

Contribution to the Study of the Influence of the Experimental Set-Up on the Vaporization Process of Vegetable Oil Droplets

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Abstract

This study presents a contribution to the development of a model for vegetable oil droplets vaporization, with a particular focus on the influence of the experimental set-up for their use as fuel in diesel engines. Two systems were considered: an open-environment system obtained through a hot gas flow, and a closed-environment system. Vaporization was conducted under identical conditions, with the results subsequently compared. The findings indicate that, for temperatures between 473 K and 673 K, droplets behaviour in both systems presents only a heating and expansion phase. For temperatures above 673 K, the behaviour of the droplets differs between the devices. In the open environment device, a linear reduction in droplets diameter is observed following the transient phase, suggesting stationary vaporization and enabling the calculation of a vaporization constant and the well-known D² law is respected. In the closed-environment device, puffing, micro-explosions and gas ejections are observed, and it is not possible to determine vaporization constant and D² law is not respected. The results demonstrate the necessity of developing a model for the thermal decomposition of vegetable oil before attempting to create a model for the vaporization of these oils. In order to achieve this, it is essential to construct an experimental setup that more closely emulates the real conditions within the combustion chamber of a diesel engine, taking into account the variables of pressure, temperature and the heating process.

Keywords

Experimental Device, Vaporization, Vegetable Oil, Open Enclosure, Closed Enclosure, Diesel Engine

1. Introduction

The principal energy challenges confronting the global community are defined by an escalating demand for energy, which is being met by a supply that is predominantly fossil-based [1] [2]. Despite the abundance of energy and mineral resources, their accessibility is uncertain, and prices are subject to significant fluctuations due to geopolitical factors [2]. In the developing countries of sub-Saharan Africa, the continued reliance on fossil fuels, coupled with the economic and demographic expansion in urban center, represents a significant challenge that must be addressed [2]. In this context, renewable energies may be an interesting alternative capable of establishing an efficient and sustainable model for energy development [3]. At the local level, first-generation biofuels, such as those derived from vegetable oil, can be a significant catalyst for socio-economic advancement [4]. For instance, vegetable oils are currently employed as a fuel source in diesel engines, supplanting traditional diesel [5] [6]. Nevertheless, the utilization of vegetable oil as fuel in diesel engines is not without its inherent challenges [7]. The prevalence of issues such as clogged injection filters, deposits and clogging of engine parts, and mechanical damage (injection pumps, piston rings, cylinders) represents a significant barrier to the widespread utilization of these fuels. The physical properties of vegetable oil (viscosity, density, flash point, volatility, etc.) [8], their chemical properties (iodine, saponification and peroxide values, etc.) [9], and the nature and geometry of the engine and/or its components are the primary factors that contribute to the observed issues [9] [10].

The combustion of vegetable oil in diesel engines necessarily entails their vaporization. The vaporization of vegetable oil droplets has been the subject of several studies in recent years, with the objective of developing a model for the combustion of vegetable oils in diesel engines [11]. Indeed, the development of a model for the combustion of vegetable oil necessarily involves the consideration of a model of vegetable oil decomposition and vaporization. The triglycerides which compose the vegetable oils need to decompose before evaporating [12]. A substantial corpus of literature exists on the vaporization of fuel droplets, yet the subject of the vaporization of vegetable oils remains a recent focus of investigation. Following the work of Godsave and Spalding in 1953 on droplets evaporation [13], further studies on vegetable oil droplets vaporization and their esters have been conducted by numerous authors [10] [14]. The findings of these studies converge on the conclusion that vegetable oil undergo vaporization similar to that observed in diesel or biodiesel at temperatures exceeding 773 K. Nevertheless, research is ongoing to investigate the vaporization of vegetable oil at temperatures below 773 K, which are typically encountered in specific regions of the combustion chamber. The primary challenge in studying the vaporization of vegetable oil droplets is the reproducibility of the real conditions that exist in the combustion chamber, including vaporization at high temperatures and high pressures. A number of experimental techniques have been developed for the study of the evaporation of liquid fuel droplets. These include the porous sphere method, the free-falling droplet method and the suspended droplet method. Details of these techniques can be found in literature [15] [16]. These experimental set-ups, which are more or less representative of an engine environment, provide a more or less accurate account of the vaporization mechanisms of vegetable oil droplets in diesel engines. The present study uses two experimental setups to determine the impact of setting on the vaporization process of rapeseed and linseed oil droplets in order to develop a model for the vaporization of vegetable oil droplets. The findings presented herein facilitate a more comprehensive comprehension of the vaporization of vegetable oil droplets in open hot flows and in closed enclosures. Moreover, the results offer experimental insights that may inform the prospective development of a combustion model for vegetable oils in their utilization as diesel engine fuels.

2. Concise Overviews of Vegetable Oil Droplets Vaporization

The vaporization of vegetable oil droplets has been an issue of much interest for decades because of its significance in engineering applications like internal combustion engine applications. Along with experimental studies, substantial efforts have been made to predict the behaviour of vegetable oil droplets vaporizing.

A large number of studies have been done on the vaporization of liquid fuels, but not much has been done on the evaporation of vegetable oil droplets. The earliest studies on the evaporation of vegetable oil droplets were conducted in the 1990s. P. Higelin conducted experiments on the vaporization of sunflower oil droplets in a stream of hot air, by means of the droplet suspension technique on a quartz fiber [17]. The main results show that sunflower oil droplets evaporate at 773 K in a way that is similar to a pure material, with a practically constant regression slope over the projected surface. [15] [17]. Figure 1 presents result of the evolution of the projected surface of sunflower oil droplets for three values of initial diameter, measured during evaporation in a hot air flow at T = 803 K and V = 1.6 m/s.



Figure 1. Evolution of the projected surface of sunflower oil drops for three values of initial diameter, measured during evaporation in a hot air flow at T = 803 K and V = 1.6 m/s. Reproduced from [17].

Vanhemelryck (1997) performed experiments in a closed heated chamber to study the behaviour of rapeseed oil droplets in inert and oxidizing environments [18]. In an oxidizing environment, the results show that no evaporation is observed at a temperature of 473 K, whereas at 573 K and above, low evaporation is accompanied by thermal degradation of the oil, which turns brown. At 673 K, a solid tarry residue is observed on the fiber, which disappears at 873 K [15] [18]. At 773 K, it is no longer possible to determine the evaporation rate of the rapeseed oil drops due to blistering (appearance of bubbles) and thermal degradation of the oil [15].

In a study conducted by G. Vaitilingom in 1992, the evaporation times and rates of vegetable oil droplets suspended at the end of a quartz fiber and placed in a flow of hot air were compared. The results yielded a ranking of the oils in ascending order of evaporation time, with the following order: copra, palm, cotton, sunflower, groundnut, soya, rapeseed, linseed [19]. Moreover, the same study demonstrates that at a temperature of 713 K, neither crude nor refined vegetable oils undergo complete evaporation. Instead, carbonaceous or tarry deposits are observed on the quartz fiber [19].

Using the suspended droplet technique, Tizane Daho carried out experiments on the evaporation of rapeseed and cottonseed oil droplets in a hot air stream [12] [20]. The results obtained showed no evaporation at 578 K for all oils, although evaporation was difficult to observe at 684 K. However, at 713 K all oils evaporated with difficulty, leaving deposits that did not disappear, while at 813 K and above all oils evaporated completely (some with formation of residues that then disappeared) [11] [20]. These results are in line with those of Vaitilingom [19] and Higelin [17] with different vegetable oils under investigation.

A.S. Zongo has conducted research into the mechanisms of degradation and thermal polymerization of vegetable oil in diesel engines, as well as undertaking experimental studies on the vaporization of droplets of linseed and rapeseed oil in a closed enclosure [21]. The results are in accordance with those of previous studies and indicate that at temperatures below 683 K there is a slight vaporization of the vegetable oil. From 683 K onwards, the vegetable oil experience a period of heating and expansion, followed by swelling and gas ejection, with a deposit of residue on the quartz fiber. The latter is found in varying quantities, dependent on the ambient temperature [10]. The frequency and amplitude of swelling vary in accordance with the nature of the environment and its temperature [10]. **Figure 2** below illustrates the various stages of the vaporization process of linseed oil droplet in a closed enclosure at a temperature of 703 K, as observed by A.S. Zongo.

This brief analysis of the literature clearly reveals the influence of the experimental set-up on the evaporation and combustion processes of vegetable oil droplets in particular. The present study checks to analyze this impact by repeating the evaporation of vegetable oil droplets on the two devices and comparing the vaporization processes. Due to the limited amount of experimental data published for this purpose, the experiment was conducted only in a stagnant environment at standard ambient pressure, and the effect of pressure was also omitted in this study. As Morin Céline notes, there are experimental studies by Goldsmith and, Hall and Diederichsen examining the impact of pressure on the rate of vaporization or combustion [15]. The studies demonstrated that for moderate pressure values between 0.1 and 2 MPa, the rate of vaporization or combustion is proportional to pressure according to a power law with an exponent between 0.2 and 0.4. Nevertheless, the suspended droplet technique presents a challenge in achieving high pressures proximate to critical conditions. This is because, at such pressures, it becomes impossible to suspend a droplet due to the reduction in surface tension. Tizane Daho also notes that when the critical pressure is reached, and the temperature is approaching the critical temperature of the liquid, the surface tension of the droplet and its latent heat of vaporization approaches zero [20]. The free-floating/falling droplet injected into a stagnant or flowing environment is the optimal method for studying the phenomena of evaporation and combustion of droplets [22]. In this configuration, the droplet is not influenced by any unphysical/external parameter/factor, thus allowing for a more accurate observation of the process. However, this technique is rarely employed due to the difficulties associated with imaging a free droplet as it drifts out of the camera focus during its lifetime [22].



Figure 2. Linseed oil droplet vaporization characteristics for temperature of 703 K in closed environment. Reproduced from [22].

3. Experimental

The fiber-suspended droplets technique has been used. The fundamental principle underlying the measurement is as follows: a droplet of vegetable oil is suspended from a quartz fiber. The droplet is then subjected to a hot air flow or placed within a heated, enclosed chamber. The droplet is placed in a fixed position and can be observed by camera during vaporization or combustion process. The evolution of the projected surface of the droplet and the determination of its vaporization constant, when a quasi-steady phase could be observed, were determined for temperatures between 543 K and 773 K at atmospheric pressure. The two experimental set-ups used have been described below.

3.1. Experimental Method

3.1.1. Experimental Device with Open Ambience

The experimental set-up is well documented [11] [12], and thus, only a brief description is provided here. The schematic diagram of the ambient experimental set-up, as illustrated in **Figure 3**, encompasses both the system for heating and channelling the flow of hot gases and the system for suspending the droplets. The hot gases are generated by a gas burner that is supplied with butane. The combustion products are dispersed in the surrounding atmosphere, which also contains the droplets. The temperature of the hot gases is regulated by controlling the pressure of the butane supply via a precision pressure regulator mounted on the supply cylinder. The hot gases are circulated in a pipe measuring 50 centimeter in length and 25 centimeter squared in cross-section, located above the burner. The velocity of the hot gas flow arriving at the droplet in this study is relatively low, with an average of approximately 0.1 m/s.



Figure 3. Diagram of the open-air experimental set-up. Reproduced from [20].

The system for image acquisition and processing is illustrated in **Figure 3**. The evolution of the droplet diameter as a function of time is achieved by acquiring the contours of the droplets and determining the equivalent diameter at each instant during the vaporization of the droplets. The system employed in this study comprises a CCD5 (Charge Coupled Device) camera, an IEEE acquisition card, a high-performance computer and associated acquisition software, as illustrated in **Figure 3**.

3.1.2. Experimental System in a Closed Environment

The experimental set-up is well documented in literature [10], and thus, only a brief description is provided here. The experimental set-up employed in the experiment is illustrated in **Figure 4** below. It comprises a closed, highly thermally insulated enclosure, a digitization and image processing system, and a heating system.



Figure 4. Schematic diagram of experimental system in a closed environment.

The vaporization chamber is a stainless-steel cuboid metal enclosure measuring $100 \times 100 \times 100$ mm internally. To isolate the chamber, an isolation system was constructed using bricks and refractory cement. Transparent and removable portholes were positioned on opposite sides of the enclosure to provide an optical path between the CCD camera and LED light source. The enclosed chamber, with its high level of thermal insulation, enables temperatures ranging from the ambient temperature to 1023 K to be achieved. An optical path through the chamber permits observation of the droplets as it undergoes vaporization. The droplet is positioned at the center of the chamber via the using of a rod on a quartz fiber. The chamber is equipped with an air inlet and outlet, allowing the atmosphere to be modified as required.

The image acquisition and processing system is identical to that of the open environment device, and enables the successive images of the droplets to be converted into digital format in real time and subsequently processed. The digital processing stage determines the contour of the droplet and calculates its projection area. The data obtained from the camera and thermocouple are recorded using the SAIGv software, which was specifically designed by Alliance Vision for use with this device. The data is subjected to processing and analysis, resulting in the generation of an output that depicts changes in temperature (in degrees Celsius) as a function of time (in seconds) and the projected surface area (in square millimeter) as a function of time (in seconds).

The heating system comprises a resistor manufactured from kanthal and su-

pport plates. The resistor is composed of a 2 mm diameter kanthal wire, which is electrically insulated with ceramic tubes. A 1 mm diameter Type K thermocouple, positioned centrally within the oven, is employed to indicate the temperature of the heating system. The kanthal resistor is supplied with a voltage of 12 V. The control unit is a Pyromat Plus 300, which is equipped with a transformer that converts 230 V to 12 V.

3.2. Materiel Used

For this work, two vegetable oils, linseed oil and rapeseed oil were used. Linseed oil, which is a tri-unsaturated oil, is more prone to polymerization phenomena, while rapeseed oil, which is a monounsaturated oil is the oil most commonly used in studies on the evaporation of vegetable oil droplets and in engine tests for use as diesel fuel. The fatty acids compositions of vegetable oils are reported in **Table 1** while the physical and chemical properties of these two oils are presented in **Table 2**.

Table 1. Fatty acid composition of rapeseed oil and linseed oil used.

Fatty acids	Oleic	Linoleic	Linolenic	Palmitic	Stearic	Other minor
%	(C18:1)	(C18:2)	(C18:3)	(C16:0)	(C18:0)	fatty acids
Formula	$C_{18}H_{34}O_2$	$C_{18}H_{32}O_2$	$C_{18}H_{30}O_2$	$C_{16}H_{32}O_2$	$C_{18}H_{38}O_2$	
Linseed oil	18.00	16.3	56.10	5.2	3.2	1.2
Rapeseed oil	60.78	19.22	8.92	4.78	1.35	4.95

Physical properties	Density	Kinematic	Flach	high heating Carbon Iodine Surface				
	(kg/m ³ at	viscosity (mm ² /s	Priasii	value	residue	value	tension	
	288 K)	at 313 K)	point (K)	(MJ/kg)	(%)	gI_2/g	(N/m)	
Linseed oil	924	26 - 27ª	514	39.3 - 39.5	0.22	180	-	
Rapeseed oil	925	34.9	483	-	0.39		32.9	

Table 2. Physical properties of rapeseed and linseed oil used.

4. Results and Discussion

4.1 Results in an Opened Environment

The normalized squared diameter of droplets of rapeseed and linseed oil demonstrates either the full range of the aforementioned evaporation characteristics or none at all. Such characteristics comprise a transitional phase, which is distinguished by an initial expansion of the droplets (positive slope), followed by a plateau (zero slope) and subsequently, a period of moderate evaporation (slightly negative slope). Furthermore, an established evaporation phase with a negative slope was identified. The slope observed in the established evaporation phase was the focus of interest, as it corresponds to the vaporization constant. This was determined through the use of the SLOPE function within the Excel spreadsheet. **Figure 5** illustrates the distinct phases described previously, obtained with a droplet of rapeseed oil under a flow of hot air at 703 K.



Figure 5. rapeseed oil droplet vaporization distinct phases under a flow of hot air of 703 K.

The evolution curves of normalized square diameters as a function of normalized time for rapeseed and linseed oil droplets at different temperatures are presented in **Figure 6** and **Figure 7** below, respectively.



Figure 6. Normalized square diameters $(d2/do^2)$ of a droplets of rapeseed oil and fuel oil as a function of normalized time (t/do^2) at different temperatures in the open environment.

Both oils have shown similar behaviour in the temperature range below 573 Kelvin, with the normalized droplet diameter squared rising from 1 to 1.10 (**Figure 7**). This indicates an increase in droplet diameter at these temperatures. This increase in droplet diameter is consistent with the observed phase transition occurring within the droplets. From the beginning the droplet is heated by the heat flux from the hot ambient gas. During this phase, the thermal energy transferred

from the surrounding environment to the droplet is used to provide heating, which results in an increase in its volume, as evidenced by the increase in diameter. Nevertheless, the diameter of the droplet remains constant throughout the duration of exposure to the hot flow. This section describes the end of the expansion phase of the droplets, during which no variation in mass related to the evaporated products is observed. It is important to note that, within the specified temperature range, the oil droplets do not undergo a vaporization phase; instead, they only expand.



Figure 7. Normalized square diameter curves $(d2/do^2)$ for a droplets of linseed oil as a function of normalized time (t/do^2) at different temperatures in an open environment.

For hot flow temperatures between 573 and 683 K, the droplets of the two oils continue to demonstrate a consistent behavioural pattern, characterized by an initial increase in droplets diameter up to a maximum, followed by a gradual decline. The square of the normalized diameter declines from a peak value of 1.13 to 1.10 (**Figure 7**).

At flow temperatures between 683 K and 773 K, the droplets of both oils continue to exhibit the same behaviour, which is now characterized by an increase in diameter up to a maximum, followed by the commencement of an evaporation phase. The reduction in the diameter of the droplet is indicative of the evaporation process. As the temperature of the hot air flow increases, the vaporization rate demonstrates a corresponding, gradual enhancement. This is calculated on the basis of the established vaporization phase. This phase is distinguished by the occurrence of intense vaporization, with minimal heating of the droplet and a nearly constant droplet surface temperature. It is in this linear portion that the droplet's vaporization coefficient, or slope, is calculated. The slope of this part provides insight into the evaporation of individual droplets under the influence of temperature. For instance, Figure 6 illustrates that, at temperatures below 673 K, the sole discernible phenomenon is the heating and expansion of the droplets. As illustrated by the evolution of the square diameter of the droplets, a modest increase in diameter was observed at the outset of the heating phase. At temperatures exceeding 673 K, a slight reduction in the square diameter of rapeseed droplets was discerned. Nevertheless, a comparison of the vaporization constants of rapeseed oil droplets under identical vaporization conditions reveals that the constants of evaporation of rapeseed oil are increasing as the temperature increases as corroborated by the data in Table 3. This phenomenon has been observed experimentally by previous studies [12]. The results of the calculation of vaporization constants dependent on temperature are summarized in Table 3 and Table 4.

Table 3. The constant of evaporation of rapeseed oil droplets depending on temperature.

Temperature (K)	513	673	753	773
K (Evaporation rate)	00	0.0120	0.0550	0.0999

Temperature (K)	503	553	643	713	753	773
K (Evaporation rate)	-	-	0.006	0.041	0.071	0.116

The same observations made with rapeseed oil can also be observed with linseed oil in the same temperature ranges, as illustrated in **Figure 7**. The aim of this study was not to compare the vaporization characteristics of the two oils, but to ascertain whether or not the vegetable oil droplets behaved identically from one experimental device to another. Nevertheless, it can be observed that in the case of the linseed oil droplets, micro-explosions of low amplitude manifest at the end of the vaporization process, as illustrated in **Figure 7**. Perhaps these micro-explosions can also be observed in the closed enclosure, but they are dwarfed by the large-scale explosions. The occurrence of these micro-explosions has also been documented in previous studies with the same experimental device. Indeed, P. Higelin observed the occurrence of micro-explosions within droplets at the terminal stage of vaporization [17]. The micro-explosion mechanism was elucidated by the pure diffusion model, which posits that light fractions entrapped in the core of the droplet vaporize before they can diffuse towards the surface [23].

It is noteworthy that, as indicated in **Table 3** and **Table 4**, the evaporation rate of the droplet in the 773 K environment is greater than that observed in the 753 K and 713 K environments. This suggests that the evaporation time of the droplet in the 773 K medium is less than that of the droplet in the 753 K and 713 K medium. The present results and those reported in [11] [12] [15] [17] confirmed that the evaporation rate, when suspending a droplet onto a cross-fiber was used, increases when the ambient temperature increases

4.2. Results in Closed Environment

The results of vegetable oil droplets vaporization in a closed environment, as a function of temperature, are presented in Figure 8 and Figure 9 respectively for rapeseed oil and linseed oil droplets. It can be observed that the initial phase of heating and expansion, during which the squared diameter of the droplet increases from the outset of the droplets' vaporization process, was observed across all temperatures. However, the observed phenomena diverge from those observed in the open-air device seen above at temperatures higher than 673 K. Indeed, following the heating and expansion phase, neither an unstable evaporation phase, whereby the diameter of the droplets returns to its initial diameter, nor the established evaporation phase, which verifies the law in D² and allows a rate of vaporization to be determined, is observed. The D-square law, also known as the D² law, describes the relationship between the diameter and time for an isolated spherical droplet undergoing quasi-stationary evaporation. This well-known law, which expresses the linear decrease in the square of the droplet diameter as a function of time, is written in the form $D^2 - Do^2 = -Kt$, where Do is the initial diameter of the droplet, D is its instantaneous diameter, K is the rate of vaporization and t is time. Instead, a phenomenon of puffing and subsequent bursting, followed by gas ejection, is evident. Furthermore, as evidenced by Figure 9, there is a notable correlation between the intensity of the bursting and blowing processes and the ambient temperature. As the temperature rises, the intensification of these phenomena becomes increasingly pronounced. The present results and those reported in [10] [15] [17] [24] confirmed the occurrence of bursting and puffing phenomena during the vaporization process of vegetable oil droplets in a closed environment.

Figure 10 illustrates the vaporization process of rapeseed oil in air at 703 K, demonstrating the temporal evolution from droplet introduction into the closed chamber to residue formation on the quartz fiber.







Figure 9. Normalized square diameter curves $(d2/do^2)$ for a droplets of linseed oil as a function of normalized time (t/do^2) at different temperatures in closed environment.



Figure 10. Image of the vaporization process of a droplet of rapeseed oil at 703 K in air as a function of time.

4.3. A Synopsis of the Two Environments

Regardless of the experimental configuration employed, the droplets exhibit iden-

tical behaviour at relatively low ambient temperatures of 683 K or below. The droplets undergo a process of heating and expansion, which is then followed or not by slight vaporization at these low temperatures. This is why an increase in droplet diameter is observed, reaching a maximum, followed or not by a slight decrease. This demonstrates that at these low temperatures, heat transfer is the primary mechanism at work. It can be reasonably deduced that other phenomena, such as mass transfer, play a relatively minor contribution to the overall process. However, when the temperature exceeds 683 K, the behaviour of the drops differs depending on the experimental set-up. As the temperature increases, additional phenomena are introduced, including mass transfer and the thermal decomposition or polymerization processes inherent in vegetable oil, which contribute to the overall heat transfer phenomenon. Subsequently, the nature of the environment will undergo a transformation, and it is self-evident that the behaviour of the drop will no longer be identical. While the open-air device undergoes a vaporization phase, the closed-air device displays a phenomenon of swelling, bursting and gas ejection. The discrepancy in the behaviour of vegetable oil droplets in the same temperature range in the two experimental set-ups requires an explanation.

A first potential explanation for these observed phenomena of puffing, bursting and gas ejection is that initially, when the droplets are immersed in the hot environment, there is a rapid oxidation of the light compounds on the surface of the droplets, or a vaporization of certain components that reach their boiling temperatures [10]. This oxidation or vaporization at the surface of the droplets subsequently results in an increase in surface temperature and oxidation within the droplets. These oxidation processes within the droplets continue and result in the formation of gaseous compounds, which are initially trapped and subsequently released when the pressure exerted by these gases is greater than the surface tension forces. In this instance, the absence of this phenomenon in the device in an open environment can be attributed to the fact that the evaporated gases and oxidation products are promptly carried away by the constant flow of lime gas arriving on the suspended droplets. Furthermore, the flow of burnt gases from butane combustion serves to restrict the occurrence of oxidation phenomena within the droplets, due to the relatively low oxygen content of said gases [11].

Youngchul Ra *et al.* [25] attributed the difference between these two experimental set-ups to the fact that, in the closed chamber, the evaporated products remain stagnant and increase the pressure of the ambient gas. The initial swelling of the droplets is increased due to the decrease in the mass fraction of fuel on the surface and the increase in heat transfer inside the droplet. This is not the case in an open enclosure, in which the pressure remains constant since the evaporated products are transported by the flow and therefore do not contribute to the overall pressure. A.S. Zongo proposes the hypothesis that the evaporated products and the increase in pressure within the closed chamber are the primary factors responsible for the formation of the observed swellings, contractions and gas ejections [10]. Indeed, as the chamber is sealed, the vaporized products remain confined

within the surrounding environment, thereby elevating the pressure of the medium and the concentration of the environment. This is not the case in the open environment device, where the hot air flow carries away the evaporated products, which are therefore unable to stagnate in the environment. In this instance, no swelling, blistering or contraction is observed. The formation of light gaseous compounds may also be a contributing factor to the observed increase in volume of the droplets. The mechanism of micro-explosions within the droplets was also observed, but towards the conclusion of the vaporization process, immediately prior to the residue deposition phase. These micro-explosions are of a markedly reduced amplitude in comparison with those observed in the closed chamber. The influence of the atmospheric oxygen on the apparition of puffing and bursting was reported in our previous studies [10].

Pascal Higelin posits that micro-explosions confer an advantage in the fuel use of vegetable oil, as they permit drop fractionation by diffusion of trapped light fractions [17]. Furthermore, these micro-explosions assist in reducing the physical ignition delay, thereby enabling vegetable oil to exhibit a delay comparable to that of fossil fuels.

The high-pressure, high-temperature environment of internal combustion engines provides an optimal setting for these micro-explosions [17]. Therefore, the closed-enclosure system appears to offer a greater number of advantages in terms of vaporization, as it allows the droplets to disintegrate into several smaller droplets.

5. Conclusion

This study analyses two vegetable oil droplets behaviour when vaporizing in the same range of temperature toward two different experimental set-ups but both used to study fuel droplets vaporization characteristics. The first is an open atmosphere created by a flow of hot air, while the second is a closed chamber with internal heating. The potential effect of experimental set-up on vegetable oil droplets vaporization process is estimated. The outcomes demonstrated that at relatively low temperatures below 683 K, the droplet behaviour is the same. On the other hand, the vaporization process (droplet behaviour) varies greatly amongst devices at temperatures above 683 K. In the first device, the established D² vaporization is replaced by a phenomenon of puffing and bursting with gas ejection in the second device. The stagnation of evaporated products within the enclosed environment constitutes a significant factor contributing to this phenomenon. This study's analysis is useful since it makes evident how much the experimental setting affected the development of a model for the evaporation or combustion of vegetable oil droplets. Failure to consider its impact may result in erroneous interpretations and misunderstanding, particularly given the abundance of experimental data published using this classic suspended-fiber technique. The closed environment is a non-pressurized cubic enclosure, the upper surface of which is heated by electrical resistance. The configuration of the closed environment represents a radiant heating system, which is a distinct approach from that employed in an engine environment, where heat exchange is essentially by convection before combustion. It would therefore be more appropriate to set up an experimental device where heating is by convection, with the possibility of varying the pressure inside the closed environment in order to more closely approximate the conditions of a diesel engine.

Authors' Contributions

Sampawinde Augustin Zongo: study conceptualization, definition of methodology, data analysis, interpretation of results, drafting of the manuscript.

Jacques Nébié: bibliographic research, interpretation of results; proofreading and validation of the manuscript.

Téré Dabilgou: bibliographic review, proofreading and validation of the manuscript.

Tizane Daho: validation of the protocol, supervision of the study, proofreading and validation of the manuscript.

Soutongnooma Bouda: data analysis, interpretation of results.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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