	0.7760	0.017080
B85-95	2465	−0.022790	0.9961	0.072730
B0-98	3.0930	−0.004876	0.9157	0.003430
B5-98	1.3070	−0.001549	0.7127	0.001855
B10-98	2.0960	−0.003125	0.5800	0.013700
B85-98	2356	−0.021870	0.9950	0.131700
B100 (butanol)	8691	−0.026090	0.9980	0.093450

Table 9. Coefficients of Arrhenius kinematic viscosity model and statistical indicators (R^2 —coefficient of determination, SSE—sum of squared estimate of errors).

Arrhenius	ν_0 (mm ² ·s ^{−1})	E_a (J·mol ^{−1})	R^2	SSE
B0-95	0.194500	3384	0.8962	0.004991
B5-95	0.279800	2594	0.7751	0.007778
B10-95	0.187100	3711	0.8129	0.014270
B85-95	0.006053	1.518×10^4	0.9995	0.010040
B0-98	0.186200	3356	0.9345	0.002662
B5-98	0.534300	1070	0.7247	0.001777
B10-98	0.337500	2211	0.6217	0.012340
B85-98	0.009614	1.459×10^4	0.9991	0.022710
B100	0.003469	1.725×10^4	0.9950	0.240900

Table 10. Coefficients of Newton kinematic viscosity model and statistical indicators (R^2 —coefficient of determination, SSE—sum of squared estimate of errors).

Newton	ν_0 (mm ² ·s ^{−1})	b (K ^{−1})	R^2	SSE
B0-95	0.194500	407.1	0.8962	0.004991
B5-95	0.279800	371	0.7751	0.007778
B10-95	0.187100	446.3	0.8129	0.014270
B85-95	0.006053	1826	0.9995	0.010040
B0-98	0.186200	403.6	0.9345	0.002662
B5-98	0.534300	128.7	0.7247	0.001777
B10-98	0.337500	265.9	0.6217	0.012340
B85-98	0.009614	1755	0.9991	0.022710
B100	0.003469	2075	0.9950	0.240900

Table 11. Coefficients of Vogel kinematic viscosity model and statistical indicators (R^2 —coefficient of determination, SSE—sum of squared estimate of errors).

Vogel	ν_0 (mm ² ·s ^{−1})	b (K)	c (K)	R^2	SSE
B0-95	0.644000	10.02 *	−237.2	0.9542	0.002200
B5-95	0.736600	3.685 *	−249.3	0.9069	0.003220
B10-95	0.740600	5.904	−247.8	0.9618	0.002911
B85-95	0.02609 *	1093	−63.79	0.9996	0.006728
B0-98	0.571300	16.83 *	−224.7	0.9670	0.001343
B5-98	0.799100	1.329 *	−250.8	0.7937	0.001332
B10-98	0.782300	2.076 *	−254.3	0.8879	0.003658
B85-98	0.0695 *	814.2	−89.9	0.9996	0.01064
B100	1.511×10^5 *	324 *	7770 *	0.9645	1.697

* coefficient is not statistically significant for confidence level $p < 0.05$.

Figure 3. Mathematical models graph for kinematic viscosity of gasoline (RON 95). Experimental data are presented as the mean ($N = 20$) for selected temperatures.

In Figures 3–7, a relatively nonlinear decrease in the kinematic viscosity during the heating of gasolines, biobutanol, and their blends (especially when the Vogel model is used) can be seen. The lowest values in the kinematic viscosity were determined for B0 (pure gasoline) and the highest values in the kinematic viscosity were determined for B100 (pure biobutanol). The viscosity properties of the B5 and B10 blends approached that of the pure gasoline, which applies to both RON95 and RON 98. The viscosity behaviour of the B85 blend is close to the pure biobutanol viscosity behaviour. Similar results and conclusions were reached in [4,21].

Figure 4. Mathematical models graph for kinematic viscosity of gasoline (RON 98). Experimental data are presented as the mean ($N = 20$) for selected temperatures.

Figure 5. Mathematical models graph for kinematic viscosity of biobutanol (B100). Experimental data are presented as the mean ($N = 20$) for selected temperatures.

Figure 6. Vogel model graph for kinematic viscosity of biobutanol-gasoline (RON 95) blends.

Figure 7. Vogel model graph for kinematic viscosity of biobutanol-gasoline (RON 98) blends.

3.4.4. Mathematical Multivariate Models

The created three-dimensional mathematical multivariate polynomial models (see Equations (11) and (12)) have a significant application potential, because it is possible to accurately calculate the exact value of the volumetric mass density or the kinematic viscosity for the whole temperatures range from -10 to 40 °C (~ 263 – 313 K) and with any possible concentration of the biobutanol in the gasoline (RON 95 and RON 98) with the obtained coefficients (Table 12). The volumetric mass density and kinematic viscosity values obtained by extrapolation from these multivariate models can also be used with a certain degree of accuracy.

From the three-dimensional graphs using the colour scale, it can be clearly seen that the lowest values (blue colour) of the volumetric mass density (Figures 8 and 9) and kinematic viscosity (Figures 10 and 11) are reached in the biobutanol-gasoline blends with a concentration below about 40 vol.% and at temperatures higher than 0 °C (~ 273 K); on the contrary, the highest values (yellow colour) were reached by the biobutanol-gasoline blends above 80 vol.% of biobutanol and at low temperatures (<0 °C). The temperature dependence of the volumetric mass density or the kinematic viscosity and the effect of the biobutanol concentration in gasoline (RON 95 and RON 98) prove a nonlinear dependence like with the bioethanol-gasoline behaviour described in [19,25].

Figure 8. Three-dimensional graph created using multivariate polynomial model for volumetric mass density of biobutanol-gasoline (RON 95) blends. Experimental data are presented as the mean ($N = 5$) for selected temperatures and concentrations.

Figure 9. Three-dimensional graph created using multivariate polynomial model for volumetric mass density of biobutanol-gasoline (RON 98) blends. Experimental data are presented as the mean ($N = 5$) for selected temperatures and concentrations.

Figure 10. Three-dimensional graph created using multivariate polynomial model for kinematic viscosity of biobutanol-gasoline (RON 95) blends. Experimental data are presented as the mean ($N = 20$) for selected temperatures and concentrations.

Table 12. Coefficients of polynomial multivariate models and statistical indicators (R^2 —coefficient of determination, SSE—sum of squared estimate of errors).

Volumetric Mass Density	x_0 ($\text{kg} \cdot \text{m}^{-3}$)	x_1 ($\text{K}^{-1} \cdot \text{kg} \cdot \text{m}^{-3}$)	x_2 ($\text{kg} \cdot \text{m}^{-3}$)	x_3 ($\text{K}^{-2} \cdot \text{kg} \cdot \text{m}^{-3}$)	x_4 ($\text{K}^{-1} \cdot \text{kg} \cdot \text{m}^{-3}$)	R^2	SSE
Bx-95	358.4	3.202	1.649	−0.006287	−0.003953	0.9944	178.1
Bx-98	375.2	3.350	0.9477	−0.006874	−0.001859	0.9902	239.7
Kinematic Viscosity	y_0 ($\text{mm}^2 \cdot \text{s}^{-1}$)	y_1 ($\text{K}^{-1} \cdot \text{mm}^2 \cdot \text{s}^{-1}$)	y_2 ($\text{mm}^2 \cdot \text{s}^{-1}$)	y_3 ($\text{K}^{-2} \cdot \text{mm}^2 \cdot \text{s}^{-1}$)	y_4 ($\text{K}^{-1} \cdot \text{mm}^2 \cdot \text{s}^{-1}$)	R^2	SSE
Bx-95	52.91	−0.3668	0.3809	0.0006412	−0.001178	0.9715	7.021
Bx-98	54.61	−0.3801	0.4105	0.0006663	−0.001265	0.9897	2.999

Figure 11. Three-dimensional graph created using multivariate polynomial model for kinematic viscosity of biobutanol-gasoline (RON 98) blends. Experimental data are presented as the mean ($N = 20$) for selected temperatures and concentrations.

4. Conclusions

It must be stated that the obtained results, especially the coefficients of the mathematical models, are usable for the advanced numerical modelling of flow properties of biobutanol-gasoline blends; for example, the modelling of the pressure drop, shear stress, maximum and mean flow velocity, volume and mass flow, two-dimensional and three-dimensional velocity profiles, friction factor, laminar and turbulent flow (Reynolds number), etc.

The results are certainly applicable in industrial practice. For instance, the models with the coefficients could be used to set a car control unit, which would be able to evaluate the exact amount of fuel needed for injection into the combustion chamber according to the current concentration of the biobutanol in the gasoline (RON 95 and RON 98) and current temperature of the fuel, because, as this paper stated, these can affect the fuel volumetric mass density and the dynamic/kinematic viscosity.

It is appropriate to emphasise these research findings:

- The RON 98 gasoline reaches higher values in the volumetric mass density than the RON 95 gasoline.
- The volumetric mass density of the biobutanol-gasoline blends almost linearly (coefficient of exponential model $b \rightarrow 0$) decreases with an increasing temperature for all concentrations.
- The RON 98 gasoline reaches lower values in the dynamic and kinematic viscosity than the RON 95 gasoline.
- The dynamic and kinematic viscosity of the biobutanol-gasoline blends nonlinear decreases with an increasing temperature for all concentrations.
- The biobutanol-gasoline blends with a higher biobutanol content have higher dynamic and kinematic viscosity values.
- The dynamic and kinematic viscosity of the biobutanol-gasoline blends with a content up to 10 vol.% of biobutanol is almost the same as the dynamic and kinematic viscosity of the RON 95 and RON 98 gasolines without a biocomponent ($p < 0.05$).
- The dynamic and kinematic viscosity of the biobutanol-gasoline blends with a content up to 85 vol.% of biobutanol is similar to the dynamic and kinematic viscosity of the pure biobutanol ($p < 0.05$).

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Appendix A

Table A1. Values of volumetric mass density of biobutanol-gasoline (RON 95) blends (mean $\pm$ Scheme 5).

Temperature (°C)	Temperature (K)	Volumetric Mass Density RON 95 (kg·m ⁻³)				
		B0	B5	B10	B85	B100
−10	263.15	765.1 $\pm$ 1.49	768.3 $\pm$ 1.63	773.5 $\pm$ 1.41	817.1 $\pm$ 1.62	824.6 $\pm$ 1.60
−5	268.15	763.8 $\pm$ 1.56	766.7 $\pm$ 1.53	771.5 $\pm$ 1.49	814.8 $\pm$ 1.81	822.8 $\pm$ 1.50
0	273.15	761.9 $\pm$ 1.27	768.4 $\pm$ 1.40	771.1 $\pm$ 1.52	813.1 $\pm$ 1.58	821.3 $\pm$ 1.31
5	278.15	761.1 $\pm$ 1.42	766.2 $\pm$ 1.48	768.3 $\pm$ 1.50	809.7 $\pm$ 1.58	817.9 $\pm$ 1.60
10	283.15	760.6 $\pm$ 1.61	764.0 $\pm$ 1.61	765.2 $\pm$ 1.45	806.5 $\pm$ 1.81	813.9 $\pm$ 1.27
15	288.15	759.6 $\pm$ 1.53	762.4 $\pm$ 1.52	762.6 $\pm$ 1.39	803.0 $\pm$ 1.83	810.5 $\pm$ 1.41
20	293.15	759.0 $\pm$ 1.48	759.7 $\pm$ 1.38	760.0 $\pm$ 1.61	798.7 $\pm$ 1.53	806.3 $\pm$ 1.44
25	298.15	755.8 $\pm$ 1.42	756.5 $\pm$ 1.29	756.6 $\pm$ 1.41	794.6 $\pm$ 1.57	801.7 $\pm$ 1.47
30	303.15	753.8 $\pm$ 1.29	750.3 $\pm$ 1.47	751.3 $\pm$ 1.48	787.9 $\pm$ 1.55	794.2 $\pm$ 1.78
35	308.15	752.3 $\pm$ 1.25	747.2 $\pm$ 1.62	749.4 $\pm$ 1.37	784.2 $\pm$ 1.58	790.8 $\pm$ 1.52
40	313.15	751.1 $\pm$ 1.55	744.2 $\pm$ 1.60	747.6 $\pm$ 1.24	780.2 $\pm$ 1.48	786.6 $\pm$ 1.57

Table A2. Values of volumetric mass density of biobutanol-gasoline (RON 98) blends (mean $\pm$ standard deviation, $N = 5$).

Temperature (°C)	Temperature (K)	Volumetric Mass Density RON 98 (kg·m ⁻³)				
		B0	B5	B10	B85	B100
−10	263.15	776.1 $\pm$ 1.63	785.1 $\pm$ 1.40	786.3 $\pm$ 1.33	820.6 $\pm$ 1.42	824.6 $\pm$ 1.60
−5	268.15	775.6 $\pm$ 1.41	784.4 $\pm$ 1.37	784.7 $\pm$ 1.36	818.3 $\pm$ 1.37	822.8 $\pm$ 1.50
0	273.15	775.0 $\pm$ 1.26	783.3 $\pm$ 1.35	783.9 $\pm$ 1.27	816.5 $\pm$ 1.39	821.3 $\pm$ 1.31
5	278.15	772.1 $\pm$ 1.37	779.9 $\pm$ 1.36	781.3 $\pm$ 1.38	812.7 $\pm$ 1.49	817.9 $\pm$ 1.60
10	283.15	769.6 $\pm$ 1.40	777.0 $\pm$ 1.57	778.7 $\pm$ 1.40	809.5 $\pm$ 1.44	813.9 $\pm$ 1.27
15	288.15	765.6 $\pm$ 1.29	773.8 $\pm$ 1.47	775.9 $\pm$ 1.45	806.0 $\pm$ 1.44	810.5 $\pm$ 1.41
20	293.15	763.2 $\pm$ 1.12	770.1 $\pm$ 1.38	771.9 $\pm$ 1.36	802.0 $\pm$ 1.48	806.3 $\pm$ 1.44
25	298.15	760.4 $\pm$ 1.17	766.6 $\pm$ 1.19	768.7 $\pm$ 1.27	797.9 $\pm$ 1.50	801.7 $\pm$ 1.47
30	303.15	754.9 $\pm$ 1.35	760.7 $\pm$ 1.29	763.2 $\pm$ 1.43	791.5 $\pm$ 1.46	794.2 $\pm$ 1.78
35	308.15	752.2 $\pm$ 1.40	757.3 $\pm$ 1.27	760.1 $\pm$ 1.30	787.6 $\pm$ 1.40	790.8 $\pm$ 1.52
40	313.15	749.4 $\pm$ 1.43	753.6 $\pm$ 1.33	756.8 $\pm$ 1.32	783.4 $\pm$ 1.42	786.6 $\pm$ 1.57

Table A3. Values of dynamic viscosity of biobutanol-gasoline (RON 95) blends (mean $\pm$ standard deviation, $N = 20$).

Temperature (°C)	Temperature (K)	Dynamic Viscosity RON 95 (mPa·s)				
		B0	B5	B10	B85	B100
−10	263.15	0.72 $\pm$ 0.025 ^{i,k}	0.73 $\pm$ 0.021 ^m	0.83 $\pm$ 0.010 ^o	5.12 $\pm$ 0.026 ^ω	7.34 $\pm$ 0.025 ^λ
−5	268.15	0.70 $\pm$ 0.018 ^{d,e,f,g,h,i}	0.71 $\pm$ 0.023 ^l	0.78 $\pm$ 0.010 ⁿ	4.50 $\pm$ 0.023 ^τ	6.71 $\pm$ 0.027 ^δ
0	273.15	0.64 $\pm$ 0.035 ^{d,e,f}	0.66 $\pm$ 0.014 ^k	0.73 $\pm$ 0.017 ^m	3.88 $\pm$ 0.017 ^ρ	5.69 $\pm$ 0.025 ^η
5	278.15	0.61 $\pm$ 0.035 ^{d,e,f}	0.63 $\pm$ 0.019 ^{d,e}	0.69 $\pm$ 0.015 ^l	3.45 $\pm$ 0.017 ^z	5.11 $\pm$ 0.031 ^ω
10	283.15	0.60 $\pm$ 0.018 ^{e,f,g,h,i,j}	0.63 $\pm$ 0.015 ^{d,e,f,g}	0.64 $\pm$ 0.012 ^{i,j,k}	3.05 $\pm$ 0.017 ^x	4.38 $\pm$ 0.016 ^π
15	288.15	0.61 $\pm$ 0.032 ^{d,e,f}	0.62 $\pm$ 0.013 ^{d,e,f}	0.64 $\pm$ 0.010 ^{h,i,j}	2.75 $\pm$ 0.015 ^v	3.76 $\pm$ 0.012 ^β
20	293.15	0.59 $\pm$ 0.025 ^{c,d}	0.62 $\pm$ 0.016 ^{d,e,f,g,h}	0.64 $\pm$ 0.014 ^{f,g,h,i,j}	2.47 $\pm$ 0.007 ^t	3.32 $\pm$ 0.010 ^y
25	298.15	0.58 $\pm$ 0.031 ^{b,c}	0.62 $\pm$ 0.015 ^{d,e,f}	0.64 $\pm$ 0.010 ^{g,h,i,j}	2.21 $\pm$ 0.011 ^s	2.88 $\pm$ 0.010 ^w
30	303.15	0.57 $\pm$ 0.024 ^b	0.60 $\pm$ 0.015 ^{c,d}	0.63 $\pm$ 0.012 ^{e,f,g,h,i,j}	1.97 $\pm$ 0.010 ^r	2.53 $\pm$ 0.009 ^u
35	308.15	0.56 $\pm$ 0.021 ^b	0.58 $\pm$ 0.021 ^b	0.62 $\pm$ 0.010 ^{d,e,f}	1.79 $\pm$ 0.010 ^q	2.21 $\pm$ 0.010 ^s
40	313.15	0.54 $\pm$ 0.018 ^a	0.57 $\pm$ 0.015 ^b	0.61 $\pm$ 0.013 ^{d,e}	1.61 $\pm$ 0.012 ^p	1.95 $\pm$ 0.010 ^r

The same indices indicate that no statistically significant difference was demonstrated between the respective dynamic viscosity at the significance level of $p = 0.95$.

Table A4. Values of dynamic viscosity of biobutanol-gasoline (RON 98) blends (mean $\pm$ standard deviation, $N = 20$).

Temperature (°C)	Temperature (K)	Dynamic Viscosity RON 98 (mPa·s)				
		B0	B5	B10	B85	B100
−10	263.15	0.69 $\pm$ 0.027 ⁱ	0.70 $\pm$ 0.010 ^k	0.77 $\pm$ 0.011 ^m	4.89 $\pm$ 0.019 ^τ	7.34 $\pm$ 0.025 ^λ
−5	268.15	0.65 $\pm$ 0.029 ^{d,e}	0.68 $\pm$ 0.010 ^j	0.74 $\pm$ 0.010 ^l	4.39 $\pm$ 0.016 ^π	6.71 $\pm$ 0.027 ^δ
0	273.15	0.62 $\pm$ 0.030 ^{d,e,f}	0.65 $\pm$ 0.008 ^{f,g,h,i}	0.69 $\pm$ 0.006 ^{j,k}	3.81 $\pm$ 0.011 ^ρ	5.69 $\pm$ 0.025 ^η
5	278.15	0.60 $\pm$ 0.029 ^{e,f,g,h,i}	0.65 $\pm$ 0.007 ^{h,i}	0.65 $\pm$ 0.007 ^{f,g,h,i}	3.28 $\pm$ 0.010 ^y	5.11 $\pm$ 0.031 ^ω
10	283.15	0.61 $\pm$ 0.031 ^{d,e}	0.65 $\pm$ 0.008 ^{h,i}	0.63 $\pm$ 0.009 ^{d,e}	2.92 $\pm$ 0.010 ^x	4.38 $\pm$ 0.016 ^π
15	288.15	0.57 $\pm$ 0.030 ^{e,f,g}	0.65 $\pm$ 0.004 ^{g,h,i}	0.63 $\pm$ 0.010 ^{d,e,f}	2.62 $\pm$ 0.013 ^v	3.76 $\pm$ 0.012 ^β
20	293.15	0.55 $\pm$ 0.022 ^{d,e,f}	0.65 $\pm$ 0.008 ^{h,i}	0.64 $\pm$ 0.010 ^{e,f,g,h}	2.31 $\pm$ 0.012 ^t	3.32 $\pm$ 0.010 ^z
25	298.15	0.54 $\pm$ 0.026 ^{d,e}	0.63 $\pm$ 0.007 ^{d,e}	0.64 $\pm$ 0.010 ^{e,f,g,h}	2.09 $\pm$ 0.010 ^r	2.88 $\pm$ 0.010 ^w
30	303.15	0.53 $\pm$ 0.035 ^{a,b}	0.63 $\pm$ 0.006 ^{d,e}	0.63 $\pm$ 0.006 ^{d,e}	1.88 $\pm$ 0.011 ^p	2.53 $\pm$ 0.009 ^u
35	308.15	0.53 $\pm$ 0.028 ^a	0.61 $\pm$ 0.008 ^{b,c}	0.63 $\pm$ 0.004 ^{d,e}	1.69 $\pm$ 0.010 ^o	2.21 $\pm$ 0.010 ^s
40	313.15	0.52 $\pm$ 0.018 ^a	0.60 $\pm$ 0.009 ^{a,b}	0.62 $\pm$ 0.010 ^{c,d}	1.50 $\pm$ 0.008 ⁿ	1.95 $\pm$ 0.010 ^q

The same indices indicate that no statistically significant difference was demonstrated between the respective dynamic viscosity at the significance level of $p = 0.95$.

Table A5. Values of kinematic viscosity of biobutanol-gasoline (RON 95) blends (mean $\pm$ standard deviation, $N = 20$).

Temperature (°C)	Temperature (K)	Kinematic Viscosity RON 95 (mm ² ·s ^{−1})				
		B0	B5	B10	B85	B100
−10	263.15	0.94 $\pm$ 0.006 ^{l,m,n}	0.96 $\pm$ 0.024 ⁿ	1.07 $\pm$ 0.011 ^p	6.27 $\pm$ 0.019 ^τ	8.90 $\pm$ 0.016 ^β
−5	268.15	0.92 $\pm$ 0.012 ^{k,l}	0.93 $\pm$ 0.024 ^{l,m}	1.01 $\pm$ 0.011 ^o	5.52 $\pm$ 0.015 ^θ	8.16 $\pm$ 0.021 ^ρ
0	273.15	0.84 $\pm$ 0.021 ^{i,j}	0.86 $\pm$ 0.011 ^j	0.95 $\pm$ 0.020 ^{m,n}	4.77 $\pm$ 0.012 ^δ	6.93 $\pm$ 0.019 ^π
5	278.15	0.80 $\pm$ 0.026 ^{e,f}	0.81 $\pm$ 0.012 ^{e,f}	0.90 $\pm$ 0.018 ^k	4.26 $\pm$ 0.013 ^λ	6.25 $\pm$ 0.015 ^τ
10	283.15	0.79 $\pm$ 0.027 ^{d,e}	0.81 $\pm$ 0.011 ^{e,f}	0.84 $\pm$ 0.014 ^{g,h,i,j}	3.78 $\pm$ 0.013 ^y	5.38 $\pm$ 0.016 ^ω
15	288.15	0.80 $\pm$ 0.021 ^{e,f}	0.81 $\pm$ 0.012 ^{e,f}	0.84 $\pm$ 0.012 ^{h,i,j}	3.45 $\pm$ 0.011 ^w	4.63 $\pm$ 0.022 ^η
20	293.15	0.78 $\pm$ 0.025 ^{c,d}	0.82 $\pm$ 0.014 ^{f,g,h}	0.84 $\pm$ 0.017 ^{g,h,i}	3.09 $\pm$ 0.003 ^u	4.12 $\pm$ 0.017 ^z
25	298.15	0.77 $\pm$ 0.020 ^{b,c,d}	0.82 $\pm$ 0.012 ^{f,g}	0.85 $\pm$ 0.017 ^{i,j}	2.78 $\pm$ 0.008 ^t	3.59 $\pm$ 0.020 ^x
30	303.15	0.76 $\pm$ 0.015 ^{b,c}	0.80 $\pm$ 0.012 ^{e,f}	0.84 $\pm$ 0.014 ^{g,h,i}	2.50 $\pm$ 0.008 ^s	3.18 $\pm$ 0.009 ^v
35	308.15	0.74 $\pm$ 0.016 ^b	0.78 $\pm$ 0.025 ^{c,d}	0.83 $\pm$ 0.012 ^{f,g,h,i}	2.28 $\pm$ 0.008 ^r	2.80 $\pm$ 0.015 ^t
40	313.15	0.72 $\pm$ 0.013 ^a	0.77 $\pm$ 0.012 ^{b,c,d}	0.82 $\pm$ 0.016 ^{f,g}	2.06 $\pm$ 0.011 ^q	2.48 $\pm$ 0.021 ^s

The same indices indicate that no statistically significant difference was demonstrated between the respective kinematic viscosity at the significance level of $p = 0.95$.

Table A6. Values of kinematic viscosity of biobutanol-gasoline (RON 98) blends (mean $\pm$ standard deviation, $N = 20$).

Temperature (°C)	Temperature (K)	Kinematic Viscosity RON 98 (mm ² ·s ⁻¹)				
		B0	B5	B10	B85	B100
−10	263.15	0.89 $\pm$ 0.010 ^{i,k}	0.89 $\pm$ 0.011 ⁿ	0.98 $\pm$ 0.012 ^p	5.96 $\pm$ 0.013 ^τ	8.90 $\pm$ 0.016 ^β
−5	268.15	0.84 $\pm$ 0.006 ^{c,d,e,f}	0.87 $\pm$ 0.011 ^{l,m}	0.94 $\pm$ 0.011 ^o	5.37 $\pm$ 0.011 ^θ	8.16 $\pm$ 0.021 ^ρ
0	273.15	0.80 $\pm$ 0.008 ^{d,e,f,g}	0.83 $\pm$ 0.009 ^{d,e,f,g,h,i}	0.88 $\pm$ 0.006 ^{m,n}	4.67 $\pm$ 0.006 ^ω	6.93 $\pm$ 0.019 ^π
5	278.15	0.78 $\pm$ 0.012 ^{g,h,i,j,k}	0.83 $\pm$ 0.008 ^{h,i,j,k}	0.83 $\pm$ 0.008 ^{e,f,g,h,i,j}	4.04 $\pm$ 0.005 ^λ	6.25 $\pm$ 0.015 ^τ
10	283.15	0.79 $\pm$ 0.014 ^{d,e,f,g}	0.84 $\pm$ 0.009 ^{i,j,k}	0.81 $\pm$ 0.010 ^{b,c,d,e}	3.61 $\pm$ 0.005 ^z	5.38 $\pm$ 0.016 ^ω
15	288.15	0.75 $\pm$ 0.012 ^{g,h,i,j,k}	0.84 $\pm$ 0.004 ^{i,j,k}	0.81 $\pm$ 0.011 ^{d,e,f,g}	3.25 $\pm$ 0.010 ^y	4.63 $\pm$ 0.022 ^η
20	293.15	0.72 $\pm$ 0.013 ^{e,f,g,h,i,j}	0.84 $\pm$ 0.009 ^{k,l}	0.83 $\pm$ 0.012 ^{f,g,h,i,j}	2.88 $\pm$ 0.010 ^w	4.12 $\pm$ 0.017 ^z
25	298.15	0.71 $\pm$ 0.013 ^{d,e,f,g,h,i,j}	0.82 $\pm$ 0.008 ^{d,e,f,g,h}	0.83 $\pm$ 0.011 ^{g,h,i,j,k}	2.62 $\pm$ 0.008 ^u	3.59 $\pm$ 0.020 ^x
30	303.15	0.70 $\pm$ 0.011 ^{a,b}	0.83 $\pm$ 0.007 ^{e,f,g,h,i,j}	0.83 $\pm$ 0.006 ^{d,e,f,g,h,i}	2.38 $\pm$ 0.010 ^s	3.18 $\pm$ 0.009 ^v
35	308.15	0.71 $\pm$ 0.009 ^a	0.81 $\pm$ 0.009 ^{b,c,d}	0.83 $\pm$ 0.004 ^{e,f,g,h,i,j}	2.15 $\pm$ 0.008 ^r	2.80 $\pm$ 0.015 ^t
40	313.15	0.69 $\pm$ 0.009 ^a	0.79 $\pm$ 0.011 ^{a,b,c}	0.81 $\pm$ 0.012 ^{d,e,f,g}	1.92 $\pm$ 0.007 ^q	2.48 $\pm$ 0.021 ^s

The same indices indicate that no statistically significant difference was demonstrated between the respective kinematic viscosity at the significance level of $p = 0.95$.

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