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Investigation of Dispersion, Breakup, and Combustion Processes of Liquid Fuel Droplets under High Turbulence

In the present study, the processes of breakup, dispersion, and evaporation of gasoline droplets in a model combustion chamber under high turbulence reacting flow were investigated using modern computational modeling methods. The influence of the initial gas temperature in the chamber on spray dynamics, droplet distribution, and thermal characteristics of the flow was analyzed. The results of computational experiments enabled the detailed visualization of the reacting flow, including the temperature, aerodynamic, and concentration characteristics of the fuel–air mixture. It was established that an increase in the initial gas temperature leads to a reduction in the mean droplet size, accelerated evaporation, and enhanced combustion intensity. It was observed that droplets spread over considerable distances from the nozzle while maintaining a relatively uniform radial distribution. As the droplets move upward in the chamber, their temperature gradually increases, reflecting complex interactions with the two-phase flow. The study demonstrated that higher gas temperatures intensify combustion and significantly raise maximum temperature levels. Based on the research conducted, the key role of the initial gas temperature in shaping the spray and flame structure was substantiated, providing a basis for recommendations to optimize the operation of combustion chambers in thermal engines.

Keywords: liquid fuel, droplets, combustion, dispersion, atomization, turbulent flow, gas temperature, spray dynamics, simulation, combustion chamber

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Introduction

Energy and transportation in the modern world remain largely dependent on hydrocarbon fuels. According to the International Energy Agency, their share of the global energy balance exceeds 80 %, with liquid fuels accounting for a significant portion. Their widespread use is attributed to a combination of high energy properties, ease of transportation, and their ability to be utilized efficiently in various applications. Despite growing interest in biofuels and other alternative energy sources, liquid hydrocarbon fuels remain a leading source of energy, ensuring the stability and efficiency of energy and transportation systems [1].

From an environmental perspective, liquid fuels offer advantages over solid energy sources. Their combustion produces virtually no ash, and pollutant emissions are significantly lower. Specific CO_2 emissions are 73–75 kg/GJ, compared to 90–95 kg/GJ for coal. The SO_2 and particulate matter content in the combustion products of liquid fuels is two to three times lower than that of coal, which complies with international environmental requirements [2].

According to the U.S.Energy Information Administration (EIA), global consumption of oil and other liquid fuels is projected to increase by 19 % between 2025 and 2040, primarily driven by the transportation and industrial sectors [3]. Demand is expected to rise from 95 million barrels per day in 2025 to 104 million barrels per day in 2030 and to 113 million barrels per day in 2040. The main drivers of this growth will be countries outside the OECD, where demand is projected to increase by 1.3 % annually, while in OECD member states, a slight decline is expected [4].

The forecast also indicates that OPEC will maintain or expand its share of global crude oil and condensate production. Renewable energy is expected to remain the fastest-growing source of energy, with an average annual growth rate of 2.3 %. Fossil fuels are expected to continue dominating the global energy mix, accounting for approximately 77 % of total consumption by 2040. Among fossil fuels, natural gas is expected to show the fastest growth, with an average annual increase of 1.4 % (Fig. 1) [5].

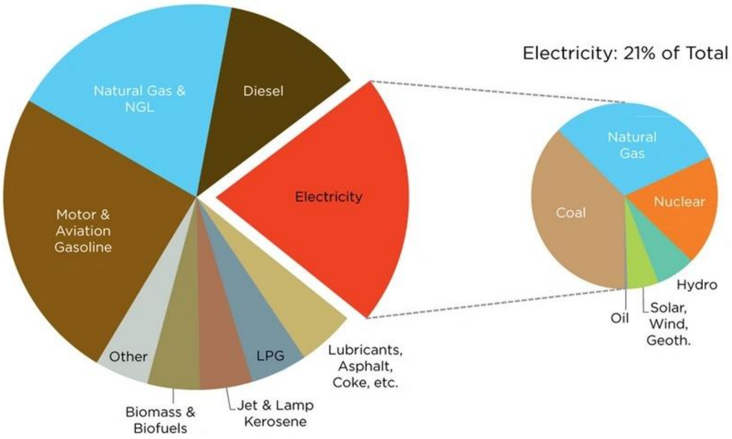


Figure 1. Structure of global energy consumption by fuel type and electricity source

The scientific novelty of the study stems from the need for a more in-depth analysis of the decomposition, evaporation, combustion, and dispersion processes of liquid fuels. The dynamics of droplets and dispersed systems directly determine the completeness of combustion and the efficiency of heating systems, as well as the level of harmful emissions.

The practical significance of the research results lies in their potential use in the design and modernization of power and transport systems. A thorough understanding of liquid fuel dispersion and combustion processes enables the development of more efficient nozzle systems for gas turbine engines, the improvement of combustion chambers in thermal power plants, and the optimization of operating processes in internal combustion engines. Ultimately, this contributes to increased energy efficiency, reduced operating costs, and a reduced environmental impact.

This study aims to comprehensively investigate the physicochemical mechanisms underlying the decomposition, evaporation, combustion, and dispersion of liquid hydrocarbon fuels under various thermodynamic conditions. Particular attention is paid to identifying the factors determining droplet size, evaporation rate, combustion flame formation, and combustion product formation mechanisms. Achieving this goal will enable the development of more accurate models of heat and mass transfer processes, improve the efficiency of liquid fuel use in power and transportation systems, and reduce harmful emissions by optimizing atomization and combustion processes.

Mathematical and geometrical models of the problem

The continuity equation governing mass conservation in a two-phase flow can be expressed as follows [6]:

$$\frac{\partial \rho}{\partial t} + \operatorname{div}\left(\rho \mathbf{u}\right) = S_{mass}. \tag{1}$$

The parameter u characterizes the velocity field of the liquid fuel, whereas S_{mass} designates the source term introduced by density variations in the surrounding gas phase induced by evaporation.

The governing relation for momentum conservation in a two-phase flow can be written as follows [6]:

$$\rho \frac{\partial u}{\partial t} + \rho\left(\operatorname{grad} \mathbf{u}\right)\mathbf{u} = \operatorname{div} \xi + \rho \mathbf{g} + S_{mom}, \tag{2}$$

In this context, S_{mom} represents the source term corresponding to the local variation of momentum in the gaseous phase because of droplet dynamics.

The governing relation for internal energy conservation can be formulated as follows [6]:

$$\rho \frac{\partial E}{\partial t} = \boldsymbol{\tau}{:}\mathbf{D} - \rho \operatorname{div} \mathbf{u} - \operatorname{div} \mathbf{q} + S_{energy}. \tag{3}$$

The parameter q is the heat flux described by Fourier's law, whereas S_{energy} designates the source term reflecting the internal energy contribution associated with droplet dynamics.

The governing relation for the transport and conservation of component m can be formulated as follows [7]:

$$\frac{\partial(\rho c_m)}{\partial t} = -\frac{\partial(\rho c_m u_i)}{\partial x_i} + \frac{\partial}{\partial x_i}\left(\rho D_{c_m}\frac{\partial c_m}{\partial x_i}\right) + S_{mass}. \tag{4}$$

The parameter $\rho_m$represents the mass density associated with component m, whereas ρ characterizes the total mass density of the mixture under consideration.

The turbulent structure of the reacting flow is quantified by means of the empirical two-equation k–ε model, which simultaneously resolves the transport equations for turbulent kinetic energy k and its dissipation rate ε [8–10]:

$$\rho\frac{\partial k}{\partial t} + \rho\frac{\partial \bar{u}_j k}{\partial x_j} = \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right]\frac{\partial \bar{u}_i}{\partial x_j} + G - \frac{2}{3}\rho k\delta_{ij}\frac{\partial \bar{u}_i}{\partial x_j} - \rho\varepsilon, \tag{5}$$

$$\rho\frac{\partial \varepsilon}{\partial t} + \rho\frac{\partial \bar{u}_j \varepsilon}{\partial x_j} - \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\sigma_\varepsilon}\right)\frac{\partial \varepsilon}{\partial x_j}\right] = c_{\varepsilon_1}\frac{\varepsilon}{k}G - \left[\left(\frac{2}{3}c_{\varepsilon_2} - c_{\varepsilon_3}\right)\rho\varepsilon\delta_{ij}\frac{\partial \bar{u}_i}{\partial x_j}\right] - c_{\varepsilon_2}\rho\frac{\varepsilon^2}{k}. \tag{6}$$

The constant values c_{ε_1}, c_{ε_2}, c_{ε_3}, σ_k, σ_ε, serving as parameters of the computational model, are generally obtained from experimental data.

A droplet tracking model was used in this study, allowing for a detailed description of the dynamics of fuel droplets in a gas flow. This model considers their individual trajectories, evaporation processes, and heat and mass transfer with the surrounding environment. This enables the analysis of the spatial distribution of droplets, their temperature characteristics, and concentrations in the flame, which is key to understanding fuel combustion and evaporation processes.

To more accurately simulate the behavior of the dispersed phase, a droplet collision model was additionally used (Fig. 2). It is based on a probabilistic approach: when droplet trajectories intersect, the probability of their interaction is estimated, allowing for phenomena such as agglomeration (droplet merging) and fragmentation (breakdown into smaller particles) [11]. This significantly improves the accuracy of spray modeling and allows for more accurate predictions of droplet size distribution, evaporation rate, and flame structure formation [12–15].

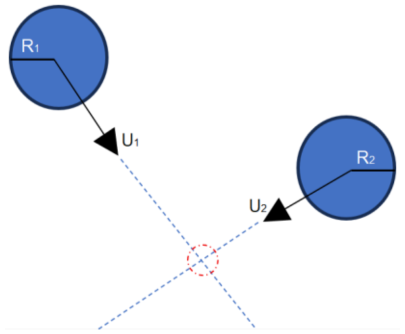


Figure 2. Illustration of the droplet collision model

The study utilized a model of a cylindrical combustion chamber 15 cm high and 4 cm in diameter (Fig. 3), with a liquid fuel injection nozzle installed in the center of its lower base. A real internal combustion engine served as the prototype for the simulated chamber, lending structural and operational realism to the computational model. The initial parameters included a pressure of 80 bar and a droplet radius of 25 μm.

The prediction of ignition delay was performed through an integral analysis using CHEMKIN. For biofuels, a simplified mechanism was employed to allow faster computations, accounting for 144 reactions involving 49 species [16, 17].

The concentrations of combustion products were determined using a model based on the detailed kinetic mechanism of the combustion process.

To predict soot formation during the combustion of hydrocarbon fuels, the global Shell soot model [18] was employed. This model accounts for key processes such as nucleation, particle growth, and agglomeration, as well as hydrocarbon pyrolysis and the formation of polycyclic aromatic hydrocarbons, which play a central role in soot generation [19, 20]. By using this approach, it becomes possible to estimate soot emissions and optimize combustion conditions, contributing to improved engine performance and reduced environmental impact.

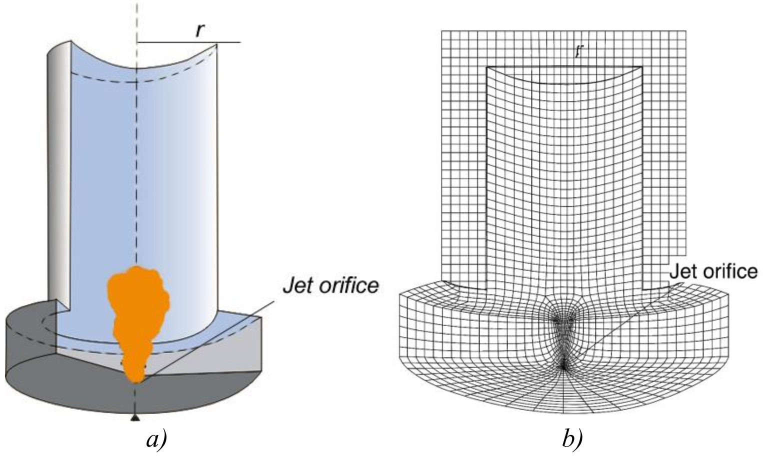


Figure 3. The main structural elements used in modeling the system under study are: *a*) a schematic representation of the combustion chamber geometry; *b*) visualization and discretization of the computational domain

For numerical modeling of the breakup, dispersion, evaporation, and combustion of liquid fuel droplets, the KIVA-3V software package developed at Los Alamos National Laboratory (USA) was employed. This code is designed for three-dimensional simulations of flows in internal combustion chambers and is based on the finite-volume method for solving the Navier–Stokes equations with consideration of turbulence, heat, and mass transfer, and chemical reactions [21, 22].

The KIVA-3V code includes modules for calculating fuel droplet trajectories, evaporation, collisions, and secondary breakup, which allows for a detailed description of the interaction between the dispersed and gaseous phases under conditions of high turbulence. The software package features an adaptive computational grid, flexible boundary conditions, and the capability to vary the thermodynamic parameters of the fuel and oxidizer. The use of KIVA-3V made it possible to obtain detailed distributions of temperature, velocity, and species concentration in the reacting flow, ensuring high accuracy in describing spray and combustion processes under various initial gas temperatures.

This study presents the results of computational experiments aimed at investigating the influence of initial temperature on the processes of breakup, dispersion, combustion, and evaporation of gasoline droplets in a model combustion chamber under conditions of high turbulence. The injection gas temperature varied from 700 to 1500 K, which made it possible to analyze its effect on spray flame formation as well as on the temperature and concentration fields of the reacting flow.

Results and Discussion

Figure 4 illustrates selected results of numerical simulations addressing the radial dispersion of liquid fuel droplets within the model combustion chamber. The analysis of the obtained data reveals that an increase in chamber temperature leads to a reduction in the mean droplet diameter. This trend is primarily associated with enhanced evaporation rates and intensified aerodynamic atomization processes. However, the magnitude of this reduction remains relatively modest, indicating that the geometric transformation of droplets is constrained under the studied conditions.

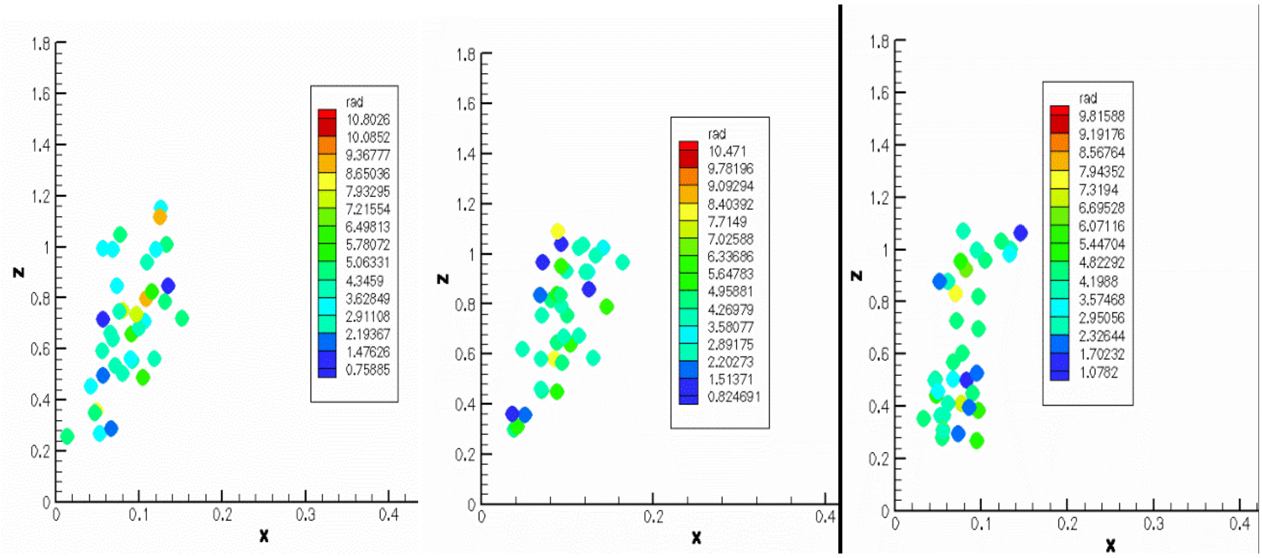
The spray dynamics of gasoline droplets exhibit characteristic spatiotemporal features in a highly turbulent flow. At 0.8 ms after injection, the droplets attain a penetration height of approximately 1.2 cm above the injector nozzle. In the radial direction, a nearly uniform distribution of droplets is observed up to 0.2 cm from the chamber axis, suggesting a stable atomization regime and well-established spray formation mechanisms.

These results highlight the significance of initial gas temperature in shaping both the evaporation–atomization interplay and the subsequent distribution of reacting phases. Despite the relatively moderate change in droplet size, the findings confirm the strong temperature dependence of spray dynamics, which is critical for predictive modeling of heat and mass transfer processes in advanced combustion systems.

Figure 5 presents the numerical simulation results of the temperature distribution of liquid-fuel droplets in the combustion chamber at 0.8 ms after injection.

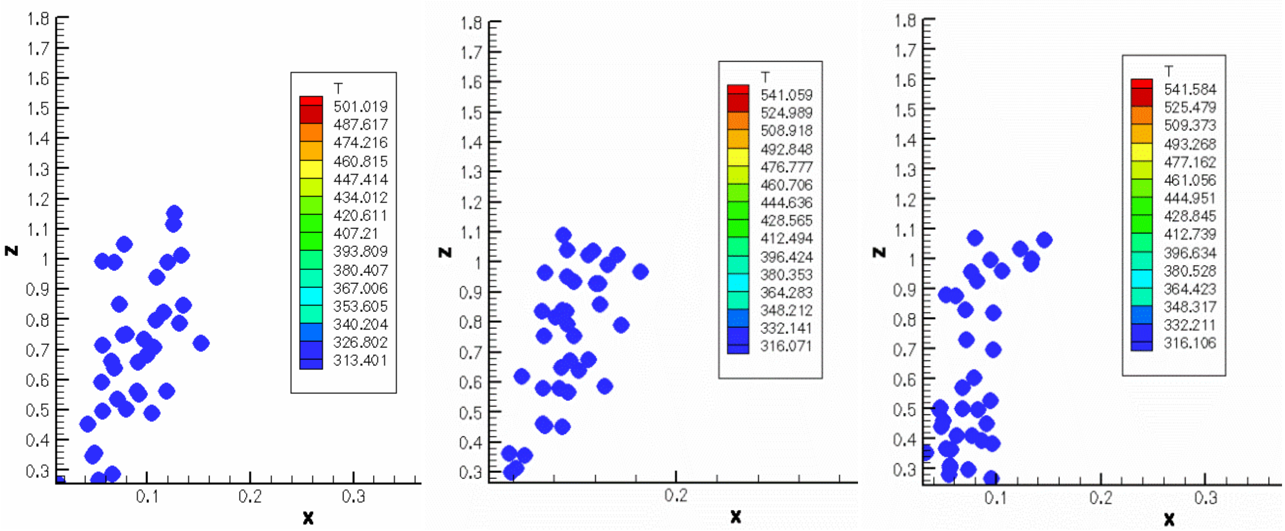
The analysis indicates that in the lower part of the chamber, droplet temperatures remain close to 300 K, which is attributed to their recent entry into the flow and the limited time available for heat and mass exchange with the surrounding hot gases. As the spray develops upward, the droplets progressively heat up, reaching maximum temperatures in the range of 500–550 K in the central and upper regions of the chamber.

This distribution highlights the presence of a pronounced temperature gradient caused by the non-uniformity of heat transfer and the variation in droplet sizes. Larger droplets retain lower temperatures due to their slower thermal response, whereas smaller ones rapidly approach equilibrium with the surrounding gaseous medium. Consequently, the droplet temperature field reflects the complex interplay of heat transfer, evaporation, and dispersion processes under turbulent combustion conditions.



a) 700 K *b*) 1000 K *c*) 1500 K

Figure 4. Dispersion of gasoline droplets by size in the combustion chamber space at t=0.8 ms at different initial temperatures of the gas



a) 700 K *b*) 1000 K *c*) 1500 K

Figure 5. Dispersion of gasoline droplets by specific temperature in the combustion chamber space at t = 0.8 ms at different initial temperatures of the gas

Unlike gasoline spray, which is characterized by relatively rapid heating of small droplets and a more uniform radial distribution within the chamber, diesel fuel spray exhibits greater heterogeneity in both droplet size and temperature. Diesel droplets are typically larger and more viscous, which slows their evaporation and heat exchange with the surrounding gases. As a result, droplet temperatures in the lower part of the chamber remain significantly lower, and equilibrium with the hot medium is reached more slowly than in gasoline sprays.

Additionally, diesel sprays often show a wider range of droplet sizes and more pronounced temperature gradients, affecting the formation of the combustion zone and overall fuel burning efficiency. These characteristics highlight the importance of considering the specific fuel properties when modeling heat and mass transfer processes under turbulent combustion conditions [23, 24].

The analysis of Figure 6 demonstrates that when the oxidizer temperature in the combustion chamber exceeds 800 K, the combustion process becomes significantly more intense. This is accompanied by accelerated ignition, an increased rate of chemical reactions, and more complete fuel oxidation. As a result, a substantially larger amount of heat is released, leading to a pronounced rise in chamber temperature, which in peak values approaches 3000 K.

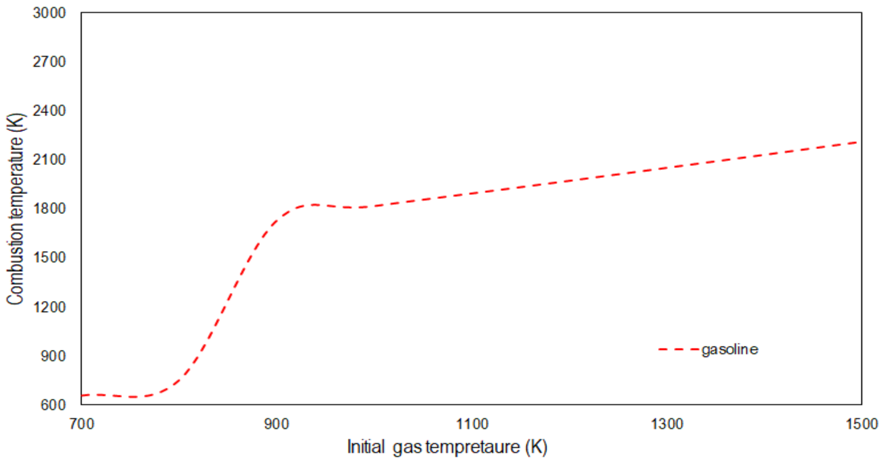


Figure 6. The distribution of the maximum combustion temperature in the combustion chamber, depending on the initial gas temperature

Particular attention should be paid to the dependence of the maximum temperature on the initial conditions. When the oxidizer temperature increases from 900 K to 1500 K, the maximum flame temperature rises from 1726.09 K to 2208.53 K.This trend highlights the strong sensitivity of the thermodynamic characteristics of combustion to the initial thermal state, which is associated with intensified heat transfer, enhanced fuel droplet evaporation, and accelerated oxidation reactions.

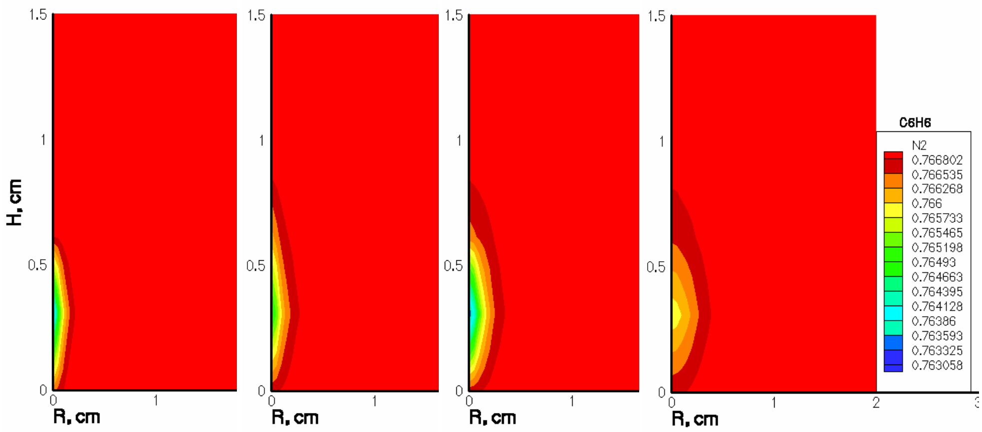
Thus, increasing the initial oxidizer temperature not only strengthens heat release but also contributes to the formation of a more stable and energetic flame, which is of key importance for optimizing combustion chamber performance under conditions of high thermal loads.

Figure 7 presents the results of numerical simulations of nitrogen concentration evolution in the combustion chamber over time. The analysis shows that nitrogen concentration remains relatively stable during the initial phase, when fuel injection has just begun and significant interaction with the oxidizer has not yet occurred.

The most pronounced variations are observed at approximately 1.5 ms, when the injected fuel is fully delivered into the chamber, has evaporated, and chemical reactions are initiated. At this stage, the combustion process is accompanied by the formation of nitrogen oxides, resulting in a noticeable redistribution of concentration fields. These findings indicate that the dynamics of nitrogen concentration are closely linked to the stages of fuel injection, evaporation, and ignition, and may serve as an indicator of pollutant formation intensity during combustion.

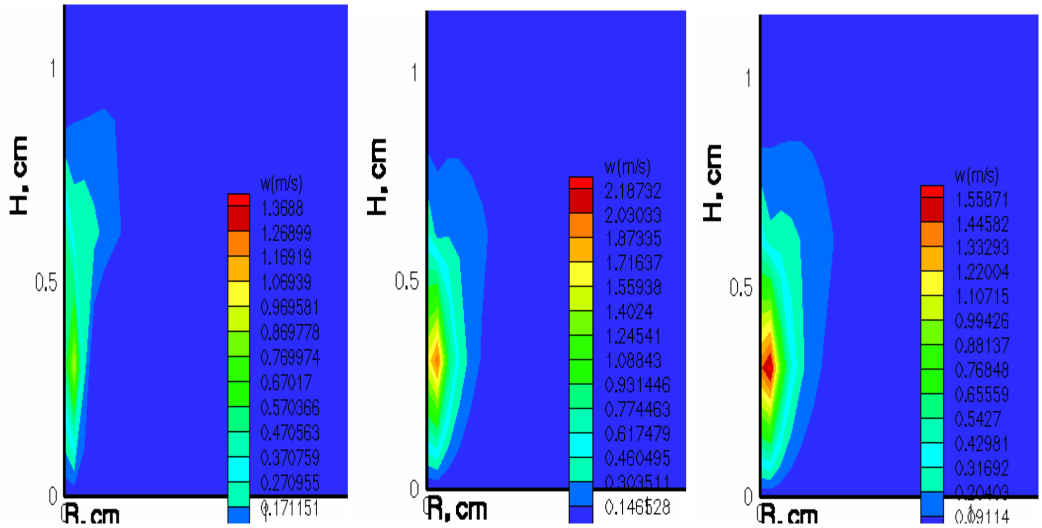
Similar insights into the effects of flow dynamics on species distribution can be drawn from [25], where the influence of throttle hole diameters on fluid flow in an inertial hydrodynamic installation was investigated. The results demonstrated that variations in the constriction geometry significantly affect the velocity and pressure fields, leading to a non-uniform distribution of fluid properties downstream of the throttle. By analogy, in combustion systems, such variations in local flow conditions can influence the mixing and transport of reactants, thereby affecting the spatial and temporal evolution of nitrogen concentration. This emphasizes that both injector geometry and flow constrictions play a crucial role in shaping concentration fields and may impact the intensity and localization of pollutant formation during combustion.

Figure 8 illustrates the gas velocity fields in the combustion chamber at different moments in time. At the initial stage of injection, gasoline droplets enter the chamber with a velocity of approximately 200 m/s, while the gaseous medium remains at rest. Due to the inertial motion of the droplets, the gas is entrained and acquires momentum, resulting in the formation of a high-velocity zone along the spray trajectory.



a) 0.5 ms *b*) 1 ms *c*) 1.5 ms *d*) 1.9 ms

Figure 7. Distribution of nitrogen concentration during gasoline combustion at different time moments



a) 0.8 ms *b*) 1.5 ms *c*) 2.0 ms

Figure 8. Distribution of gasoline droplet velocities at different time moments

The highest gas velocities are observed in the central axial region of the chamber, where the fuel jet develops. The maximum velocity occurs within a radial distance of about 1 cm from the chamber axis. In the radial direction, the velocity gradually decreases, forming a characteristic flow profile with a distinct high-velocity core and peripheral regions of deceleration.

Compared to biodiesel spray, gasoline droplets heat up and evaporate significantly faster due to their smaller size and lower viscosity. Biodiesel droplets are typically larger, more viscous, and contain oxygenated compounds, which slow down evaporation and delay thermal equilibrium with the surrounding hot gases. Consequently, biodiesel exhibits stronger temperature gradients and a less uniform distribution within the combustion chamber than gasoline [26]. Gasoline, in contrast, achieves more uniform heating and dispersion, which enhances rapid mixing with air and promotes faster and more efficient combustion, giving it a clear advantage over both diesel and biodiesel in terms of spray dynamics and ignition responsiveness [27].

In addition, the lower surface tension of gasoline promotes more intense breakup of the liquid jet into fine droplets even at moderate injection pressures [28]. This ensures a more uniform spray formation and improves vapor–air interaction throughout the combustion chamber. As a result, gasoline is characterized by a shorter ignition delay and greater combustion stability, especially under transient operating conditions. Fine atomization also contributes to more complete utilization of the injected fuel, reducing the likelihood of locally rich zones that typically lead to incomplete combustion and soot formation.

Furthermore, the chemical composition of gasoline, characterized by a high-octane number and high volatility, provides better controllability of the combustion process. The high-octane number enhances resistance to detonation and allows for higher compression ratios, thereby improving the engine's thermal efficiency. Rapid evaporation of gasoline ensures earlier and more uniform flame front propagation, promoting stable combustion and reducing emissions of unburned hydrocarbons. Compared to heavier fuels, gasoline provides smoother flame development and lower cycle-to-cycle variations, making it particularly effective for high-speed and highly turbulent combustion systems where precise fuel–air mixture formation is critical.

The comparison of the results obtained in the present study with the numerical analysis data of gasoline sprays from the Engine Combustion Network (ECN) Spray G case, performed using the Large Eddy Simulation (LES) method and the Eulerian–Lagrangian framework, shows good agreement in the fundamental patterns of droplet breakup, dispersion, and evaporation [29]. Both studies confirm the key role of initial thermodynamic conditions, such as gas temperature and pressure, in shaping the spray structure and combustion intensity. With an increase in the initial gas temperature, a reduction in the mean droplet diameter and an acceleration of the evaporation process are observed, leading to a more uniform distribution of the fuel–air mixture and higher maximum temperatures in the combustion zone. Unlike the ECN Spray G configuration, which considered early and late injection regimes, the present work analyzed a temperature range from 700 to 1500 K at fixed injection parameters. Nevertheless, the penetration dynamics and radial distribution of droplets show similar trends: at higher temperatures, a stable spray plume with smaller droplets and a pronounced vertical temperature gradient is formed. Thus, the modeling results confirm the universality of the regularities identified within the ECN Spray G framework for various chamber geometries and turbulence conditions, enhancing the reliability of the findings and the validity of recommendations for optimizing spray and combustion processes.

These results demonstrate that the injection process strongly governs the gas-dynamic structure of the flow, determining the intensity of turbulent mixing and establishing the conditions for subsequent combustion.

Conclusions

This study simulated the processes of gasoline droplet breakup, dispersion, evaporation, and combustion in a model combustion chamber at various initial gas temperatures under high turbulence. The results obtained allow the following conclusions:

1. Increasing the initial gas temperature leads to a decrease in the average droplet diameter, which is associated with intensified evaporation and aerodynamic breakup processes, although the change in droplet size remains relatively small;
2. The droplet propagation dynamics demonstrate stable plume formation: at 0.8 ms, the droplets reach a height of up to 1.2 cm and are uniformly distributed across the chamber width to a width of 0.2 cm;
3. A pronounced droplet temperature gradient was established: in the lower zone, the temperature is approximately 300 K, while in the upper regions it reaches 500–550 K, reflecting the influence of droplet size and heat and mass transfer conditions;
4. As the oxidizer temperature increases above 800 K, the combustion process becomes more intense, with the maximum chamber temperature reaching 3000 K.As the initial temperature changes from 900 to 1500 K, the maximum temperature increases from 1726.09 K to 2208.53 K;
5. The nitrogen concentration changes most significantly at 1.5 ms, due to the completion of injection, fuel evaporation, and the onset of a chemical reaction accompanied by the formation of nitrogen oxides;
6. The gas-dynamic flow structure is determined by the injection process: maximum gas velocities are observed near the chamber axis and reach values within 1 cm along the radius, forming a characteristic flow profile with a high-velocity core and deceleration zones at the periphery.

Thus, the study confirms the decisive role of the initial gas temperature in shaping the characteristics of fuel atomization and combustion. The results obtained can be used to improve heat and mass transfer models and optimize the operating modes of combustion chambers in power and transport systems.

The proposed numerical solutions and identified regularities are applicable within the range of parameters characteristic of small-scale model combustion chambers operating under high turbulence. The results obtained describe the behavior of fuel droplets under conditions similar to those occurring in gasoline and diesel internal combustion chambers. The model can also be adapted for the study of biodiesel fuels, considering their specific physicochemical and thermodynamic properties. However, direct extension of the results to large-scale industrial systems requires additional verification and refinement of boundary conditions.

The developed comprehensive model has a universal character and can be applied to a wide range of liquid hydrocarbon petroleum fuels, as well as adapted for simulations involving biofuels. However, variations in the geometry or design features of the combustion chamber, as well as changes in operating conditions, require additional adjustment of the input parameters and refinement of boundary conditions. This approach ensures the reliability and adequacy of the computational results when extending the applicability of the model to broader operating ranges.

The numerical modeling methods implemented in the KIVA-3V software package are reproducible when using similar computational grids, time steps, and turbulence models. Under these conditions, the results can be verified not only by other researchers but also compared with experimental data, demonstrating satisfactory agreement in the main thermal characteristics. This confirms the reliability and physical validity of the applied approach.

The analysis showed that the general trends in spray and combustion characteristics remain consistent under moderate variations in the initial gas temperature and injection velocity. However, with significant deviations of input parameters, the stability of the numerical solution may decrease due to the nonlinear relationship between the turbulence intensity and the evaporation rate of fuel droplets. This relationship is confirmed both by the computational data obtained in the present study and by previously published experimental [13] and numerical works [6, 19], which demonstrate that an increase in turbulence intensity enhances phase mixing, heat and mass transfer, and consequently accelerates droplet evaporation.

To assess the accuracy, stability, and reliability of the obtained numerical results, a series of verification calculations was carried out. Convergence tests with respect to the computational grid and time step were performed, along with a sensitivity analysis of key parameters through sequential variation of input conditions. Calibration of chemical kinetic mechanisms was conducted to reproduce the ignition delay. The reliability of the numerical results was assessed using statistical indicators that characterize the accuracy and internal consistency of the model. In addition, mass and energy conservation were verified, and the influence of input uncertainties was assessed using the Monte Carlo method. The results confirm the stability, physical validity, and reproducibility of the comprehensive model within the range of initial gas temperatures of 700–1500 K, pressure of 80 bar, and mean droplet radius of approximately 25 μm.

The obtained results advance the understanding of the physicochemical mechanisms of breakup, dispersion, evaporation, and combustion of liquid fuel droplets under high turbulence conditions. The identified relationships between the initial gas temperature, spray flame dynamics, and thermochemical characteristics of the reacting flow make it possible to refine heat and mass transfer models and improve the accuracy of combustion parameter predictions. Of particular importance is the revealed role of oxidizer temperature in determining maximum flame temperatures and nitrogen concentration distributions, which contributes to the development of combustion theory and reactive flow modeling.

The findings can be applied in the design and optimization of combustion chambers in power plants and internal combustion engines. It has been shown that higher initial gas temperatures promote more intense combustion and stable flame formation, thereby increasing fuel efficiency and reducing emissions of harmful substances, including nitrogen oxides. The results may serve as a basis for improving fuel injection and atomization systems and for developing more environmentally friendly and energy-efficient combustion technologies.

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Жоғары турбуленттіліктегі сұйық отын тамшыларының дисперсиясын, ыдырау және жану процестерін зерттеу

Жұмыста модельдік жану камерасындағы жоғары турбуленттіліктегі әсерлесетін ағындағы бензин тамшыларының ыдырау, дисперсиясы және булану процестері заманауи компьютерлік модельдеу әдістерін пайдалана отырып зерттелінді. Камерадағы газдың бастапқы температурасының бүрку динамикасына, тамшылардың таралуына және ағынның жылулық сипаттамаларына әсері талданды. Модельдеу бойынша жүргізілген есептік эксперименттердің нәтижелері әсерлесетін ағынның температуралық, аэродинамикалық және концентрациялық сипаттамаларын қамтитын толық визуализациясын алуға мүмкіндік берді. Газдың бастапқы температурасының өсуі тамшылардың орташа өлшемінің кемуіне, олардың булануын жеделдетуге және жану интенсивтілігінің артуына алып келетіні анықталды. Тамшылар соплодан едәуір қашықтыққа таралып, салыстырмалы түрде біркелкі радиалды үлесуге ие болатындығы байқалды. Камера бойымен жоғары қозғалған сайын тамшылардың температурасы біртіндеп артып, екі фазалы ағынмен күрделі әрекеттесуді бейнелейді. Газ температурасының өсуі жанудың қарқындылығын арттырып, максималды температуралық көрсеткіштердің айтарлықтай жоғарылауына ықпал ететіні дәлелденді. Жүргізілген зерттеу нәтижелері бойынша газдың бастапқы температурасының бүрку мен алау құрылымын қалыптастырудағы негізгі рөлі айқындалып, жылу қозғалтқыштарының жану камераларының жұмысын оңтайландыру бойынша ұсыныстар жасауға негіз болды.

Кілт сөздер: сұйық отын, тамшылар, жану, дисперсия, бүрку, турбулентті ағын, газ, температура, бүрку динамикасы, модельдеу, жану камерасы

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Исследование процессов дисперсии, распада и горения капель жидкого топлива при высокой турбулентности

В настоящей работе исследованы процессы распада, дисперсии и испарения капель бензина в модельной камере сгорания в реагирующем потоке при высокой турбулентности с использованием современных методов компьютерного моделирования. Проведен анализ влияния начальной температуры газа в камере на динамику распыла, распределение капель и тепловые характеристики потока. Результаты вычислительных экспериментов по моделированию позволили получить детализированную визуализацию реагирующего потока, включающую температурные, аэродинамические и концентрационные характеристики топливно-воздушной смеси. Установлено, что повышение начальной температуры газа приводит к уменьшению среднего размера капель, ускорению их испарения и усилению интенсивности сгорания. Выявлено, что капли распространяются на значительные расстояния от сопла, демонстрируя при этом относительно равномерное радиальное распределение. При продвижении вверх по камере температура капель постепенно увеличивается, отражая сложное взаимодействие с двухфазным потоком. Доказано, что с ростом температуры газа сгорание становится более интенсивным, а максимальные температурные показатели значительно возрастают. На основе проведенного исследования обоснована ключевая роль начальной температуры газа в формировании структуры распыла и факела, что позволяет формулировать рекомендации по оптимизации работы камер сгорания тепловых двигателей.

Ключевые слова: жидкое топливо, капли, горение, дисперсия, распыл, турбулентный поток, газ, температура, динамика распыла, моделирование, камера сгорания

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