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State of the Art of Fuel Droplet Evaporation

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ABSTRACT

The process of fuel droplet evaporating is one of the most important factors that directly affect the efficiency of the combustion process. Therefore, the current study reviews previous studies that focused on the process of evaporation of a drop of fuel. The review is divided into points. The first part is concerned with modeling of the evaporation process under different initial condition and temperature of the droplet. The second part present the experimental studies concerned with measuring the evaporation time of the droplet, as well as the shape of the droplet during the evaporation process. Most of the studies related to this subject can be divided into three categories: The first category is the studies that are concerned with the process of heating the droplet and studying the evaporation time for different types of fuels or by adding nanomaterials to the fuel and studying their effect on the evaporation process. The second category is the studies concerned with the mechanics of droplet evaporation and the study of droplet shape. The third category is the studies that focus on studying the effect of initial conditions, such as temperature and pressure, as well as the concentration of gasses surrounding the drop and their types. There are other studies concerned with projecting the electric field onto the drop during the evaporation process and studying its effect.

1. INTRODUCTION

The studying of fuel evaporation helps to better understanding of combustion process and to reduce the emission. Al Qubeissi [1] studied and analyzed the fuel droplet evaporation by using Discrete Component Model (DCM). They used diesel, biodiesel, gasoline, and blended fuels. The results showed that increasing the fraction of biodiesel in the diesel-biodiesel mixture on the droplet evaporation and surface temperature of droplet was noticeable. So that its needs more than 5% fraction of biodiesel to effected on the droplet evaporation time.

Sazhin et al. [2] introduce novel method for simulating the evaporation of fuel droplet. They used gasoline fuel with specific condition as in real condition in internal combustion engine. The numerical model used to simulate the number of components of gasoline with identical chemical formulae and similar thermodynamic and transport properties. The modeling process used to replace the 83 components of original composition of gasoline fuel with 20 components only. In a subsequent study by the same researcher Al Qubeissi et al. [3] the blended Diesel and biodiesel fuel was used .They found that Multi-component model gives longer evaporation time and higher surface temperature than single component model for both gasoline and diesel fuel droplet.

Poulton et al. [4] studied the evaporation process theoretically by using A Discrete Component Model (DCM). The used kerosene droplet with suspended technique. They focused on the effect of natural convection and wire material on the evaporation process. The simulation results showed that the supporting wire material very affect the evaporation time.

They used droplet diameter ranges from 0.9 mm to 1.1 mm with ambient gas temperature range from 400°C to 800°C. The SiC fiber with 100µm diameter used to suppurated the droplet. The results showed that at gas temperature 400°C. The droplet diameter reaches 0.127mm after 6.540 s, and reached to 0.199mm after 1.3085 for 800°C gas temperature. Many studied analyzed the discrete component model or individual component to simulate fuel droplet heating and evaporation such as [5-9]. They found that discrete component model gives highest accuracy. A multi-dimensional quasi-discrete model was utilized in several investigations [3, 10]. A modest number of representative components were used in place of a huge number of other components in this modeling.

Rybdylova et al. [11] modeled the analytical approximations to the heat conduction and species diffusion equations in the liquid phase, the multi-component droplet heating and evaporation was using ANSYS Fluent software. They used three droplets (25% ethanol/75% acetone), (50% ethanol/50% acetone), (75% ethanol/25% acetone). The results indicated that the highest variation between estimated temperatures did not exceed 0.16% for t = 4 ms, 0.14% for t = 5 ms, and 0.13% for t = 6 ms. This indicates that the consistency between ANSYS Fluent's predictions and the in-house code is reasonably excellent. In practically all practical applications, this disparity between the findings can be disregarded.

Dai et al. [12] investigated the evaporation of characteristics of Nano fuel with different dose 0.05% ,0.25% ,1.25% and 5% by weight Diesel/cerium oxide nanofluid fuel. The nanoparticle used is ceria nanoparticles at temperature 673K and 873K under normal gravity. The results showed that the evaporation is improved with nanoparticle, especially with 0.25% to 1.25%.

Pinheiro et al. [13] studied and investigated the affect ambient temperature and pressure on the evaporation rate. The fuel which used was ethanol. The ranges of the temperature, pressure and concentrations were 400-1000 K ,0.1-0.2 MPa and 0.0-0.75, respectively. The results showed that this increasing of the pressure the rate of the evaporation decreases. When the ambient temperature increases the rate of evaporation increased. The droplet lift time increased as concentration increase at ambient temperature 400 K and decrease for ambient temperature 800 K. Many studies focused on the ambient temperature and pressure effect on the droplet evaporation rate for hydrocarbon fuel such as [14-17].

Mouvanal et al. [18] investigated experimentally and numerically the evaporation of single and multi-component hydrocarbon film in a spray in a hypothetical spherical bubble. In this studying three types of fuel heptane, hexade cane and mixture from both 50% heptane and 50% hexadecane. The results showed that the effects of neighbor droplets become significant for spray parameters. For single component fuel, the fluctuation in film thickness with time was found to be linear; for multi component fuel, it represented fractional distillation.

Valiullin et al. [19] explained the combustion characteristic for droplet group of coal-water slurry containing petrochemicals and oil surrounded by water droplets. The results showed that the rate of the evaporation of water decrease by 25% when the distance between of them increased.

Luo et al. [20] studied and investigated experimentally the combustion of fuel droplet with electric field. The results showed that the combustion time is dropped by 14% compared with combustion without the electric field, also the electric field effected on the shape of the droplet as shown in Figure 1. also, many study focused on the electrical field effect on the droplet evaporation such as [21-23], while Zong et al. [24, 25] study the droplet combustion with electrical field, and Ahmed et al. [26] study the droplet combustion with electrical field.

Dodd et al. [27] studied numerically the n-heptane fuel droplet evaporation in turbulence interaction by using Direct Numerical Simulation. Also, this study carried out to analyze the effect of initial droplet diameter to Kolmogorov length scale(d_0/η) and the liquid volume fraction (α) on evaporating rate of n-heptane droplets at high temperature and pressure. The results presented when liquid volume fraction increased the evaporation rate decreased because of decreasing in mass transfer potential. Also, when liquid volume fraction was ($\alpha=10^{-2}$) led to evaporate the droplet more slowly in comparison with (d^2-law) because of reduction in droplet surface area due to merging droplet-droplet and decreasing of mass transfer potential.

Ruitian et al. [28] investigated the evaporation and condensation of n-heptane and multi component diesel droplets. They studied the influence of ambient composition on the evaporation and condensation rate. The results showed that by increased of vapor concentration the droplet evaporation rate decreased. Figure 2 showed the effect of ambient temperature and vapor concentration on lift time. the are many studies that focus on the effect of vapor concentration on the droplet evaporation such as [13, 29, 30].

Lupo et al. [31] develop theoretically a new method based on direct numerical simulation is called Immersed Boundary Method (IBM) for spherical droplet evaporation in gas space. This method coupled energy momentum and species transport in gas phase. They used hydrocarbon droplet in isotropic homogeneous turbulence. The results described this method by robustness, without loss accuracy in phase change and low computational cost.

Ma et al. [32] studied experimentally a single suspended hydrocarbon droplet in normal gravity conditions and sub-critical pressure situations. The findings revealed the ratio of evaporation rate to combustion time changes slightly in sub-critical pressure conditions but rapidly drops in super-critical pressure situations, indicating that the droplet evaporation process completes faster in super-critical pressure environments.

Gong et al. [33] studied the droplet evaporation process for fuel have six –component hydrocarbon (13.81 mol% n-decane,13.16 mol% toluene, 11.47 mol% n-octadecane, 14.66 mol% n-hexadecane, 24.60 mol% n-tetradecane, and 22.30 mol% n-dodecane). The droplet in environment of nitrogen. The ambient pressure ranged from 2Mpa to 16Mpa.The results showed that the evaporation process faster when ambient temperature increased. They showed that the supercritical transition temperature had both a minimum and a maximum at a specific ambient pressure. The evaporation of droplets in supercritical circumstances has been reviewed from a variety of perspectives. [16, 34-37].

During the actual evaporation and combustion process inside the combustion engines, the evaporation process is through aggregates of droplets and not a separate drop. Therefore, the process of overlapping between the drops leads to a more complex evaporation process, as was clarified by Bouaziz et al. [38-40].

Therefore, the process of separating and studying the drop separately will give approximately an example of the actual process of evaporation and combustion as it was done through [41, 42].

The evaporation of small droplet phenomenon is occurring in many situations. In aerosol applications such as inhalation drug delivery. In other satiations such as fogs, falling rain drop. Also in many industrial applications like spray combustion, gas absorption, flam spray.

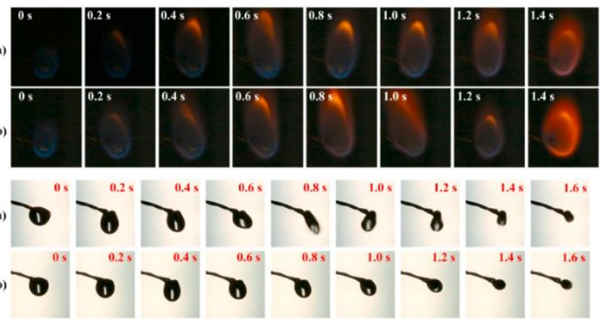


Figure 1. Flame and droplet image (a) without electrical filed (b) with E = 50 kV/m [20]

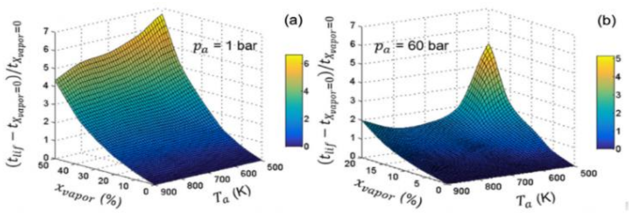


Figure 2. The effect of vapor concentration and ambient temperature on lift of n-heptane droplet [28]

2. DROPLET EVAPORATION TECHNIQUES

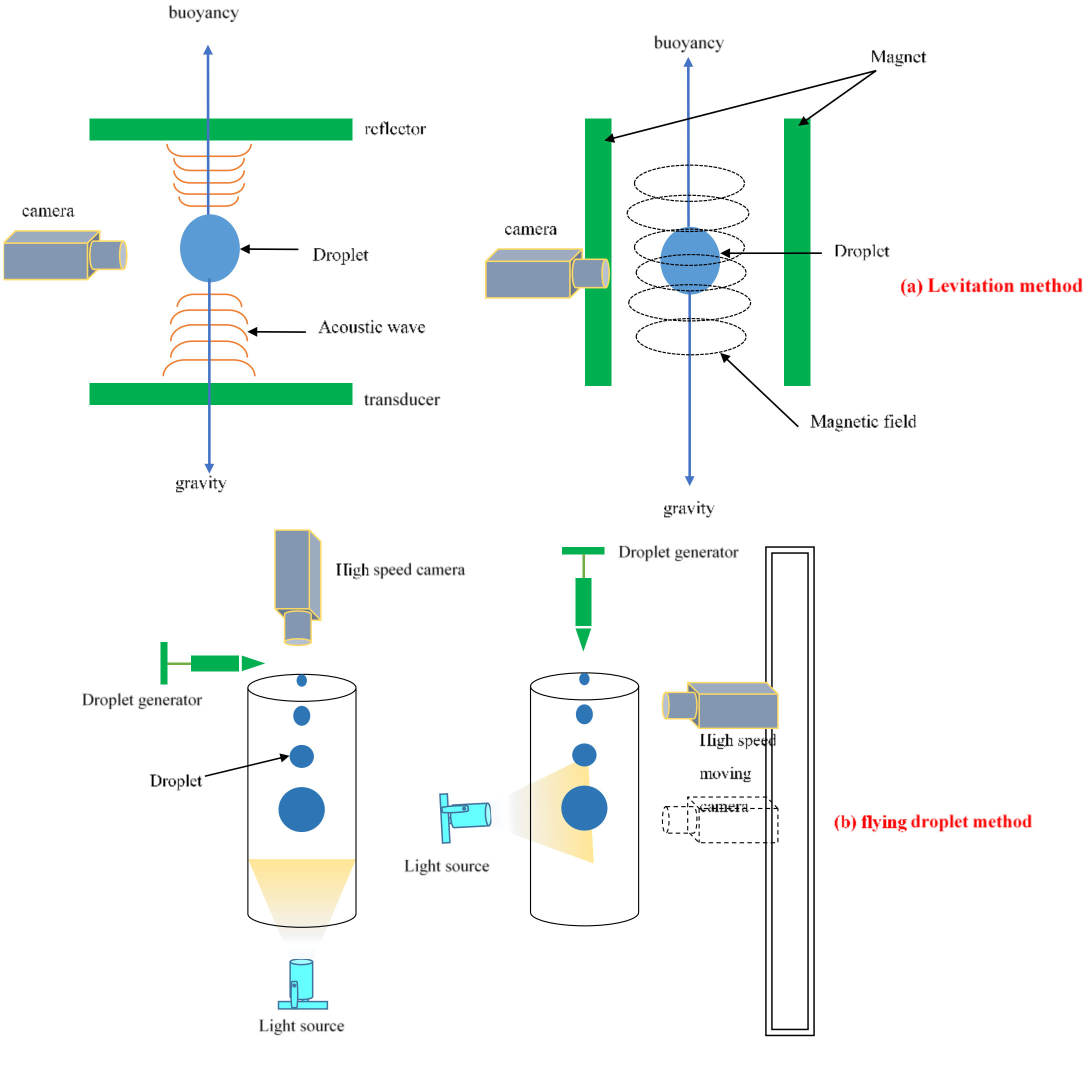
2.1 Levitated droplet

This method depends on the balances between the gravity force and magnetic, acoustic, fuel vapor bounce force as showed in Figure 3a, the schematic diagram of this methods. In this method the droplet shape is stable (spherical) without any deformation. The droplet can be observed for a long time as investigated by Grosshans et al. [43]. On the other hand, the droplet takes time to levitation droplet to stable. the levitations force by acoustic or magnetic field effects on the evaporation process. The levitated method can be used only with low ambient temperature and with atmospheric pressure.

Fu et al. [44] descripted this method in their study as explained in Figure 4, a systematic explanation of the single droplet drying system's operation. A solitary droplet is created and introduced into a stream of conditioned air.

By examining the projected droplet shadows photographed by a camera, Kastner et al. [45] observed the diameter variations of single droplets dried in an acoustic field. However, determining the rate of evaporation was more difficult than determining the rate of size change. According to changes in droplet volume, they separated each droplet drying procedure into two stages. In the first drying stage, the droplet volume was used to estimate the evaporation rate; however, in the second drying stage, when the volume reduction becomes minimal, the evaporation rate was measured by changes in the position of the droplet particles in the acoustic field. It was also used by Brenn et al. [46] to estimate the rate of evaporation using changes in droplet diameter. The evaporation rate was not taken into consideration in the reports by Mondragon and coworkers [47, 48]; instead, the droplet drying behavior in the acoustic field was simply assessed by the size changes, with the effects of drying conditions and initial droplet conditions on the final particle properties being investigated. to make it easier to measure the rate of droplet evaporation in the SDD processes that use sonic levitation. For the purpose of accomplishing a continuous, on-line measurement of the droplet moisture content while drying progressed, Groenewold et al. [49] included a dew point hygrometer to the system. Calculating the partial vapor pressure of outflow air converted the experimental data into droplet drying curves [50, 51]. A droplet with a diameter of 1 m is suspended from the end of a thin glass or glass capillary tube and placed in a regulated air stream in a contact levitation experiment. A camera and a thermocouple (one placed in the core of the droplet and the other in the tube) are used to evaluate drying variables such the droplet's mass as well as diameter reductions [52].

Junk et al. [53] studied experimentally the evaporation of single droplet levitation. They studied different parameters such as droplet deformation, temperature, and surrounding flow field. The used acoustically levitated droplets as shown in Figure 5. The results showed that the droplet aspect ratio as shown in Figure 6 affects the rate of evaporation. Also many studies used acoustic levitation such as [54-56] where they investigated the effect of an acoustic stream on the mass and heat transfer around the droplet.



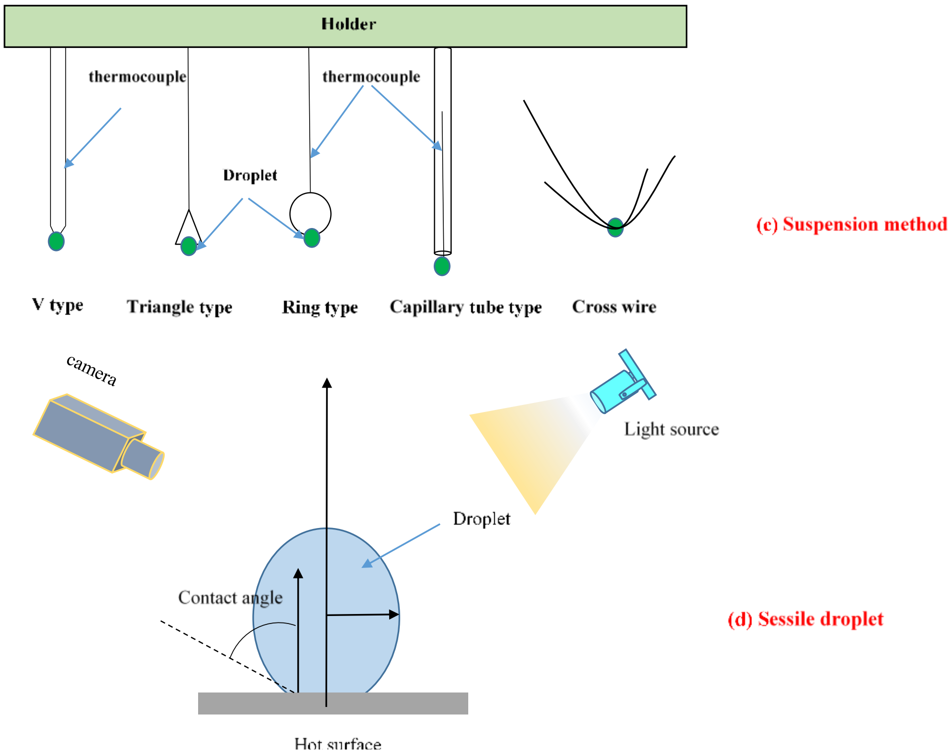


Figure 3. Schematic diagram of droplet evaporation methods: (a) Levitation method, (b) flying droplet method, (c) suspension method, (d) sessile droplet method

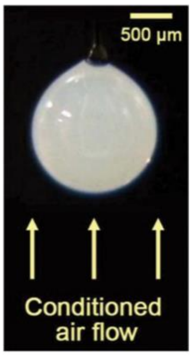


Figure 4. The glass filament single droplet drying system [44]

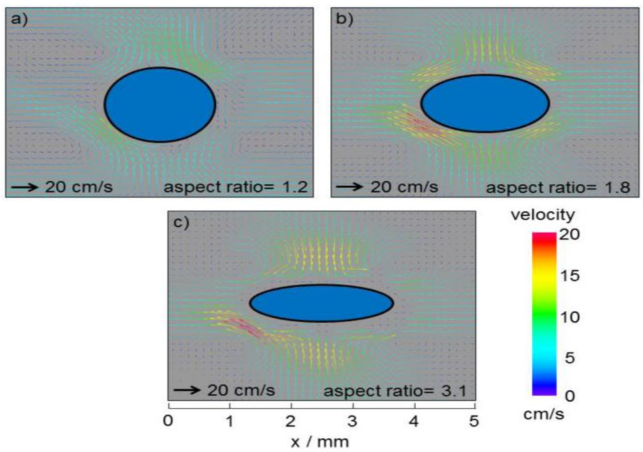


Figure 6. Acoustic flow velocity with different aspect ratio [53]

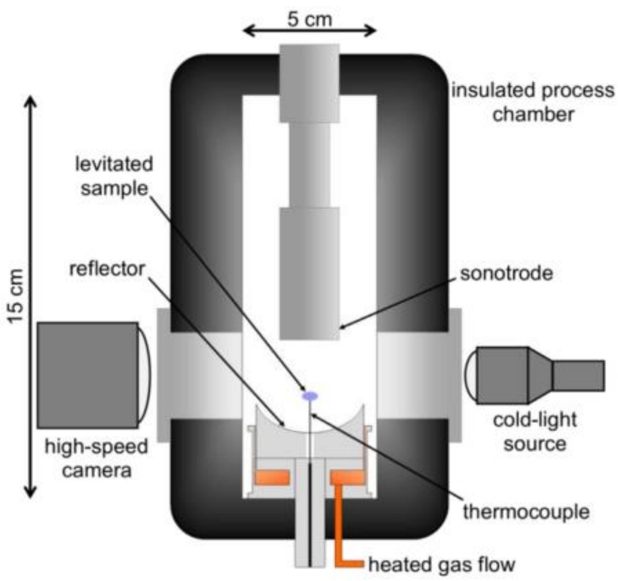


Figure 5. Experimental setup of single droplet levitation by acoustic [53]

2.2 Free-flying droplet

In this method the droplet falling freely under gravity force in the experimental chamber. The evaporation process captured by high speed camera. The camera may be a wide angle fixed or moving camera as shown in Figure 3b. In this method easy to control the droplet evaporation and may be produced a small droplet as in real engine. The droplet evaporation in this method don't effected by any external force. This method involves creating one homogeneous free-falling droplet or a chain of them at the top of the drying tower using a regulated air stream [57, 58].

A non-contact optical sensor for the detection of single droplets in flight was described by Tröndle et al. in their study Tröndle et al. [59]. The sensor enables non-contact dispensing systems that deliver droplets in the nanoliter range to have online process control.

Bae and Avedisian [60] studied the evaporation and combustion of JP8 fuel droplets mixed with hexanol ($C_6H_{14}O$) additives in a low gravity environment. The used two types of evaporation technique free flying and supported droplet to examined the affect convection on the evaporation rate under the low gravity environment The initial droplet diameters was ranged 0.40 to 0.52 mm. The results showed that the evaporation rate of JP8 with additives and pure JP8 as shown in Figure 7.

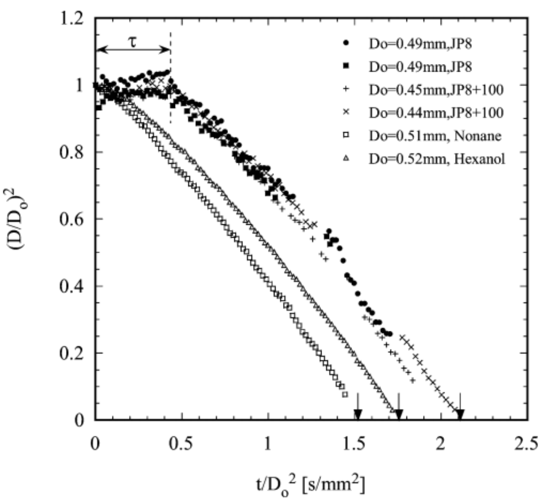


Figure 7. Evolution of droplet diameter in the coordinates of the classical D^2 law [60]

2.3 The suspension droplet method

In this method the droplet supported by thermocouple wire [61-63], Ceramic wire [64, 65], or quartz wire [15, 65]. The suspension method can be explained in Figure 3c and 3d. The supported shape may be crossed, ring shape, or by using capillary tube. This method used for only large droplet evaporation but in this method easy to observed and measured the temperature and evaporation rate of droplet for a long time. The supported material very effected on the evaporation process. In the suspension droplet method, a wider of temperatures can be studied. Calculating the droplet temperature during the evaporation process is one of the most important features of the droplet method. This method allows the use of a wide range of pressures surrounding the droplet.

2.4 Sessile droplet

This method involves properly placing a droplet with size ranged from nanometer to millimeter on a hydrophobic surface inside a dry well with regulated environmental conditions. Xu et al. [66-70] covered the latest recent findings from research on liquid droplet evaporation on solid substrates.

The process of evaporation through Sessile droplet method goes through four stages that can be illustrated by Figure 8. The Spreading stage. During this stage, the initial droplet diameter is as large as possible and the contact angle is advanced. Therefore, the rate of evaporation during this stage is very low for simple fluids. Therefore, most studies neglected the evaporation during this stage, only the remaining three stages are focused on [71-73]. The drop base radius remains constant throughout the first stage of evaporation, but the contact angle lowers to the value of the decrees angle. As a result, the first step of evaporation is an example of angle hysteresis. The second step sees no change in the angle., but the drop base radius decreases. In the third and last stage of evaporation, the angle and drop base radius both decrease until the drop disappears.

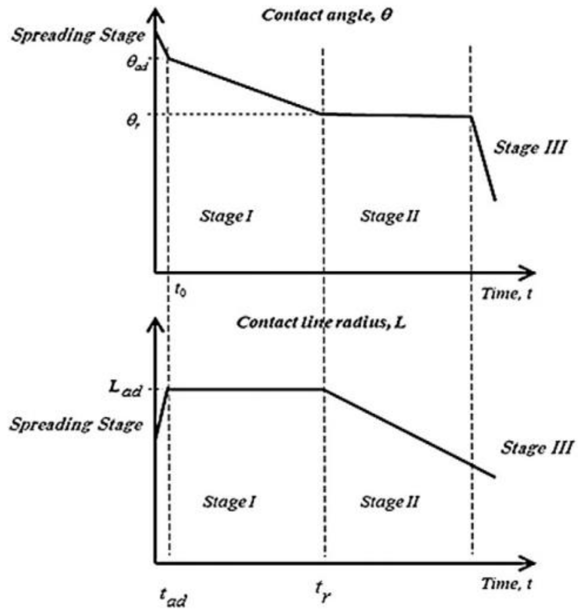


Figure 8. The stages of evaporation of Sessile droplet [70]

Cai et al. [74] conducted a novel mechanistically based Leiden frost point (LFP) model for a sessile droplet, a theoretical inquiry. The model is made up of smaller models that represent temporal variations in droplet size and form as well as the thickness of the vapor layer that separates the droplet from the hot surface during evaporation. After talking about the significance of LFP, this paragraph will highlight how difficult it is to forecast LFP. LFP for spray quenching, as depicted in Figure 9, differs significantly from that for bath quenching because it takes place within impacting droplets instead of a liquid pool. The evaporation profile for a sessile droplet was described in Figure 8b.

Vafaei et al. [75] examined the relationship between the quality and composition of the substrate material, the concentration and size of the nanoparticles, and the variation in contact angle of droplets of nanofluid functionalized with thioglycolic acid molecules. A micro emulsion technique was used to generate and disseminate in water bismuth telluride nanoparticles with an average size varying from 2.50 to 10.40 nm and functionalized with thioglycolic acid groups.

The evaporation of sessile droplets of single and multi-component fuel was studied by Erbil et al. [76, 77]. The study of sessile depend on the surface topology as explained by Itaru, and Kunihide [78], who used hot and smooth surface of brass, copper, and steel to study the evaporation of water droplet on the surface. Also, Fardad, and Ladommatos [79] studied the evaporation of hydrocarbon fuel on different metal plate. The results showed that the greatest evaporation occurs near the saturation temperature of the fuel. Further increasing the surface temperature over the saturation point decreases the rate of vaporization because less heat is transferred from the metal surface to the liquid film due to the accumulation of a vapor cushion below the liquid film.

Due to the larger droplets and the fact that their drying behavior might be affected by the experimental drying equipment, their static state, and the experimental environment, single-droplet investigations are not recommended [80].

Heat conduction between the solid support and the droplet can impact the transmission of mass and heat [44]. Additionally, spray drying, which uses convection for heat transfer, differs significantly from the heating of levitated droplets by laser radiation [81].

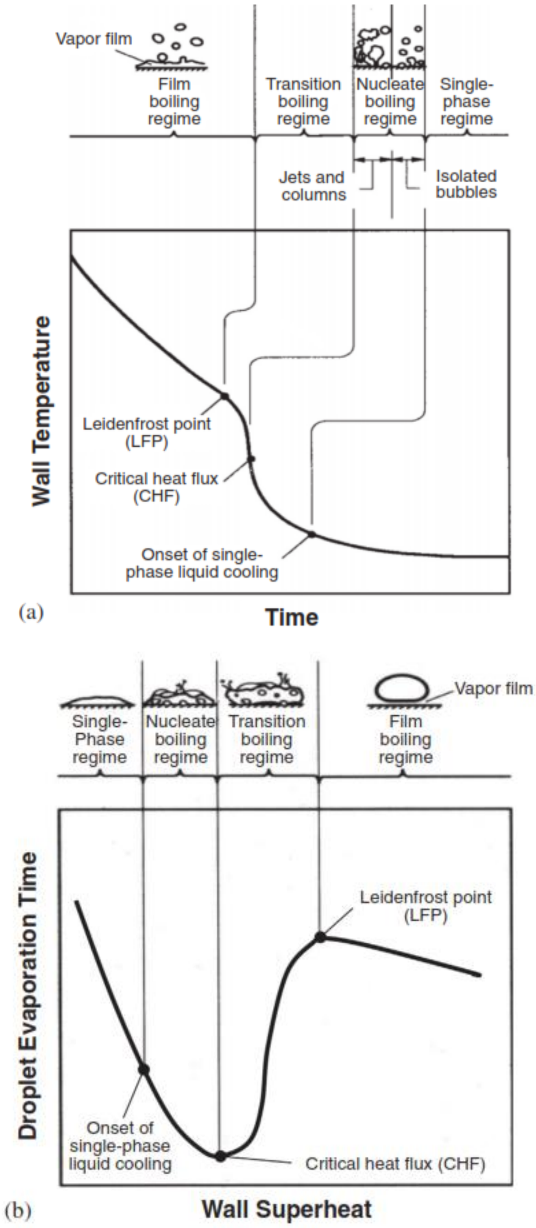


Figure 9. A sessile droplet (a) quenching curve, (b) Evaporation rate [74]

2.4.1 Mathematical model for evaporation of a sessile droplet

Evaporation can be explained as mass, heat and movement of stream. The heat transfer could be in three ways diffusion, conduction and radiation as shown in Figure 10. The heat transfer in diffusion and conduction happened during contact between substances in the rest. Also, the radiation happed during the propagation of electromagnetic waves [81]. Convectional heat transfer is represented by the flow of gases and liquids up and down. Heat is carried from the heated air to the liquid surface by conduction and convection, where it is translated to latent heat. Mass is then moved from the liquid surface back to the air through diffusion and convection [82]. The study of evaporation is very complex problem because there are many different factors affect the evaporation such as the saturation not constant (vary), the system is exposed to surface tension, vapor, temperature, heat transfer by convection, conduction, radiation and diffusion.

At the liquid-vapor interface in thermodynamic equilibrium, the rate of evaporation of droplet is equal the rate of mass diffusion at any given moment, according to Fick's law [76]. Following the analogy between the rate of heat transfer during evaporation and the rate of diffusion [83]. The following, as shown in Figure 11, provides the rate of mass loss via evaporation.

The diffusions of fuel gas through air can be described by using Fick's law. At one-dimensional binary diffusion, Fick's law on a mass basis is

$$\dot{\boldsymbol{m}}''_{\mathrm{A}} = C_{\mathrm{A}}\left(\dot{\boldsymbol{m}}''_{\mathrm{A}} + \dot{\boldsymbol{m}}''_{\mathrm{B}}\right) - \rho\mathcal{D}_{\mathrm{AB}}\nabla C_A \quad (1)$$

Assuming the droplet is spherical shape, the surface area is ($A=4\pi R^2$) the mass has expressed as [84, 85].

$$-\frac{dm}{dt} = -4\pi \mathrm{R}^2 D_v \frac{dC}{dR} \quad (2)$$

where, (m) is mass;
(t) time;
R the droplet radius;
(D_v) diffusion coefficient of vapor in air;
C concentration of vapor in environment;
the vapor concentration at surface of the droplet is C_s;
the vapor concentration at an infinite distance from the droplet center is C_∞.

At boundary conditions:
$C=C_s$
$R=R_s$
The Eq. (18) will be integrated as:

$$\int_{C_S}^{C_\infty} dC = \frac{1}{-4\pi D_v}\int_{R_s}^{R_\infty}\frac{1}{R^2}dR \quad (3)$$

$$-\frac{dm}{dt} = -4\pi \mathrm{R}_s D_v\left(C_s - C_\infty\right) \quad (4)$$

where:
R_s represent the radius of a spherical droplet (m);
R_∞ the infinite distance from the center of the droplet;

Opposite to measurements made in a vacuum, when the evaporation process is induced, the rate of evaporation in Eq. 4 is related to the radius of the spherical droplet (big droplets evaporate quicker to small droplets), however not to the surface area of the droplet.

$$-\frac{dm}{dt} = 4\pi \mathrm{R}_s D_v \frac{M}{\mathfrak{R}T}\left(P_s - P_\infty\right) \quad (5)$$

$$-\frac{dR_s^2}{dt} = \frac{2DM}{\rho_L \mathfrak{R}T}\left(P_s - P_\infty\right) \quad (6)$$

$$R_{s,O}^2 - R^2 = \frac{2DM}{\rho_L \mathfrak{R}T}\left(P_s - P_\infty\right)t \quad (7)$$

$$-\rho_L\left(\frac{dV}{dt}\right)=4\pi R_s D_v \frac{M}{\Re T}(C_s - C_\infty) f\ (\theta) \qquad (8)$$

where, ρ_L is the droplet density;

f (Θ) contact angle function. As shown in Figure 12 the evaporation models for a sessile droplet.

The evaporation happens for droplets which consists of many components which have different of different physical and chemical properties [86]. Additionally, the evaporation process was impacted by the temperature and concentration dependency on the liquid characteristics, particularly in terms of a decreased diffusional resistance [81]. This evaporation involves a number of scenarios, including non-isothermal behavior internal, unsteady state kinetics and variations in physical properties. It is important to consider the mass and energy transports at the interface and inside the droplet [87].

The four methods mentioned earlier are the most famous methods through which the process of evaporation of the fuel drop was studied. A comparison between the previously mentioned methods is shown in Table 1. Some methods are easy to measure, while other methods require more advanced techniques.

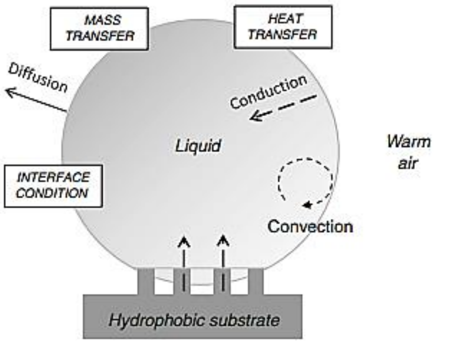


Figure 10. The evaporation mechanism for a sessile droplet [81]

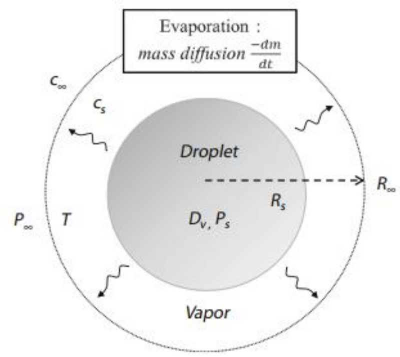


Figure 11. Evaporation model of single-droplet drying [84]

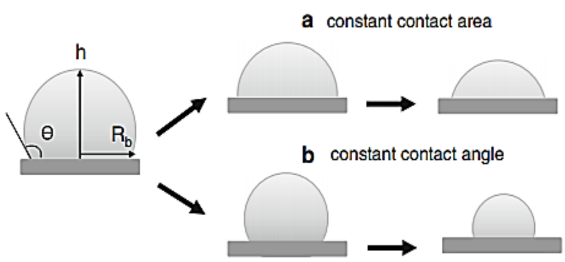


Figure 12. Evaporation models for a sessile droplet [84]

Table 1. Comparison of evaporation techniques used in previous studies

Suspension droplet	levitation droplet	free flying droplet	sessile droplet
the droplet size larger than droplet in real engine	may be produced small or large droplet	Droplet size can be controlled	Large droplet
the supporting wire affects the evaporation rate	the levitation force (acoustic or magnetic) affects evaporation rate	no external force but the air liquid interface is affect the evaporation rate	the surface material very affect greatly the evaporation rate
shape of droplet unstable because the support wire	shape of droplet approximately spherical (stable)	the shape of droplet deformed by the interaction between air and droplet	the shape of droplet depend on the contact angle between the surface and droplet
easy to generate droplet	takes time for levitation droplet to stable	easy to generate droplet	easy to generated droplet
easy to measure the surface temperature and evaporation time.	easy to measure the evaporation rate for long time	difficult to measure the evaporation rate.	easy to measure the evaporation rate for long time.

3. NANOTECHNOLOGY

The nano fuel is a pure hydrocarbon fuel dobed with nano metallic oxides particles. The advantage of dobing nano-particles with the pure fuel are to improve the physical properties such as the thermal conductivity, density, specific heat, ...etc. The ordinary fuel delivering system to the engine cylinder can be used with nano fuels with no or minor modifications [88, 89]. Many researches have focused on nano-fuels [90-92].

The addition of nanoparticles to the gasoline has various benefits. These benefits include:

(1) Very quick burning.
(2) High reactivity when reacting.
(3) Lower emissions when in use and after usage.
(4) Lower temperature needed for igniting.

Dai et al. [12] examined experimentally the evaporation characteristics of diesel/cerium oxide nanofluid fuel droplets by using droplet suspending technique with conditions of normal gravity and atmospheric pressure at ambient temperatures of 672 K and 872 K.

The hypothetical model of diesel and nanofluid fuel droplet evaporation and micro explosion shown in Figure 13. Initially, the diesel droplet was heating up at the surrounding air temperature of 872 K. A bubble then developed as a result of component variations in the diesel droplet. The pressure difference between the external and interior of the diesel droplet caused the bubbles to travel and gather near the boundary once they had formed. The microdroplets at the gas-liquid interface of the diesel droplet were stretched as the bubble moved there, which reduced the diesel droplet's surface tension [93]. The micro-explosions happened when the bubble lancinated the gas-liquid contact, and the little droplets were expelled as a result. following two or three micro explosions. Figure 6b depicts a nano fuel droplet evaporating. The diesel droplet's ceria nanoparticles, which were employed, were evenly scattered throughout. Because of the convection in the droplet, the ceria nanoparticles continued to move and collide after the nanofluid fuel droplet heated to the ambient temperature of 872 K [94].

Wang et al. [95] studied the evaporation properties of a nanofluid fuel mixed with various amounts of ceria nanoparticles (0.05%, 0.25%, 1.25%, and 5% by weight) at ambient temperatures of 672 K and 872 K in a gravity-free environment. The findings shown that at an ambient temperature of 673 K, the rate of fuel droplet evaporation is increased at ceria levels in the range of 0.05%–0.25% and lowered at ceria concentrations ranging from of 0.25%–5% As shown in Figure 14. When the nano partials concentration in the nanofluid fuel exceeds 5%, the viscosity of the fuel significantly decreases, resulting in poor fuel atomization properties.

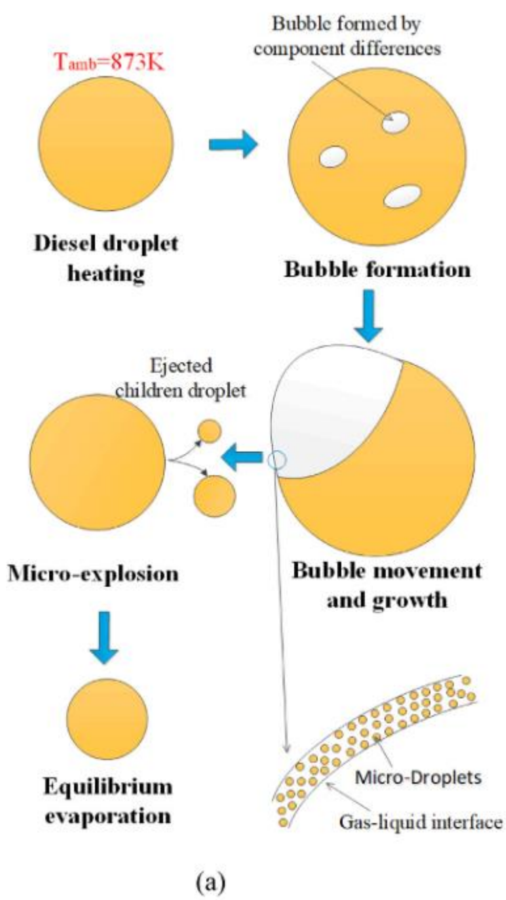


Figure 13. Droplet evaporation process (a) diesel, (b) nanofluid fuel [12]

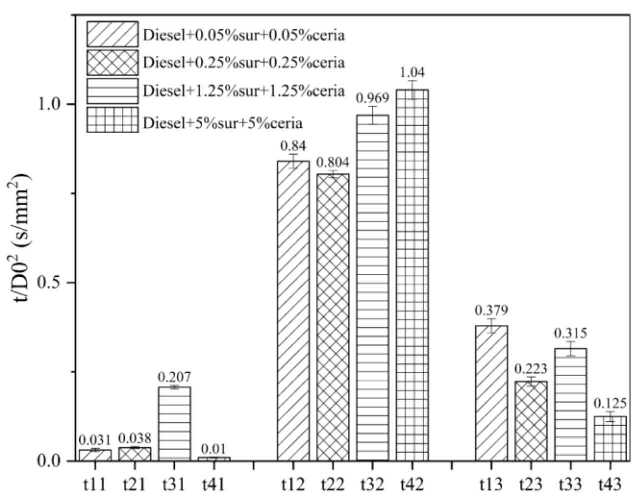


Figure 14. Equivalent evaporation rates in different evaporation phases for nanofluids [12]

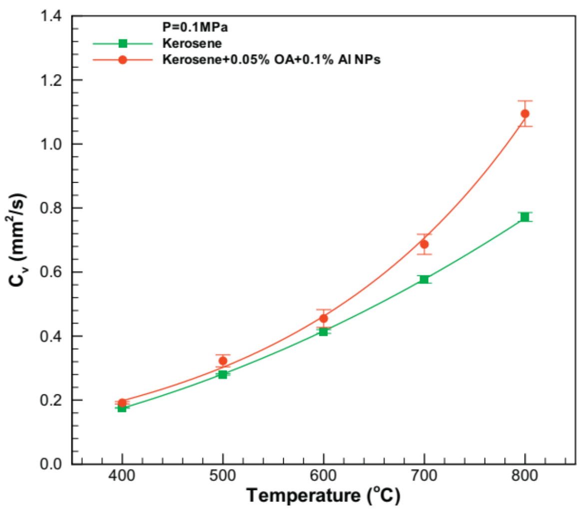


Figure 15. The evaporation rates of kerosene-based nanofluid fuel [96]

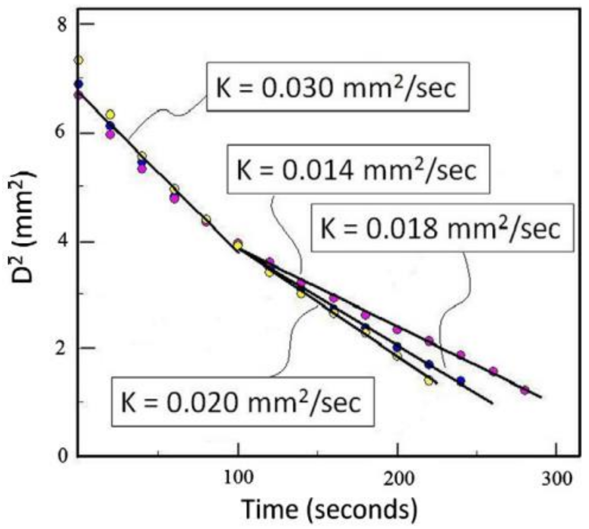


Figure 16. D^2 as a function of time for Diesel with Ag nanoparticles [97]

There are many previous studies that focused on improving the evaporation of a drop of fuel using nanoparticles, such as Javed et al. [96] who studied a droplet of kerosene doped aluminum nanoparticles. the evaporation rate of the kerosene with aluminum nano droplets was considerably higher than that of or pure kerosene droplets as shown in Figure 15, Wang et al. [95] used Diesel with Ceria, Chen et al. [97] used Diesel with Ag nanoparticles as shown in Figure 16 the effects of Ag in DW + 1%PVP, Wang et al. [98] used Diesel with Cerium oxide nanoparticles, and Ferrao et al. [99] used Hydro-processed vegetable oil with Aluminum nanoparticles. The proportion of nano mixed with pure fuel is determined depending on the type of nano material and the size of the nano particles.

4. CONCLUSIONS

The current study is a study in which many previous studies that were concerned with the evaporation rate of the fuel droplet were reviewed. Through the previous studies, various factors studied such as the conditions surrounding the droplet and the mechanisms of evaporation of the drop as well as the type of fuel and additives used to improve the evaporation process. From the previous research mentioned above the following conclusion may draw:

1- The evaporation rate increased by increasing the ambient temperature, and decreased by increasing the ambient pressure. The evaporation characteristics of liquid fuel droplet generally correspond to the d^2 law.

2- By increasing vapor concentration around the fuel droplet the lift time increased.

3- The high evaporation rate for fuel droplet when concentration is around 50% for light component due to the strong of micro explosion.

4- There are four evaporation techniques used in Previous studies levitation, suspension, free flying, sessile droplet each method has its own advantages and disadvantages, leading to different applications. Among them, suspension and sessile methods are the most widely applied due to their simple setups.

5-The addition of Nanoparticles also affects the evaporation of nanofluid fuels. The speed of the fuel droplet evaporation is increased at ceria concentrations.

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