

# Numerical Study of Evaporation Modelling for Different Fuels at High Operating Conditions in a Diesel Engine <sup>†</sup>

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<sup>†</sup> Presented at the 1st International Conference on Energy, Power and Environment, Gujrat, Pakistan, 11–12 November 2021.

**Abstract:** A fuel injection system in a diesel engine has different processes that affect the complete burning of the fuel in the combustion chamber. These include the primary and secondary breakups of liquid fuel droplets and evaporation. In the present paper, evaporation of two different diesel fuels has been modelled numerically. Evaporation of n-heptane and n-decane is governed by the conservation equations of mass, energy, momentum, and species transport. Results have been plotted by varying the droplet diameter and temperature. It was observed that droplet size, temperature of droplets, and ambient temperature have notable effect on the evaporation time of diesel fuel droplets in the engine cylinder.

**Keywords:** droplet evaporation; RANS; turbulence; diesel fuel; combustion; numerical analysis



**Citation:** Raza, A.; Miran, S.; Islam, T.U.; Malik, K.I.; Zunaira-Tu-Zehra; Hadia, M. Numerical Study of Evaporation Modelling for Different Fuels at High Operating Conditions in a Diesel Engine. *Eng. Proc.* **2021**, *12*, 8. <https://doi.org/10.3390/engproc2021012008>

Academic Editor: Shahid Iqbal

Published: 22 December 2021

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## 1. Introduction

Automotive industries aim to enhance the efficiency and power output of engines whilst remaining within the range of imposed standard emission principles, which are becoming more strict and rigorous day by day [1]. Evaporation modelling of diesel fuel droplets was started by Landis and Mills [2], followed by Law [3]. Fuel is injected in the form of spray from a nozzle hole at a temperature higher than its saturation temperature. In this way, the fuel becomes superheated and its temperature rises above the critical value [4,5]. During the evaporation process, the gas phase is governed by the Eulerian approach, while droplet trajectories are traced in a Lagrangian frame [6]. In the present work, conservation equations of energy, mass, momentum, and species have been coupled and numerically solved to model the overall evaporation of two different diesel fuels. Evaporation of fuel droplets present in the engine cylinder starts from the surface diffusion [7]. Droplets are injected into the engine cylinder by creating a discrete phase injection. There are different types of injections that can be applied. In this work, a single injection was used to inject the liquid fuel into the chamber [8–12]. Unsteady particle tracking was done through the DPM in the continuous phase. Liquid particles were injected in the form of spray from a hole that dispersed in the continuous phase. Particle trajectories were also observed in the continuous phase at a high temperature and pressure in the Lagrangian frame of reference.

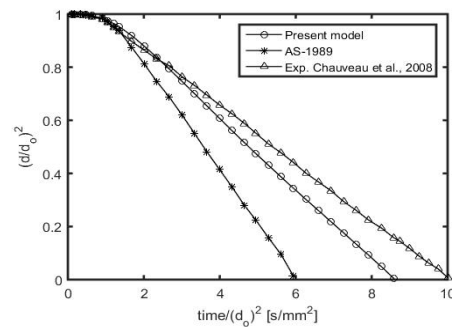
## 2. Numerical Modelling

The presented model was applied to govern the evaporation of droplets of n-heptane and n-decane fuels in Ansys Fluent. The DPM was applied to solve the discrete phase, i.e.,

fuel droplets entering into the continuous phase present in the combustion chamber. The presented model was applied to the engine specifications available in [13].

### 3. Model Validation

The droplet evaporation model presented above was implemented in the Ansys Fluent; obtained numerical results were compared with the vaporization experiments by Chauveau et al. [8] as shown in Figure 1. The numerical results of the presented model were also compared with the evaporation of model of Abramzon and Sirignano [9] and additionally with the earlier work in [12,13].



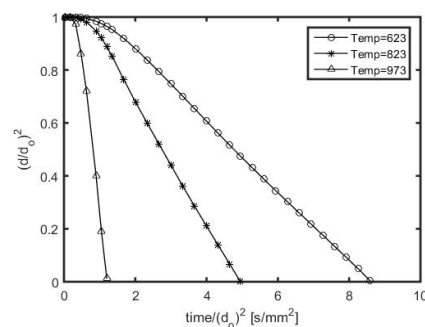
**Figure 1.** Comparison of model for n-decane droplet vaporization with experiment of Chauveau et al. and numerical results for AS-1989 at 623 K.

### 4. Results and Discussion

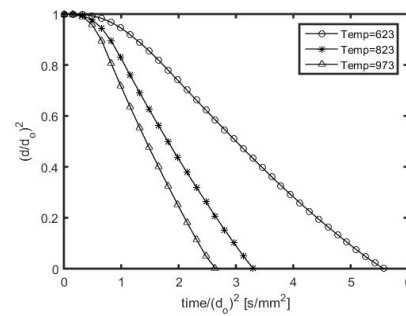
In the following section, results for n-decane and n-heptane fuel droplets are presented under different ambient conditions. Normalized droplet diameters have been plotted using D-square law against the normalized time.

#### 4.1. Case 1 Fuel: n-Decane

From Figure 2, we can clearly see that the n-decane droplets of 10 microns in diameter evaporated completely within a short period of time at a high ambient temperature of 973 K compared to the lower ambient temperatures of 623 K and 823 K. Similarly, in Figure 3, vaporization of n-decane droplets of 20 micron in diameter has been plotted, once again playing the same trend. Droplets of the same size evaporated more quickly at high temperatures. As the temperature increases, vaporization time decreases and vice versa.

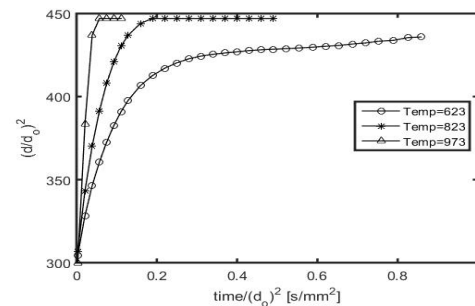


**Figure 2.** Vaporization of 10-micron n-decane droplets at different ambient temperatures.

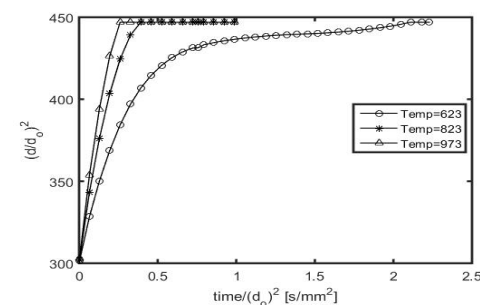


**Figure 3.** Vaporization of 20-micron n-decane droplets at different ambient temperatures.

In Figures 4 and 5, increases in droplet temperature have been plotted. Droplets evaporated and disappeared within a short period of time at high ambient temperatures, while lower ambient temperatures caused droplets to take more time to evaporate completely.



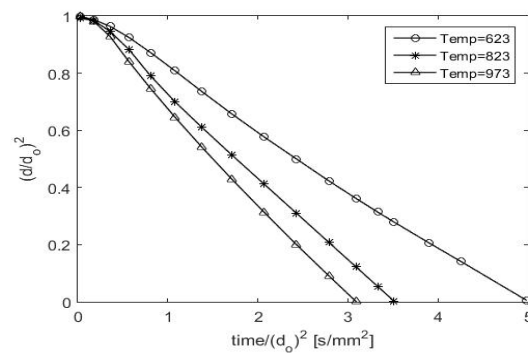
**Figure 4.** Effect of ambient gas temperature on the evaporation of 10-micron n-decane droplets.



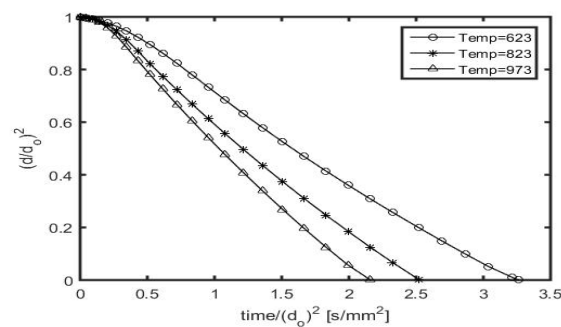
**Figure 5.** Effect of ambient gas temperature on the evaporation of 20-micron n-decane droplets.

#### 4.2. Case 2 Fuel: n-Heptane

In Figures 6 and 7, vaporization results for n-heptane fuel droplets are presented. In this section, droplets sized 10 and 20 microns were considered. It was observed that droplets of smaller size evaporated within a short time compared to droplets of larger sizes. Ambient temperature also affects the evaporation of diesel fuel droplets. At a temperature of 973 K, the droplet lifetime was much shorter than at a temperature of 623 K. Also, it was observed that the evaporation time of n-heptane fuel droplets was lower than that of n-decane.

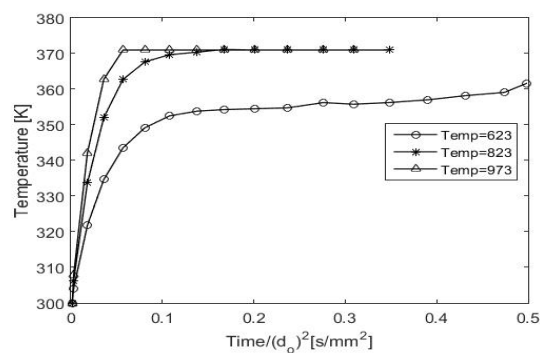


**Figure 6.** Vaporization of 10-micron n-decane droplets at different ambient temperatures.

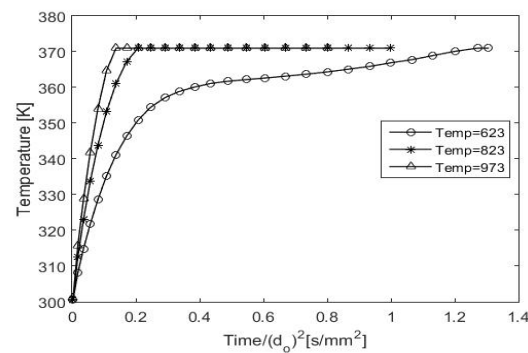


**Figure 7.** Vaporization of 20-micron n-decane droplets at different ambient temperatures.

In Figure 6, decrease in the diameter of n-heptane fuel droplets 10 microns in size have been plotted using the  $D^2$ -law against the normalized time. It is obvious that at a lower temperature of 623 K, droplet life is higher than at the temperatures of 823 and 973 K. For the temperature of 623 K, the droplet residence time is greater than at the temperatures of 823 K and 973 K. In Figure 7, the evaporation of 20-micron droplets has been plotted against the normalized time. In this figure, it can be clearly seen that by increasing the droplet size, the evaporation time of droplets also increased. In Figure 7, the regression rate of 20-micron droplets has been plotted at three different ambient temperatures. Evaporation time at high ambient temperatures is low and vice versa. In Figures 8 and 9, temperature profiles of 10- and 20-micron droplets have been plotted against the normalized time. The same trend can be observed across the different ambient temperatures.



**Figure 8.** Effect of ambient gas temperature on the evaporation 10-micron n-decane droplets.



**Figure 9.** Effect of ambient gas temperature on the evaporation 20-micron n-decane droplets.

## 5. Conclusions

Our results show that droplet with a large diameter take more time to evaporate completely compared to the smaller ones. Small droplets evaporate more quickly due to a shorter heat up period than for the larger ones. Droplets of the same size behave differently at different ambient temperatures. The droplet evaporation time for a high temperature is smaller than for a low temperature. Further temperature profiles of droplets plotted against the injection time shows that small droplets evaporate quickly by absorbing the temperature quickly.

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