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Modelling of biodiesel fuel droplet heating and evaporation: Effects of fuel composition

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HIGHLIGHTS

- Discrete Components Model taking into account liquid species diffusion.
- A comparative analysis of time evolutions of droplet surface temperatures and radii.
- Various types of biodiesel fuels.

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ABSTRACT

A comparative analysis of predictions of several models of biodiesel fuel droplet heating and evaporation in realistic Diesel engine-like conditions is presented. Nineteen types of biodiesel fuels composed of methyl esters are used for the analysis. It is shown that the model, based on the assumption that the diffusivity of species in droplets is infinitely fast and the liquid thermal conductivity is infinitely large, under-predicts the droplet evaporation time compared with the model taking into account the effects of finite diffusivity and conductivity, by up to about 15%. A similar under-predictions of the model in which the transient diffusion of species is ignored and the liquid thermal conductivity is assumed to be infinitely large, is shown to be about 26%. The latter result is not consistent with the earlier finding, based on the analysis of only five types of biodiesel fuels and different input parameters, in which it was shown that the deviations between the evaporation times predicted by these models do not exceed about 5.5%. As in the case of Diesel and gasoline fuel droplets, for biodiesel droplets the multi-component models predict higher droplet surface temperatures at the final stages of droplet evaporation and longer evaporation times than for the single-component models. This is related to the fact that at the final stages of droplet evaporation the mass fraction of heavier species, which evaporate more slowly than the lighter species and have higher boiling temperatures, increases at the expense of lighter species.

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1. Introduction

The interest to biodiesel fuels has been mainly stimulated by depletion of fossil fuels and the need to reduce carbon dioxide emissions that contribute toward climate change [1]. The term 'biodiesel' typically refers to "a fuel comprised of mono-alkyl esters of long-chain fatty acids derived from vegetable oils or animal fats" [2]. Biodiesel fuel is typically produced by chemical conversion of animal fats or vegetable oils [3,4]. The use of biodiesel fuel is expected to contribute to the reduction of global warming [5]. Also, using biodiesel fuel as an alternative to conventional fuels has a number of other advantages: it readily mixes with fossil Diesel fuels, it is less polluting, has higher lubricity, higher flash point, it is cost effective, and can be used in Diesel engines with minimal modifications [6–9]. According to the U.S. Environmental Protection Agency – Tier I and Tier II standards (see [10] for details), currently produced biodiesel types have passed the health effects testing requirements [11].

The analysis presented in this paper is focused on the modelling of biodiesel fuel droplet heating and evaporation, which is an important stage of the process leading from the injection of biodiesel fuel into combustion chamber to its ultimate combustion, producing the driving force for internal combustion engines. In contrast to most previously suggested models for these processes, the temperature gradients and species diffusion inside droplets are taken into account based on the analytical solutions to heat transfer and species diffusion equations, which are incorporated into a

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Table 1
Types of biodiesel fuels, their abbreviations, acid codes and molar fractions of the components (pure methyl esters). Symbols ‘M for the acid codes are omitted.

Methyl esters	Abbreviations	Fatty acids																	
		C8:0	C10:0	C12:0	C14:0	C16:0	C17:0	C18:0	C20:0	C22:0	C24:0	C16:1	C18:1	C20:1	C22:1	C24:1	C18:2	C18:3	Others
Tallow	TME	–	–	0.20	2.50	27.90	–	23.00	0.40	0.40	–	2.50	40.00	0.30	0.30	–	2.00	–	0.50
Lard	LME	–	–	–	1.00	26.00	–	14.00	–	–	–	2.80	44.00	2.00	2.00	–	8.00	–	0.20
Butter	BME	5.19	2.80	3.40	10.99	31.66	–	10.79	0.40	0.40	–	2.40	26.37	1.00	1.00	–	3.00	0.60	–
Coconut	CME	6.00	8.00	50.00	15.00	9.00	–	3.00	–	–	–	–	7.00	–	–	–	2.00	–	–
Palm Kernel	PMK	2.60	4.00	50.00	17.00	8.00	–	1.70	1.50	1.50	–	0.40	12.00	–	–	–	1.30	–	–
Palm	PME	–	–	0.26	1.29	45.13	–	4.47	0.35	0.17	–	0.21	38.39	–	–	–	9.16	0.19	0.38
Safflower	SFE	–	–	–	–	5.20	–	2.20	–	–	–	–	76.38	–	–	–	16.22	–	–
Peanut	PTE	–	–	–	0.50	8.00	–	4.00	7.00	7.00	–	1.50	49.00	–	–	–	23.00	–	–
Cottonseed	CSE	–	–	–	2.00	19.00	–	2.00	–	–	–	–	31.00	2.50	2.50	–	41.00	–	–
Corn	CNE	–	–	–	1.00	9.00	–	2.50	–	–	–	1.50	40.00	1.00	1.00	–	44.00	–	–
Sunflower	SNE	–	–	–	–	5.92	–	4.15	1.38	1.38	–	–	18.46	–	–	–	68.41	0.30	–
Tung	TGE	–	–	–	–	3.64	–	2.55	–	13.14	–	–	10.10	0.81	–	–	13.75	51.64	4.37
Hemp1	HME1	–	–	–	–	6.62	0.21	2.06	0.45	0.25	0.23	0.33	11.88	0.27	0.17	0.15	56.71	20.67	–
Soybean	SME	–	–	–	0.30	10.90	–	4.40	0.40	–	–	–	24.00	–	–	–	52.80	7.20	–
Linseed	LNE	–	–	–	0.20	6.20	–	0.60	–	–	–	–	18.00	–	–	–	16.00	59.00	–
Hemp2	HME2	–	–	–	–	6.51	–	2.46	0.90	–	–	–	11.88	0.90	–	–	54.82	20.07	2.46
Canola seed	CAN	–	–	–	–	4.48	0.14	1.99	0.62	0.35	0.16	0.36	59.66	1.49	0.42	–	20.89	9.44	–
Waste oil	WME	–	–	0.20	0.67	15.69	0.20	6.14	0.39	0.44	0.30	0.73	42.84	0.56	0.15	–	29.36	2.03	0.30
Rapeseed	RME	–	–	–	–	4.93	–	1.66	0.56	–	–	–	26.61	–	22.32	0.77	24.75	9.70	8.70

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