



Development of a new model for biodiesel viscosity prediction based on the principle of corresponding state

F.R. do Carmo, P.M. Sousa Jr., R.S. Santiago-Aguiar, H.B. de Sant'Ana*

Grupo de Pesquisa em Termofluidodinâmica Aplicada, Departamento de Engenharia Química, Centro de Tecnologia, Universidade Federal do Ceará, Campus do Pici, Bloco 709, Fortaleza, CE, CEP: 60455-760, Brazil

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ABSTRACT

A new model for predicting the viscosities of biodiesel is presented in this work. This model is based on the principle of corresponding states, using one- and two-reference fluids. For the critical constants of methyl esters, the Marrero–Gani method was used. For biodiesels, Lee–Kesler's mixing rules were used for critical constants calculations. The two models studied in this work were compared with Ceriani et al. [5], Yuan [6], and Revised Yuan [7] models. A set of data on biodiesel viscosity was used in this work, consisting of 31 pure biodiesels and 4 mixtures of biodiesel (totalizing 193 experimental data). The best result was found using a two-reference-fluids model, methyl laurate (C12:0) and methyl oleate (C18:1), with a global average relative deviation of 6.66%.

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1. Introduction

In the last decade, vegetable-oil based fuels have been attracting greater attention due to depleting fossil fuel reserves, soaring petroleum prices, pollution derived from conventional fuels and more stringent emission regulations. These concerns are the driving forces for research on alternative fuels. The production of biodiesel from vegetable oils is one of the alternatives in the global strategy to expand renewable energy sources. Biodiesel has many advantages, especially in regards to its ignition quality, energy content, higher density and cleaner burning properties, and its renewability, non-toxicity, and almost zero sulfur content [1]. For this reason, it has been increasingly used as a substitute for conventional diesel fuel. The most popular method for producing biodiesel is the transesterification process using a basic homogeneous catalyst. In Brazil, the Brazilian National Agency of Petroleum, Natural Gas and Biofuels (Agência Nacional do Petróleo, Gás Natural e Biocombustíveis – ANP), has established a biodiesel content of B5 (in other words, 5 vol.% of biodiesel) for the diesel blends that have been commercialized since 2010 [2].

Viscosity is a measure of a fluid's resistance to flow. It describes the internal friction of a moving fluid [3]. Viscosity of fluids is industrially significant from the standpoint of both equipment design and process control. In the biodiesel industry, understand-

ing how it works is also important for the atomization process, which is the initial stage of combustion in a diesel engine. This process is affected by the fuel's viscosity, especially the formation of larger-sized droplets when injected into the diesel engine chamber, creating operational problems for fuel injection, spray development and the combustion process [4]. It should be noted that biodiesels and diesel have a multi-component composition. Nevertheless, they were treated here as a pseudo-pure component (e.g., the molecular weight of biodiesel was considered as a weighed average in terms of mass fraction). Their mixtures were treated as pseudo-binary mixtures only for the purpose of estimating parameters. The ester nomenclature adopted in this work was based on the fatty acid chain length. A C_x:y ester means the methyl ester of fatty acid with x carbons and y unsaturations.

There is still a lack of viscosity data on pseudo-pure biodiesel, biodiesel blends, and biodiesel–diesel over the whole composition range under different operational conditions. Although viscosity is an important factor for the biodiesel industry, there are, in the literature, few methods for estimating biodiesel viscosity when compared to those for crude oils [5–7]. As a result, the use of theoretical approaches for estimating the viscosity of biodiesel systems is of great practical interest.

In this paper, an equation based in one- and two-reference-fluid corresponding states model was proposed, which takes into account the effects of temperature and compositional changes that accurately predict the viscosity of biodiesel fuels.

* Corresponding author. Tel.: +55 85 3366 9611; fax: +55 85 3366 9610.
E-mail address: hbs@ufc.br (H.B. de Sant'Ana).

Table 1

Experimental databank used in this work, along with number of experimental data and temperature range.

References	Biodiesel	Nexp	Range <i>T</i> (K)	References	Biodiesel	Nexp	Range <i>T</i> (K)
[6]	SME ^c	5	293.15–373.15	[10]	Peanut	1	313.15
	YGME ^d	5	293.15–373.15		Rapeseed	1	313.15
	CCME ^e	5	293.15–373.15		Canola	1	313.15
	PME ^f	5	293.15–373.15		Coconut	1	313.15
	CME ^g	5	293.15–373.15		Palm	1	313.15
[8]	Soy A	15	283.15–353.15	[11]	Soybean	1	313.15
	Soy B	18	278.15–363.15		Coconut	5	293.15–373.15
	B1 ^a	15	283.15–353.15		Soybean	5	293.15–373.15
	Sunflower	17	283.15–363.15	Colza	5	293.15–373.15	
	Rapeseed	18	278.15–363.15	[12]	Babassu	5	293.15–373.15
	Palm	16	288.15–363.15		Cotton seed	5	293.15–373.15
[9]	GP ^b	18	278.15–363.15	[13]	Soybean	5	293.15–373.15
	Coconut	1	313.15		Fish	5	293.15–373.15
	Peanut	1	313.15		Sunflower	5	293.15–373.15
	Soya	1	313.15				
	Palm	1	313.15				
	Canola	1	313.15				

^a B1 = biodiesel composed by 71% methyl oleate.^b GP = blending of soy and rapeseed.^c SME = soybean oil methyl esters.^d YGME = yellow grease methylester.^e CCME = coconut oil methyl ester.^f PME = palm oil methyl ester.^g CME = canola oil methyl ester.

2. Experimental data bank

The viscosities data were taken from different sources from the literature [6,8–13], and from experimental measurements determined by our research group [11–13]. To validate the new model, a databank of viscosity data was collected from the literature [6,8–13]. To our knowledge, only 34 pure biodiesels and 4 mixtures

of biodiesel (totalizing 193 experimental viscosity data) were available. It is important to mention that only data associated with information about their composition were taken into account in building the databank, since such information was essential in several calculations that were made. In spite of this small amount of experimental information, the corresponding states model can provide a very accurate estimate of transport properties. Table 1 shows all 31 pure

Table 2

Composition of the biodiesel studied, in mass fraction (100 w).

References	Biodiesel	C8:0	C10:0	C12:0	14:00	C16:0	C16:1	C18:0	C18:1	C18:2	C18:3	C20:0	C20:1	C22:0	C22:1	C24:0
[6]	SME	0.02	–	–	0.08	10.49	0.12	4.27	24.20	51.36	7.48	0.36	0.28	0.40	0.07	0.14
	YGME	–	–	–	1.70	19.47	–	14.38	54.67	7.96	0.69	0.25	0.52	0.21	–	–
	CCME	9.20	6.40	48.70	17.00	7.70	–	2.20	5.40	2.20	–	–	–	–	–	–
	PME	–	–	–	–	40.60	–	5.10	42.80	11.00	0.50	–	–	–	–	–
	CME	–	–	–	–	4.20	–	1.70	56.80	21.70	15.70	–	–	–	–	–
[8]	Soy A	–	–	–	–	16.18	–	3.82	28.80	50.46	–	–	–	–	–	–
	Soy B	–	–	–	0.07	10.78	0.07	3.95	23.02	53.66	7.03	0.38	0.23	0.80	–	–
	B1	–	–	–	1.80	4.70	4.70	1.90	71.13	9.89	–	5.89	–	–	–	–
	Sunflower	–	–	0.02	0.07	6.41	0.09	4.23	23.93	64.25	0.12	–	0.03	0.77	0.08	–
	Rapeseed	–	0.01	0.04	0.07	5.26	0.20	1.63	62.49	20.94	6.99	0.60	1.23	1.35	0.19	–
	Palm	–	0.03	0.25	0.57	42.52	0.13	4.03	41.99	9.81	0.09	0.36	0.15	0.09	–	–
	GP	–	–	0.02	0.13	10.57	0.13	2.66	41.05	36.67	7.10	0.44	0.67	0.45	0.12	–
[9]	Coconut	7.50	6.00	53.30	17.10	7.30	–	1.90	5.50	1.40	–	0.20	–	–	–	–
	Peanut	–	–	–	–	10.50	0.40	2.70	46.60	30.10	1.00	1.30	1.40	2.40	–	3.50
	Soya	–	–	–	–	5.80	0.80	1.70	60.00	19.90	9.60	0.70	1.60	–	–	–
	Palm	–	–	0.40	1.30	48.10	0.30	4.00	37.30	8.00	0.20	0.30	0.10	–	–	–
	Canola	–	–	–	4.20	0.40	2.00	57.40	21.30	11.20	1.20	2.10	0.10	–	–	–
[10]	Peanut	–	–	–	–	10.40	–	8.90	47.10	32.90	0.50	–	–	–	0.20	–
	Rapeseed	–	–	–	–	2.70	–	2.80	21.90	13.10	8.60	–	–	–	50.90	–
	Canola	–	–	–	0.10	3.90	–	3.10	60.20	21.10	11.10	–	–	–	0.50	–
	Coconut	8.30	6.00	46.70	18.30	9.20	–	2.90	6.90	1.70	–	–	–	–	–	–
	Palm	0.10	0.10	0.90	1.30	43.90	–	4.90	39.00	9.50	0.30	–	–	–	–	–
	Soybean	–	–	–	0.10	10.30	–	4.70	22.50	54.10	8.30	–	–	–	–	–
[11]	Coconut	4.08	3.65	35.35	19.84	13.83	–	3.94	14.30	4.73	–	–	–	–	–	–
	Soybean	–	–	–	–	11.32	–	–	25.68	54.94	8.07	–	–	–	–	–
	Colza	–	–	–	–	3.99	–	3.91	56.67	23.61	9.88	1.94	–	–	–	–
[12]	Babassu	–	5.10	28.11	25.56	15.41	–	5.04	20.79	–	–	–	–	–	–	–
	Cotton seed	–	–	–	0.62	24.06	–	2.56	15.74	56.99	–	–	–	–	–	–
	Soybean	–	–	–	–	11.29	–	3.96	19.98	58.39	5.86	–	–	0.52	–	–
[13]	Fish	–	–	–	3.76	5.66	28.09	7.46	42.29	12.74	–	–	–	–	–	–
	Sunflower	–	–	–	–	7.10	–	4.80	22.60	65.50	–	–	–	–	–	–

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