Journal of Engineering Science and Technology
Vol. 20, No. 1 (2025) 99 - 113

A STUDY ON THE COMBUSTION CHARACTERISTICS OF FUELS MIXED WITH MICROEMULSION ADDITIVES WITH A RATIO OF 1/8000 IN VIETNAM

NGUYEN PHI TRUONG[1],
PHAM HUU TUYEN[2], NGUYEN VAN TUAN[3,*]

[1]School of Mechanical and Automotive Engineering, Hanoi University of Industry, No. 298, Cau Dien Street, Bac Tu LiemDistrict, Hanoi 100000, Viet nam.
[2]School of Mechanical Engineering, Hanoi University of Science and Technology, No. 1 Dai Co Viet Street, Hai Ba Trung District, Hanoi 100000, Vietnam.
[3]School of Transportation Engineering, University of Transport Technology, No. 54 Trieu Khuc Street, ThanhXuan District, Hanoi 100000, Vietnam,
*Corresponding Author: nguyenvantuan@utt.edu.vn

Abstract

One way to improve the economy and performance and reduce the negative environmental impact of internal combustion engines is to incorporate additives into diesel fuel. When used individually as fuel additives for diesel fuel, water-in-oil microemulsion additives, and metal oxide nano-additives have demonstrated benefits, including improved technical properties and reduced emissions. However, the emulsion particles are still quite large. Increased mixing ratios result in the utilization of substantial energy and equipment to produce sizable and intricate additives, which impacts both the preservation of fuel quality and the quality of exposed components. Hence, the authors employed a novel generation additive that merges the benefits of a water-in-oil microemulsion additive and a metal oxide nano additive. This article summarizes the findings of a study conducted on the combustion process in a constant volume combustion chamber (CVCC) using a new-generation microemulsion additive combined with diesel fuel (DO) at a ratio of 1/8000. The findings indicate that the combustion of diesel fuel blended with microemulsion additives exhibits accelerated kinetics, leading to increased pressure and a higher heat release rate. Additionally, this combustion process results in reduced emissions, 18.9% carbon monoxide (CO), 8.2% hydrocarbons (HC), and 18.1% nitrogen oxides (NO) compared to pure diesel fuel.

Keywords: Constant volume combustion chamber, Diesel fuel, Fire process, New generation additives.

1. Introduction

Diesel engines are efficient and powerful energy sources widely employed in several sectors of the economy, including construction, manufacturing, agriculture, and transportation. The majority of diesel engines continue to rely on diesel fuel derived from fossil sources. Due to the swift growth of economic sectors throughout most continents, there is a rising need for energy, specifically diesel fuel. This increase in demand raises concerns about a potential lack of fossil energy supplies [1, 2].

In addition, the exhaust emissions from diesel engines contain numerous hazardous compounds that contribute to environmental pollution and adversely affect human health [3, 4]. Hence, exploring efficient fuel utilization and reducing environmental contamination caused by diesel engines have become subjects of significant study interest [5-8].

Countries have implemented progressively stricter emissions standards to regulate diesel engine emissions [9-13]. Scientists discovered that adding water to diesel engines has numerous potential advantages [14, 15]. Water-based emulsion diesel fuel is a sustainable fuel alternative that may be used in any diesel engine without requiring any modifications to the engine's structure [16]. Multiple research indicates that combining diesel fuel and water is more productive than using diesel fuel alone. The presence of water content directly and directly impacts the improvement of power, fuel consumption, and emissions [17, 18].

Water-in-oil microemulsion additives consist of water dispersed as emulsion particles, with sizes ranging from micro to nanometers, within the oil. This additive consists of a continuous phase, the oil phase, and a dispersed phase, the water phase. These two liquids are immiscible substances, and microemulsifying additives can be created by utilizing surfactants [19-21].

In recent times, several research have examined novel microemulsifying additives of the latest generation. This additive combines a water-in-oil microemulsion additive and a metal oxide nano additive. It is designed to simultaneously enhance the benefits of both types, which have been the subject of research in previous studies [22-26]. The addition serves the purpose of conserving fuel and diminishing polluting emissions through two distinct mechanisms: the micro-explosion mechanism of water-in-oil microemulsion additives and the catalytic mechanism facilitated by metal oxide nanoparticles, which promotes full combustion.

An exceptional benefit of additives is their ability to be sized at the molecular level (nm), allowing them to completely showcase nanomaterials' unique and superior characteristics [27, 28]. Hence, employing a minimal quantity of additives can yield substantial fuel efficiency gains and reductions in emissions. The use of a small amount of additive will not have a significant impact on the fuel's properties. It can be easily blended and has minimal additional cost. This approach offers high socio-economic efficiency and does not compromise the safety of engine operation, fuel storage, and transportation [29].

When utilizing microemulsion additives of the latest generation, which have a size of several nanometers (nm), these particles can facilitate the full oxidation of fuel hydrocarbons during the combustion process. Simultaneously, the presence of metal oxide nanoparticles in liquid fuel will enlarge the reaction area, introducing additional oxygen to the combustion process and facilitating a more efficient combustion process. Consequently, fuel efficiency will be enhanced, leading to a substantial reduction in pollutants generated by incomplete combustion, such as CO and HC.

In this study, the authors will analyse the effects of a new generation of microemulsion fillers on diesel fuel, with a ratio of 1/8000. The investigation was conducted using a combustion chamber with a consistent environment and transparent doors, facilitating the observation and analysis of the combustion process. This study presents novel findings about the use of microemulsion additives in research. Simultaneously, the study's findings will serve as the foundation for further guidance in the selection of additives for diesel fuel.

2. Research Sequence and Test Fuel

2.1. Research sequence on new generation microemulsion additives

The sequence of studying the effect of new-generation microemulsion additives on the combustion process and emissions in a constant combustion chamber is shown in Fig. 1. The evaluation of the effect of microemulsion additives includes the following steps:

+ **Step 1:** Select the type of additive, the ratio of substances in the additive, and the appropriate ratio of microemulsion additives based on experiments.

+ **Step 2:** Build a test model of the combustion process of the original fuel and the fuel mixed with the new generation microemulsion additives in a constant combustion chamber (when testing, consider the test conditions).

+ **Step 3:** Conduct the test to obtain the results of the development of the flame film, the pressure changes in the combustion chamber, heat, and emissions (NO, CO, HC).

+ **Step 4:** Compare the results of the original fuel and the fuel after mixing the microemulsion additives.

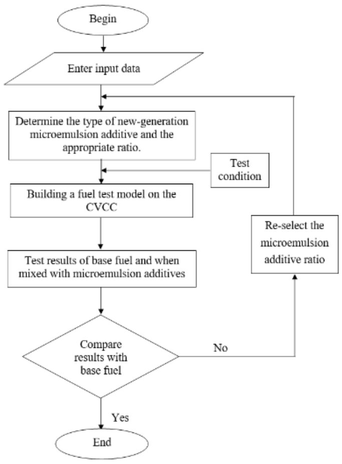


Fig. 1. Schematic diagram of the study of the effect of microemulsion additives on the combustion process and emissions.

2.2. Test fuel

2.2.1. Select the ratio of components in the new generation micro-additive

The new generation of microemulsion fuel additives for diesel fuel is created by combining two types of water-in-oil microemulsion additives and metal oxide nano additives. The components are displayed in the following Selection.

- **Select diesel oil**

Selecting diesel sources with parameters as in Table 1 as a fuel object for additives-related experiments.

Table 1. Some main properties of mineral diesel used in research.

Targets	Diesel
Density at 15 ^{0}C	0.837
Dynamic viscosity at 40 ^{0}C (mm^2/s)	3.14
Cetane value	53
Thermal treatment (MJ/kg)	43
Sulphur content by volume, %	0.05

- **Surface compound selection**

Surfactants are chemical compounds that decrease the force of attraction between molecules at the surface of two different liquids, between a gas and a liquid or between a liquid and a solid. Research has shown that fuel efficiency, decrease in emissions of environmental pollutants from engine exhaust, and longevity of additives and emulsion fuels are significantly influenced by the size of emulsion particles. The extent of this relies mostly on the nature and arrangement of the surfactant. The surfactant must possess combustible qualities and must not generate soot, sulphur, and free nitrogen, in addition to its great effectiveness in emulsion formation.

Surfactants are utilized to create advanced microemulsion additives that improve the thermodynamic stability of water-in-oil microemulsion droplets. This helps to prevent particle breakage, particle aggregation, sedimentation, and phase separation. Various surfactants include Triton X-100, Tetra methyl ammonium hydroxide solution, and others. For this study, the authors selected a surfactant composed of a mixture of ethoxylated coconut oil, Hydroxyethyl imidazoline, and polyethylene glycol ester of fatty acids in a ratio of 3:2:1.

- **Selection of metal oxide nano additives**

Metal/metal oxide nano-based fuel additives can be introduced directly into the fuel by dispersing them in the presence of surfactants with magnetic stirring, ultrasonic stirring, or ball milling assistance. Metal/metal oxide nanoparticles can be synthesized by chemical or physical methods such as sol-gel, hydrothermal, pyrolysis, hydrothermal-microwave, etc. In addition, metal/metal oxide nano additives can be indirectly introduced into the fuel by creating a dispersion system containing metal/metal oxide nano additives with good compatibility with the fuel. The metal oxide nano studied is an iron oxide nano, and the indirect mixing form was chosen.

Many metal/metal oxide nano additives include compounds containing iron, cerium, manganese, barium, nickel, etc. Comparing the specific advantages and disadvantages of different types of metal and metal oxide nano additives needs to be researched separately. The comparison is difficult to make because individual studies are on a particular subject. The authors chose metal oxide nano additives in this study as iron oxide nano additives.

- **Select the components that make up the micro-emulsifying additives**

The features and additives of the newly developed micro-additives for diesel fuel include water emulsion additives in oil and nano oxide additives. The surfactant combines an ethoxylated mixture derived from coconut oil, hydroxyethyl imidazoline, and polyethylene glycol ester of fatty acids. The ratio of these components is 3:2:1. The surfactant ratio is 10.3%, the water content is 20%, and there are 220 ppm of iron nano additions.

The new generation of microemulsion fuel additives for diesel fuel is created by combining two types of water-in-oil microemulsion additives with metal oxide nano additives. Both additives are produced independently and include distinct structures, including surfactant presence. Thus, the selection of the proportion of components in the additive is established through empirical experimentation. In the following section, the authors comprehensively explain the procedure used to determine the optimal water ratio in the additive.

To examine the impact of water content in additives, experiment by combining additives with water concentrations ranging from 5% to 30%, along with 10.3% surfactant and the remaining portion of oil. To achieve a transparent combination, the additive mixture is agitated and exposed to high-intensity ultrasound at 300 rpm for the whole duration of catalyst addition. After this, the mixture is mixed and stable for 32 minutes. The additive was stored for one month to assess its stability. The findings of this evaluation are shown in the Table 2.

Table 2. Effect of water content in the additive with selected surfactant.

Aqueous phase content (%)	**Appearance**	**Emulsion particle size in DO after phase (nm)**	
		Early brewing time	**After 2 months**
5	Transparent, stable after 1 month	4	6
10	Transparent, stable after 1 month	6	7
15	Transparent, stable after 1 month	7	10
20	Transparent, stable after 1 month	9	12
25	Transparent, cloudy after 1 month	14	-
30	opaque	-	-

To simplify the computation, the water phase content is represented as the ratio of the mass of water added to the mass of the mixture before adding water. It is evident that by utilizing specific surfactants and maintaining a water content below 20%, the size of the water-in-oil microemulsion is 9 nm. Simultaneously, the efficacy of generating water microemulsions in DO fuel mixed with additives remains reasonably consistent even after one month of storage.

Based on the data above, it is evident that, among the surfactants examined, there is a maximum limit to the amount of water that may be included in the additive combination while still meeting the criteria for appearance and compatibility in DO. The study determined a water content of 20% based on the given criteria.

- **Estimate the appropriate proportion of microemulsion additives to be mixed with the oil**

By incorporating new-generation microemulsion additives into the fuel, it is observed that the efficiency of producing water emulsions in DO oil is significantly increased when the additive ratio is rather large, ranging from 1/3000 to 1/1000. However, adding additives to fuel does not guarantee compliance with fuel stability criteria. Micro emulsion additives are mixed into gasoline at a ratio of 1/8000 to 1/5000, providing high water-in-oil emulsification efficiency while maintaining fuel stability. Microemulsion additives are mixed into gasoline at 1/8000 to 1/5000, providing high water-in-oil emulsification efficiency while maintaining fuel stability. Nevertheless, the size of the emulsion particles exceeds 1 nanometre within the range of 1/8000 to 1/5000.

The objective is to choose the smallest ratio of additives mixed with fuel that guarantees the promotion of the micro-explosion mechanism of the new-generation microemulsion additive. This selection is based on visual assessment and the detection limit. The emulsion particle size meter is used to analyse and evaluate the quality of the additive. Based on the findings presented in Table 3, the authors selected a mixing ratio of 1/8000 for the experimental research, using DO oil as an addition.

Table 3. Appearance and particle size of fuel emulsion mixed with new generation microemulsion additives with different mixing ratios.

Phase ratio (v/v)	Appearance	Emulsion Particle Size (nm)
1/1000	Transparent, the bottom appears after 2 weeks at level storage conditions and 1 month at normal storage conditions	2
1/3000	Transparent, the bottom appears after 2.5 weeks at level storage conditions and 1 month at normal storage conditions	2
1/5000	Transparent, no agglomeration occurs after storage under survey conditions for a period of 1 month	3
1/6000	Transparent, no agglomeration occurs after storage under survey conditions for a period of 1 month	3
1/8000	Transparent, no agglomeration occurs after storage under survey conditions for a period of 1 month	3

2.2.2. Evaluate the quality of added additives into diesel fuel

- **Assessing the quality of each additive**

The indicators of the closed cup, the density, the corrosion of the copper plate, the viscosity and the bonded are determined in the results shown in Table 4.

Table 4. New generation micro-additive properties.

Name of target	Unit	Test method	Result
Fluttering point of closed cup	^{0}C	ASTM D93 - 06	73.0
Viscosity at 40 ^{0}C	mm^2/s	ASTM D445-11	42.13
Corrosion at 50 ^{0}C	-	ASTM D130 - 04e1	1b
Density at 15 ^{0}C	kg/m^3	ASTM D1298 - 05	927.2
External inspection	-	ASTM D4176 - 04e1	Red-brown, clean

- **Evaluation of diesel quality additives**

The quality of diesel and diesel fuel mixed with new-generation microflora is evaluated as in Table 5.

3. Diagrams and Testing Equipment

3.1. Objects and test diagrams

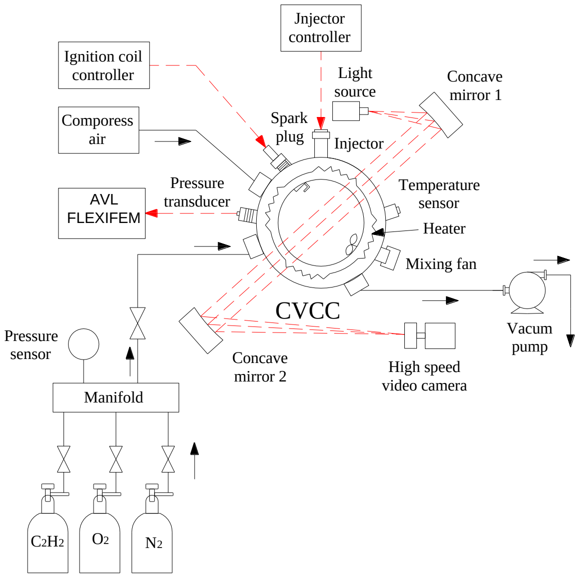
The test object is a constant volume combustion chamber (CVCC). This combustion chamber has been designed, manufactured and tested safely with 80 bar pressure inside the combustion chamber. This combustion chamber can control the air residue, temperature, pressure and time of fuel spray and observe the mixing and burning process through the observation window. The combustion chamber is a unified fire chamber with a diameter of 80 mm, a height of 90 mm and a thickness of the combustion chamber of 60 mm (Fig. 2(b)). Test arrangement diagram (Fig. 2(a)), including the system of high-pressure fuel supply (Common Rail), air intake and emissions, information system, Mixing system and signal system [30].

- AVL Flexifem pressure measuring device and AVL QC33C XYLANG pressure sensor measure the pressure in the cylinder and have a meter range of 0 ÷ 200 bar in real-time.
- Chrónos 4.1 high-speed camera captures a maximum of 40000 frames per second to capture the entire fire process in real-time.
- The CVCC testing chamber can observe the burning process from the outside through the observation glass and can be tested with internal fire pressure up to 80 bar.
- The Common Rail fuel supply system provides up to 200 MPa, and the injection signal control system can control the amount of fuel spray over time, not depending on the fuel supply system.
- In real-time controlled ignition system.

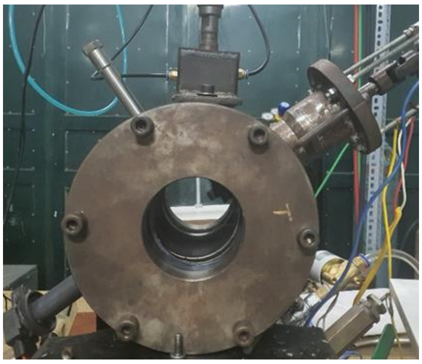
- The intake supply system provides the exact air intake into the fire with a maximum pressure of 80 bar.
- Computers use AVL Indicom Mobile V2.9 and LabView software.

Table 5. Quality indicators, properties of diesel fuel and diesel mixed with new-generation micro-additives.

Name of target	Unit	Test method	Review threshold	Sample DO	Model DO mix with the new generation
sulphur content	mg/kg	ASTM D5453-12	⩽ 500	213.0	213.1
Cetane value	-	ASTM D613-10a	⩾ 50	55.3	55.3
Storage temperature at 90% of the recovery volume	^{0}C	ASTM D86-10a	⩽ 360	346.4	347.8
Fluttering point of closed cup	^{0}C	ASTM D93 - 06	⩾ 55	69.0	66.0
History viscosity at 40 ^{0}C	mm^2/s	ASTM D445 -11	2.0 ÷ 4.5	3.50	3.49
Carbon sediment of 10% distillation Frozen	% mass	ASTM D4530 - 06e1	⩽ 0.30	0.05	0.03
Frozen	^{0}C	ASTM D97 - 11	+3 ÷ +12	0	0
Ash content	% mass	ASTM D482-07	⩽0.01	0.005	0.005
Water content	mg/kg	ASTM D6304-07	⩽ 200	61.8	71.5
Granular impurities	mg/L	ASTM D6217 - 03e1	⩽ 10	2.2	2.6
Corrosion Corrosion at 50 ^{0}C	-	ASTM D130 - 04e1	Type 1	1a	1a
Density at 15 ^{0}C	kg/m^3	ASTM D1298 - 05	820 ÷ 860	839.6	839.6
External inspection	-	ASTM D4176 – 04e1	Clean without free water and impurities	Yellow, clean	Yellow, clean



(a) Test arrangement diagram.



(b) Actual image of CVCC combustion chamber on the test stand.

Fig. 2. CVCC system testing scheme.

3.2. Experimental conditions

The experiment was done using CVCC with 6-hole nozzle, 0.14 mm hole diameter; Spray pressure kept unchanged at 1500 bar; 3 ms fuel injection time; Environmental temperature changes 450 K; Oxygen concentration is kept at 20% for testing purposes; DO test fuel; Due to the new generation micro -additive phase 1/8000.

4. Results and Discussions

4.1. Fire film development

The image, as shown in Fig. 3, shows that the brightness of the micro-phase fuel of 1/8000 emulsion when burning is brighter, showing that the development of fire film is faster than diesel. The emulsion additive increases the surface area, causing the reaction rate to react faster; the firing process ends earlier than the diesel fuel.

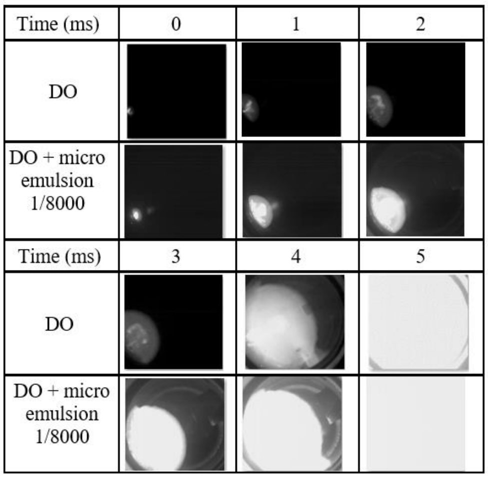


Fig. 3. Fire film development of experimental fuel in CVCC.

4.2. Pressure in the fire chamber

Scientific experiments have demonstrated that the combustion process may be enhanced by combining the new generation microemulsion additive with DO fuel at a ratio of 1/8000. This results in the achievement of maximum pressure at an earlier stage, as shown in Fig. 4. When combined with a microemulsion additive, the fuel undergoes a minuscule detonation of the water-in-oil microemulsion additive, which aids in efficiently dispersing and blending the fuel throughout a broad spectrum. Conversely, the additive also introduces oxygen atoms to improve the combustion process and expand the area of a chemical reaction.

Once the maximum pressure is reached, the rate at which the pressure drops tends to decrease, similar to the behaviour observed with DO fuel, as demonstrated by reference [31]. Nevertheless, the maximum pressure attained is lower than DO fuel due to its reduced calorific value (32.3 bar as opposed to 33.1 bar).

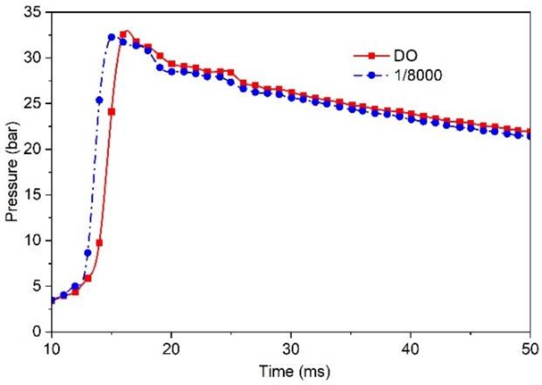


Fig. 4. Pressure movements in the fire chamber.

Figure 5 illustrates the pressure rise rate in the combustion chamber for two fuels adhering to the same standard. Notably, the micro-emulsion of Fuel Due to

1/8000 exhibits an earlier and more pronounced increase in pressure, reaching a peak value of 16.75 bar/ms compared to the fuel without the micro-emulsion (14.5 bar/ms). This notable difference is primarily attributed to the influence of emulsion additives, directly impacting the pressure increase in both fuels.

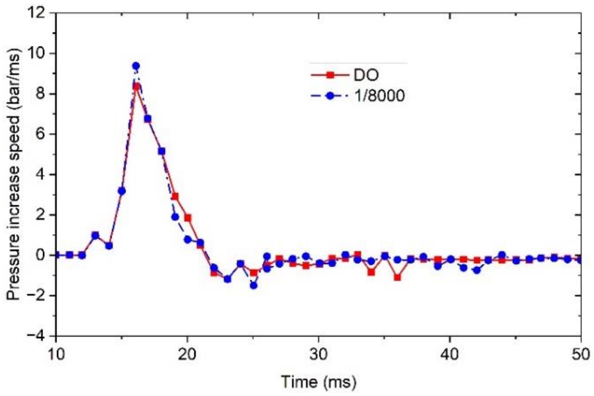


Fig. 5. Graph pressure increase in CVCC.

4.3. The law of radiating heat

Figure 6 shows that the heat of the micro-phase fuel takes place earlier and reaches the most prominent peak of 12.7% (1406.2 J/MS compared to 1247.9 J/MS of DO), more significant than the DO fuel. This is consistent with the properties of nano additives that create a larger reaction surface and provide more oxygen for the reaction process [31].

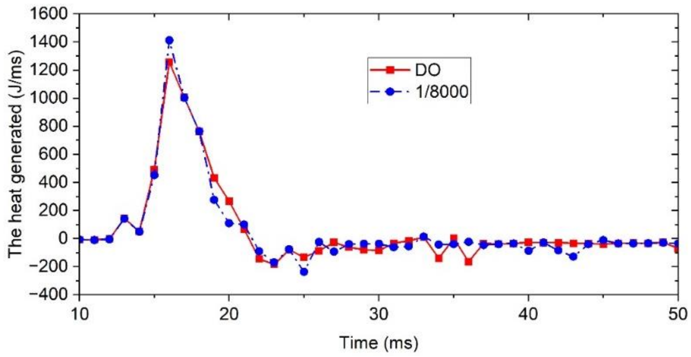


Fig. 6. The heating graph of the test fuel.

4.4. Emissions composition

The graphs in Figs. 7-9 demonstrate that the NO and HC components of fuel emissions, when mixed with 1/8000 microemulsion additives, are consistently smaller than diesel fuel alone. Specifically, the average value of NO decreased by 18.1%, and HC decreased by 8.2%. The average CO percentage notably fell by 18.9%. This demonstrates that the combustion process is influenced by the micro-explosion mechanism of the microemulsion additive, resulting in faster and more complete fuel burning and an increased supply of oxygen for the combustion process.

Utilizing the micro-explosion mechanism of fuel combined with advanced micro-emulsion additives, the combustion process is uniformly distributed across the injection area, resulting in more efficient burning of the dense fuel core region. This leads to a reduction in emissions of CO, HC, and smoke. After the combustion phase, the temperature of the area where NO is produced decreases because less exhaust gas and water vapor are present. Nevertheless, the overall average level in the cylinder remains greater than constant. This finding also aligns with prior research on additives for water-in-oil microemulsions [24, 25].

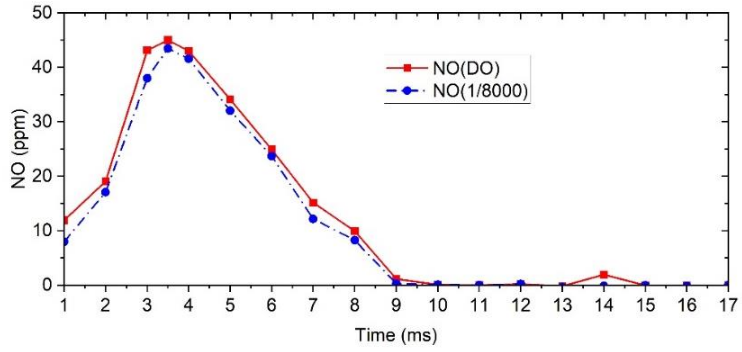


Fig. 7. NO emissions composition.

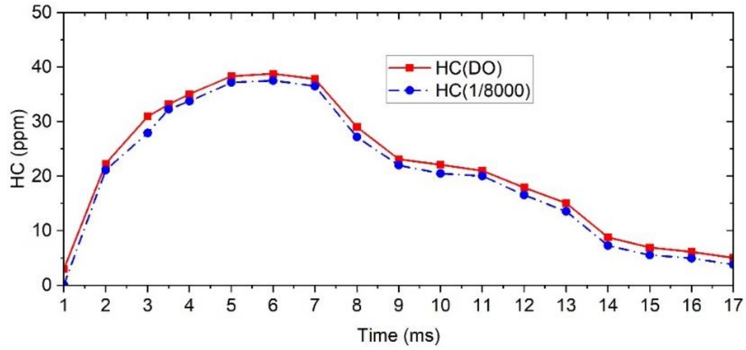


Fig. 8. HC emissions composition.

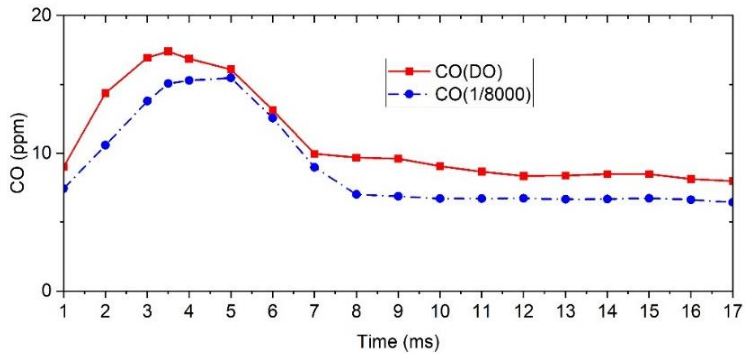


Fig. 9. CO emissions composition.

The change in pressure, the increase in the rate of pressure, and the heat released by microemulsion additive fuel are due to the properties of the new generation micro-additive. After the water-in-oil microemulsion explosion, the fuel mixes and diffuses over a large area, and the combination of additives makes the fuel burn completely, leading to increased energy release per unit of fuel and reduced HC and CO emissions. In addition, the newly introduced microemulsion additive containing water increases the amount of oxygen, causing NO emissions to improve, so the local combustion area in CVCC to create NO is reduced. However, the average level across the entire combustion chamber is still high.

5. Conclusion

This study presented experimental data on using diesel fuel (DO) combined with a new-generation microemulsion additive in a CVCC-type combustion chamber at a ratio of 1/8000. The results showed that the combustion chamber pressure and heat release rate increased faster when the fuel was blended with a microemulsion additive at a ratio of 1/8000 compared to other fuels.

These findings demonstrate that combining diesel fuel with a microemulsion additive at a ratio 1/8000 provides superior technical and economic advantages over control fuels. The micro-explosion mechanism of this additive promoted the combustion process, leading to faster and more efficient combustion.

Microemulsion fuel emissions reduce NO, HC, and CO components compared to using diesel fuel alone. More precisely, the mean value of NO declined by 18.1%, HC down by 8.2%, and CO declined by 18.9%. These data will be the foundation for analysing fuel characteristics combined with this microemulsion additive in diesel engines.

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