EXPERIMENTAL STUDY ON SPRAY IMPINGEMENT DURING DIESEL ENGINE STARTING

by

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A lot of research has been carried out in the field of improving combustion efficiency and reducing exhaust gas, but the phenomenon of engine fuel spray hitting the wall cannot be solved well all the time, thus the phenomenon will increase exhaust gas emissions and reduce combustion efficiency. Based on oil pump test bench of Diesel engine, we designed spray-wall impingement's test, did high speed camera shooting to capture the relevant motion characteristics of fuel spraing-hitting the wall by mosquito-rope method, under the starting process, the influence of different working condition on spray impingement was studied. The results showed that under the condition of high injection rate/low gas pressure, the impact time gets early and the diffusion range gets to be increased. When the injection rate/background gas pressure is constant, the diffusion distance will change dynamically due to the wall roughness, that is to, increase first and then decrease. The increase of the roughness of the contact wall will promote the increase of the height of spray impingement, however, as the temperature of the contact wall rises, the difference in height of spray impingement gets to be decreased due to roughness. When the wall roughness is small, increasing the wall temperature will reduce the horizontal development distance of spray, increases roughness, the difference in height of horizontal development distance gets to be decreased due to wall temperature.

Key words: *starting process, spray-wall impingement, working condition, roughness of the contact wall, temperature of the contact wall*

Introduction

Due to its high thermal efficiency, low fuel consumption and stable operation, diesel engines are widely used in automobiles and other industrial equipments [1-3], however, there is a problem when the Diesel engine is running, that is, the phenomenon of fuel spray wall impingement cannot be avoided [4, 5]. Many new combustion methods can improve the efficiency of fuel utilization and reduce exhaust emissions, but at the same time, they will also make fuel

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spray wall impingement more frequently [6, 7]. The phenomenon of fuel spray hitting the wall has adverse effects on the operation of Diesel engines, including fuel waste, increased pollution emissions, fuel spray distortion, fuel deposition and carbon deposition, and uneven temperature distribution in the cylinder. Therefore, when designing and optimizing the combustion environment, it is necessary to consider and solve the problem of fuel spray impingement to improve combustion efficiency and engine performance. When the Diesel engine is started, unstable factors such as speed, cylinder pressure and temperature will cause the spray to hit the wall, which cause a lot of oil in the cylinder to adhere to the wall and then cool [8, 9]. Due to the complex environment in the engine cylinder, the characteristics of fuel spray impingement lack in-depth theoretical system, therefore, the design of spray wall impingement test during starting is helpful to understand the influence of injection rate, cylinder pressure, wall roughness, wall temperature and other factors on spray wall impingement, and it provides a basis for the optimization design of combustion environment [10].

The spray process of high pressure fuel in the engine or the spray impingement process occurs in a relatively short time. Considering the complex environment in the cylinder, it is difficult to carry out the spray test based on the Diesel engine [11-13]. First of all, high speed camera technology has promoted positive progress in the research of spray impingement [14, 15]. Safiullah *et al.* [16] used the constant volume bomb as the test environment, introduced the laser extinction method and the concentric circuit method to analyze the influence of different conditions on the fuel spray penetration distance, the results showed that increasing the injection pressure and reducing the ambient pressure would help to increase the penetration distance of spray wall impingement. Ahamed *et al.* [17] set the temperature and pressure to normal values, divided the spray wall collision process into different regions, and measured the distribution of particle diameters and their horizontal velocities after wall collision with a phase Doppler analyzer, the results showed that with the rise of wall temperature, the size of the spattered particles formed by spray impingement would gradually decrease. Putrasari *et al.* [18] used a laser analyzer and a high speed camera to record the development process of fuel spray impingement at room temperature and high pressure, the results showed that the development distance of particles in the horizontal direction would increase with the increase of fuel injection pressure and the decrease of ambient pressure, at the same time, the wall temperature had little influence on this characteristic. With the deepening of experiments, many studies have proposed models based on spray impingement [19, 20]. Subedi and Kong [21] put forward the spray impingement model in the 1990's, the model is divided the wall collision process into three stages, but the model ignores the momentum loss in the wall collision. Hanafi *et al.* [22] proposed the spray impingement model from the perspective of energy conservation and momentum conservation, this model was proposed under the condition that the wall temperature is less than the fuel boiling point, so there are certain restrictions. Recently, the visualization method [23, 24] has been widely used in the research of engine spray wall impact due to its intuitive, efficient and other characteristics, among them, the constant volume bomb [25-27] has become an important auxiliary means to study the spray wall impact process because of its simple structure, low cost, short test cycle and other characteristics. Mujtaba *et al.* [28] analyzed the change rule of diffusion distance caused by fuel adhesion and spray impingement when conducting impact test for airway injection. Anurag *et al.* [29] studied the change of the oil film thickness of spray impingement, designed a oil film test platform of vertical shooting, and measuring the change of the oil film thickness of wall surface under different temperature conditions by laser induction method. The aforementioned research has made a lot of achievements in the field of spray wall impact, but lacks visual effect. Although spray impingement temperature is a common variable, none of the aforementioned literatures has analyzed the effect of this variable on spray impingement effect. Increasing the spray impingement temperature will change the wall roughness in the existing test environment [30, 31], the spray impingement temperature and wall roughness should be taken as a whole assumption analyze their impact on the spray impingement effect, the aforementioned research only tests them as a single condition, respectively, there is a lack of relevant research on using them as an overall experimental condition for testing.

Therefore, this study introduces a visual method to analyze the effects of fuel injection rate, background gas pressure, wall roughness and wall temperature on spray impingement during Diesel engine starting. The spray impingement temperature and wall roughness were taken as the overall assumptions, and were comprehensively considered in the experiment. Through visualization method, we can directly observe the influence of different parameters on spray wall impact effect, and deeply analyze their interaction. This comprehensive analysis method can provide more comprehensive and accurate results, and provides a new way to further explore the influencing factors and mechanism of spray impingement phenomenon during Diesel engine starting.

Experimental set-up

Test system composition

The spray impingement device of this test consists of constant volume spray bombs, high pressure mechanical fuel injection pump test bench, high speed camera system, data acquisition and control parts:

– *Constant volume spray bomb*: Constant volume spray bomb is a device used to produce spray after impact. The utility model comprises a sealed container, which is filled with spray liquid and compressed gas. In the experiment, through the trigger device, the spray liquid and compressed gas are released to produce impact, so that the spray is formed.
– *High pressure mechanical fuel injection pump test bench*: The high pressure mechanical fuel injection pump test bench is used to generate high pressure spray. It usually consists of a high pressure oil pump, fuel injector, and related control system. The high pressure fuel pump sends fuel to the fuel injection nozzle through the pressure transmission system, and produces high speed spray through the fuel injection nozzle. This part is mainly used to compare with the constant volume spray projectile and study the influence of different spray modes on the impact spray.
– *High speed camera system*: High speed camera system is used to capture the image of spray after impact. It usually includes high speed cameras, appropriate lenses, and related light sources. The high speed camera system can take continuous images at a very fast speed to capture the dynamic process of spray.
– *Data collection and control part*: The data collection and control part is used to monitor and record various parameters in the experiment. It usually includes sensors, data acquisition devices, and corresponding control software. This part can obtain the data of each part of the spray wall impinging device in real time, such as pressure, temperature, flow*, etc.*, and store them or conduct real-time analysis.

These parts together constitute a spray wall impingement device, which is used for the related experimental research of spray after impact. Through the reasonable configuration and operation of these parts, valuable data and information about the post impact spray behavior can be obtained. The composition of spray wall impact test is shown in fig. 1.

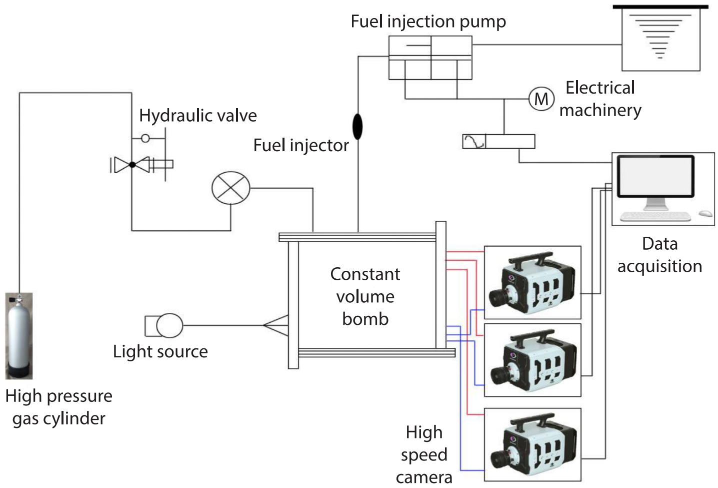

Figure 1. System composition of spray wall impingement

In the spray impingement test, in order to reduce the influence of the oil spray between adjacent orifices, the oil baffle ring is used for drainage, the oil baffle ring of the injector is set as shown in fig. 2, and the effect of the oil spray drainage is shown in fig. 3.

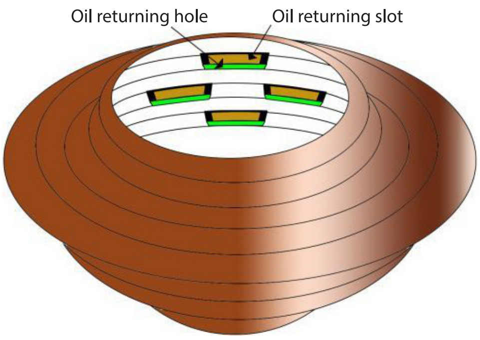

Figure 2. Design of fuel injector retaining ring

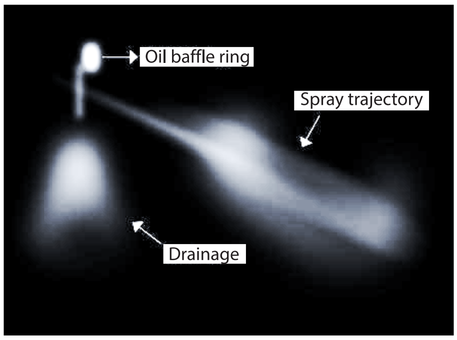

Figure 3. The drainage effect of the oil baffle ring

In the high speed camera set, a specific oil beam will be observed, the diameter of the fuel injector's nozzle is 0.30 mm, the number of nozzles is eight, and the injection opening pressure is 19.6 MPa, the parameters of the fuel injector and injection pump in the test are shown in tab. 1.

Table 1. Parameter table for each factor

Parameter Name	Parameter value
Plunger diameter [mm]	13
injection advance angle [°]	–30
Injection opening pressure [MPa]	19.6
Oil delivery pressure [MPa]	0.25~0.30
Jet cone angle [°]	140
The ratio of nozzle length to aperture	6.88

Test plan

During the spray wall impact test, –35# diesel fuel was selected as the fuel injection material to conduct a comparative study on the spray impingement according to the fuel injection rate, background gas pressure, wall roughness, and wall temperature, the scheme formulation is shown in tab. 2.

Table 2. Overall test scheme of spray impingement

Test steps	Description
Effect of fuel injection rate on spray impingement	The background gas pressure inside the constant volume bomb is controlled at 1.5 MPa, the gas temperature and fuel temperature inside the constant volume bomb are both 20 °C, and the wall roughness of the combustion chamber is W_r= 0.55 μm, start recording when the time point of fuel injection is 0
	Set the fuel injection rates to 50 mg/ms, 90 mg/ms, and 140 mg/ms, respectively
	The images of spray impingement and diffusion distance l at different injection rates at different time points are recorded
Influence of background gas pressure on spray impingement	The fuel injection rate is 50 mg/ms, the gas temperature and fuel temperature inside the constant volume bomb are both 20 °C, roughness of combustion chamber wall surface W_r = 0.55 μm, start recording when the time point of fuel injection is 0
	The background gas pressures are 1.5 MPa, 2.0 MPa, and 2.5 MPa, respectively
	The images of spray impingement and diffusion distance l at different background gas pressure at different time points are recorded
Impingement characteristics of fuel injection on different roughness levels	The fuel injection pressure is 80 MPa, the fuel injection lasts for 1 ms, and the wall temperature is set to 85 °C
	Obtain the extended images of spray impinging on the wall in the horizontal direction under different roughness conditions
	Obtain the change of fuel spray impingement height under different roughness conditions
	Change the wall temperature to obtain the radial penetration distance of spray under different roughness conditions
	Change the wall temperature to obtain the spray impingement height under different roughness conditions
Impingement characteristics of fuel injection at different wall temperatures	The fuel injection pressure is 80 MPa, the fuel injection lasts for 1 ms, and the wall roughness is 3.83 μm
	Acquire the horizontal expansion image of spray impinging on the wall under different wall temperature conditions
	Obtain the change of fuel spray impingement height under different wall temperature conditions
	Change the roughness to obtain the radial penetration distance of spray under different wall temperature conditions
	Change the roughness to obtain the height of spray impingement at different wall temperatures

In the experiment, to reduce experimental errors, each group of experiments was repeated three times, and the corresponding experimental conditions are shown in tab. 3.

Table 3. Test conditions

Reference name	Parameter value
Ambient temperature [°C]	20
Fuel temperature [°C]	20
High speed camera shooting speed [kHz]	20
Image resolution [pixel]	573 × 341
Time of exposure [μs]	1.1

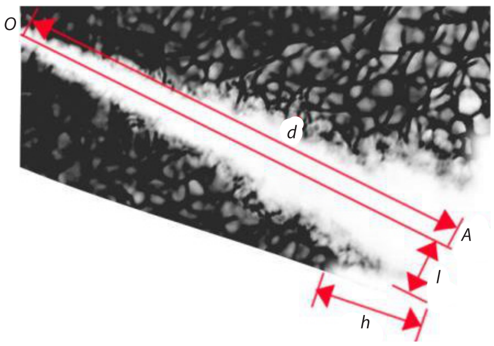

Figure 4. Macroscopic parameters of spray impingement

Definition of spray impingement parameters

In this paper, the macro parameters of spray impingement are mainly focused on the left side of the spray, where the pistonp wall is set. When defining the fuel spray impingement parameters, let the distance from spray to impingement be expressed, d. The distance that develops along the pistonp wall towards the pistonp direction after the collision is called the collision diffusion distance or radial penetration distance, that, l, the reflection height of the same side spray after impingement, h, as shown in fig. 4.

Image acquisition method

In order to visually analyze the spray process and the oil film evaporation formed by the spray impingement, it is necessary to capture the spray process and the impingement process of the fuel in a very short time, generally only 0-3 ms, therefore, the ordinary camera technology cannot capture the required image information, and high speed camera technology is required. Image acquisition consists of high speed cameras, a light source, and a data acquisition section connected to cameras.

The experimental image is collected by the Mini UX100 high speed camera produced by Fastcam company, based on different experimental requirements, the shooting speed range is between [2000 fps, 10000 fps], and the camera lens adopts short focus lens of NIKKOR AF 24 mm *f*/2.8*D*. The experiment is selected a 200W LED light source and processed the light according to different experimental needs. The experiment has a more accurate grasp of the fuel injection process, in order to ensure the synchronization of the captured images, the trigger of the camera and the trigger of the fuel injector in the fuel injection system are controlled by the same signal during the experiment. The image information captured by the camera is stored in the computer by a connecting circuit, and experimental data is obtained by post-processing.

Results and discussion

Effect of fuel injection rate on spray impingement

Figure 5 shows the change curve of fuel injection speed accompanied by oil pump speed during Diesel engine starting, the peak values of fuel injection speed are 50 mg/ms, 90 mg/ms, and 140 mg/ms, respectively, and the images of circulating spray impingement at different fuel injection speeds are compared.

In the test of the influence of fuel injection speed on spray impingement, the background gas in the constant volume bomb was controlled at 1.5 MPa, the gas temperature and fuel temperature in the constant volume bomb were both 20 °C, and the combustion chamber wall roughness W_r = 0.55 μm, set the starting point of fuel injection zero and start recording. The corresponding spray impingement image when the injection speed is 50 mg/ms, 90 mg/ms, and 140 mg/ms, respectively is shown in fig. 6, and corresponding curve of spray impingement diffusion distance *vs.* time is shown in fig. 7.

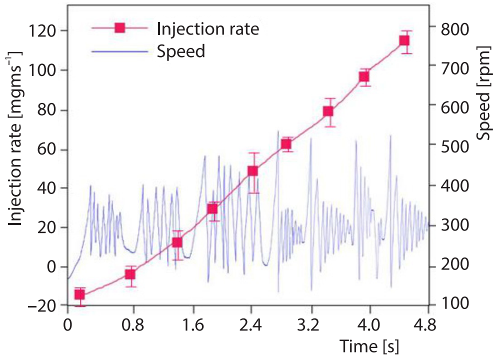

Figure 5. The curve of fuel injection speed following the change of oil pump speed during the starting process

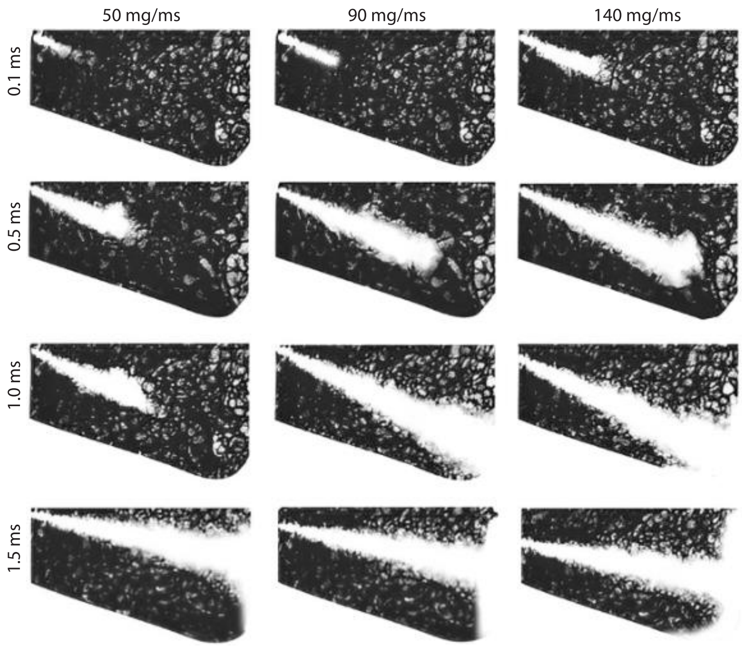

Figure 6. Images of spray impingement at different injection rates

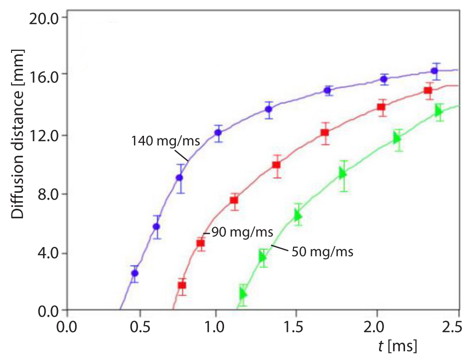

Figure 7. Variation curve of spray wall impingement diffusion distance/time under different peak fuel injection speeds

In figs. 6 and 7, under the same background gas pressure, with the increase of the injection speed, the spray impingement time is advanced, when the injection speed is 50 mg/ms, 90 mg/ms, and 140 mg/ms, the spray impingement time points are 1.2 ms, 0.8 ms, and 0.4 ms, respectively. After impingement, when spray for 2.5 ms, the impingement diffusion distance will also increase with the increase of injection speed, which is 11.8 mm, 13.6 mm, and 15.2 mm in sequence. The reason for the different diffusion distances after impingement may be due to the increase in injection molding, which also accelerates the emission speed of the droplets, the average Weber number of the droplets is higher when they come into contact with the wall, which results in splashing of the droplets during the impingement, thereby it will increase the diffusion distance of impingement. In practical applications, the diffusion range of spray on the wall can be limited by adjusting the wall temperature and changing the distance between the spray and the wall to avoid excessive droplet splash and energy loss.

Influence of background gas pressure on spray impingement

Install a sensor for measuring pressure in the cylinder of the Diesel engine, with the model being Honeywell's PX3 series. The sensor will convert the cylinder pressure signal into an electrical signal and transmit it to a computer or data recording device through a data acquisition system to measure and record the pressure changes inside the cylinder in real time.

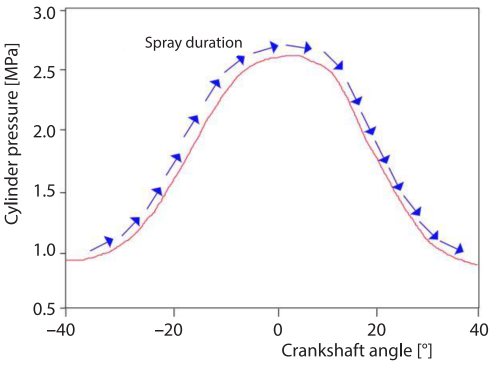

Figure 8. Curve of the change in cylinder compression pressure during the process of starting and reversing a diesel engine`

Figure 8 shows the change curve of the compression pressure in the cylinder during the Diesel engine starting and backward dragging, in which the corresponding cylinder pressure range during the spray duration is about 1.5~2.5 MPa. In the test of the influence of background gas pressure on spray impingement, background gas pressures are taken 1.5 MPa, 2.0 MPa, and 2.5 MPa, respectively, to test the difference of spray impingement images under different background gas pressures, the injection speed was set to 50 mg/ms, the gas and fuel temperature in the constant volume bomb were both 20 °C, and the combustion chamber wall roughness W_r = 0.55 μm, set the starting point of fuel injection zero and start recording. The corresponding spray impingement image under different background gas pressure conditions is shown in fig. 9, and the change curve of spray impingement diffusion distance with time is shown in fig. 10.

It is found in figs. 9 and 10 that when the injection speed is constant, the spray impingement time is advanced with the decrease of the background gas pressure, when the background gas pressure is 2.5 MPa, 2.0 MPa, and 1.5 MPa, the spray impingement time point is 0.86 ms, 0.72 ms, and 0.63 ms, respectively, after impingement, when spray is applied for 3.0 ms, the impingement diffusion distance increases with the decrease of background gas pressure, which is 8.8 mm, 9.7 mm, and 10.6 mm in turn. The reason may be a decrease in background gas pressure and droplet resistance, which accelerates the droplet injection speed and increases the average Weber number of droplets when they come into contact with the wall, which leads to splashing when a large number of droplets collide with the wall per unit time, thereby it increases the diffusion distance of the impingement. In practical application,

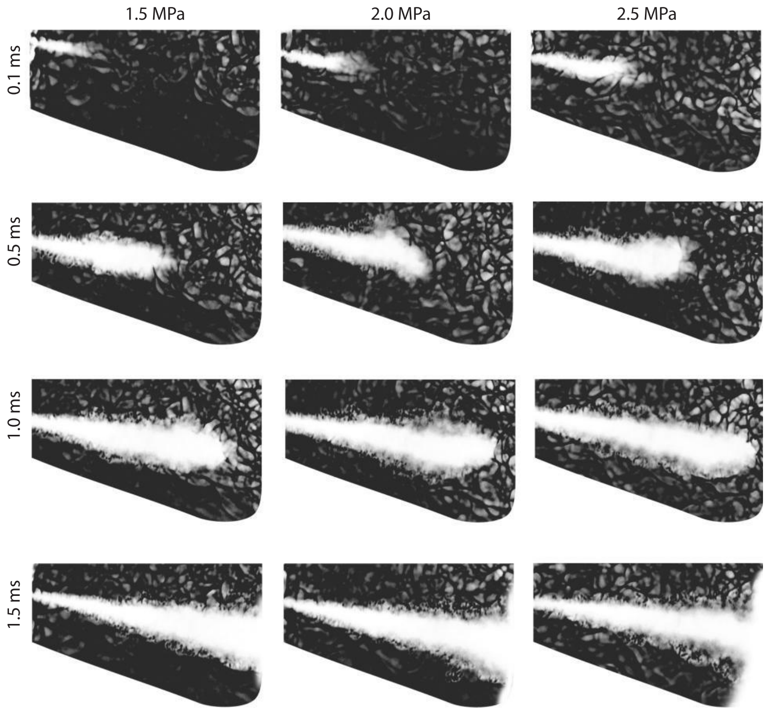

Figure 9. Images of spray impingement on the wall under different background gas pressures

when designing and optimizing the spray system, the background gas pressure can be adjusted to achieve better spray wall impact effect.

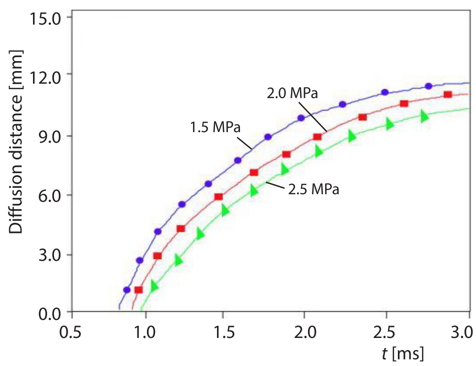

Figure 10. Variation curve of spray wall impingement diffusion distance/time under different background gas pressure conditions

Effects of wall roughness and wall temperature on the characteristics of spray impingement

Effect of wall roughness on wall impingement characteristics of spray

Set the fuel injection pressure to 80 MPa, the fuel injection duration 1 ms, and the wall temperature to 85 °C, calculate the development of –35# Minchai fuel doing spray impingement in the horizontal direction under different wall roughness, as shown in fig. 11.

The spray images are collected in 0.5 ms, 1 ms, and 1.5 ms after the oil spray contacts the wall in fig. 11, it can be seen from the macro images that with the development of time, the spray impingement continues to expand outward, and the extended spray front will gradually become thin, and form a certain angle along the development direction of spray. At the same time, comparing the spray with different wall roughness at the same time point, it can be found that with the increase of spray roughness, the spread distance of the oil spray along the horizontal direction gradually decreases, but with the progress of time, the difference does not further increase, so it cannot be clearly demonstrated that its differences in their development speed in the horizontal direction.

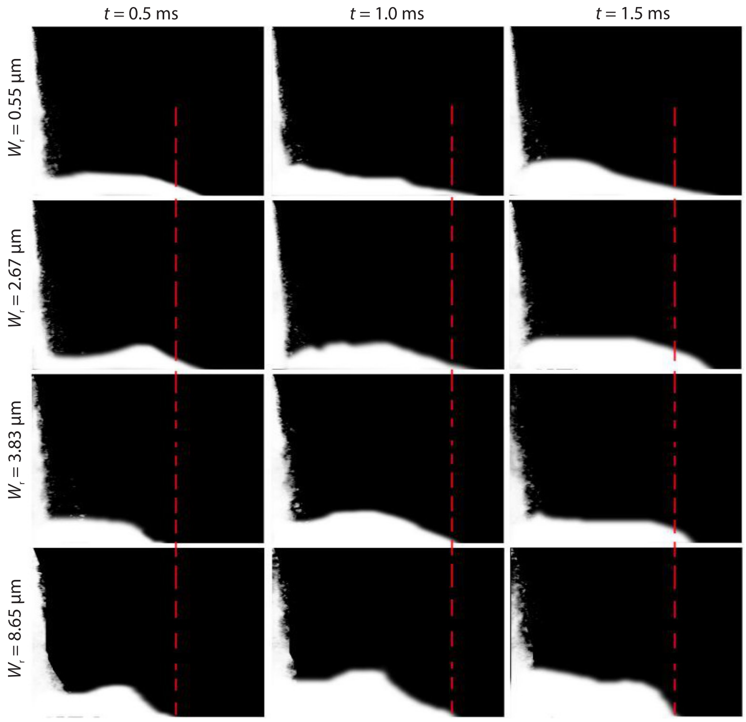

Figure 11. Comparison of the influence of wall roughness on the radial penetration distance of spray

Figure 12 shows the influence of wall roughness on the height of spray impingement under the same test conditions, from the macro image, it can be seen that the height of spray impingement at the same time point gradually increases with the increase of wall roughness, with the progress of spray, the difference between the height of spray impingement under different roughness has a gradually increasing trend. This is because the rough wall changes the interaction between spray and wall, and increases the contact area, turbulence effect and wettability, so that more spray particles collide, scatter and attach when they hit the wall, thus increasing the impact height of spray. Some macro images show that we increase the surface roughness of collision walls at the same wall temperature, and the development distance along the horizontal direction gradually decreases after the spray impingement, but the influence of roughness on the development speed after spray impingement is not obvious.

In figs. 13(a)-13(c), at the same wall temperature, the radial development distance of spray impinging on the wall gradually decreases when the roughness of the contact wall increases. When the roughness continues to increase, the influence on the horizontal development distance of spray becomes more and more obvious, especially when the wall temperature is low. This is because the high temperature wall increases the heat conduction and heat transfer rate between spray particles and the wall, promotes the rapid evaporation of spray particles and reduces the radial diffusion speed of droplets. These factors make spray particles evaporate completely in a short distance, and limit their diffusion range in the horizontal direction, thus

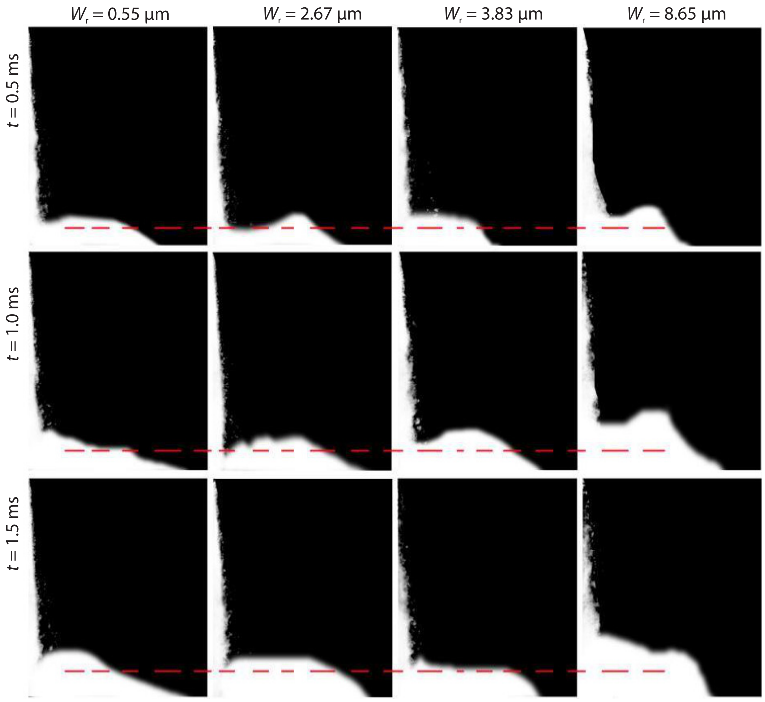

Figure 12. Comparison of effects of wall roughness on spray impingement height

reducing the horizontal spread distance of spray. On the one hand, when the temperature rises, the impact of spray on the wall makes the difference in the horizontal development distance of spray under various wall roughness gradually narrow, that is, the rise of wall temperature weakens the influence of roughness on the horizontal propagation of spray, on the other hand, the increase in wall temperature makes the time point of differences in radial development distance occur gradually move back due to different roughness.

In figs. 13(d)-13(f), although the data has been corrected, the data fluctuation of spray impingement height is larger than that of horizontal development distance from the perspective of data error. From the overall curve change, with the increase of the wall roughness, the height of spray impingement will gradually increase, and with the rise of the temperature of the contact wall, the difference in the height of spray impingement caused by the roughness will decrease. In practical application, the surface treatment technology is used to fine adjust the wall roughness to achieve accurate control of the height of spray hitting the wall.

According to the aforementioned experimental results, it can be concluded that when the roughness of the contact wall increases, the radial development distance of the spray against the wall decreases gradually. This shows that when the roughness of the wall increases, the concave-convex structure on the wall will cause air-flow disturbance near the wall. These disturbances will affect the trajectory of the spray, making it impossible for the spray to travel at its original speed and distance in the radial direction. Therefore, with the increase of wall roughness, the radial development distance of spray against wall decreases.

At the same time, the increase of wall temperature will weaken the influence of roughness on the spray propagation in the horizontal direction and reduce the horizontal spreading

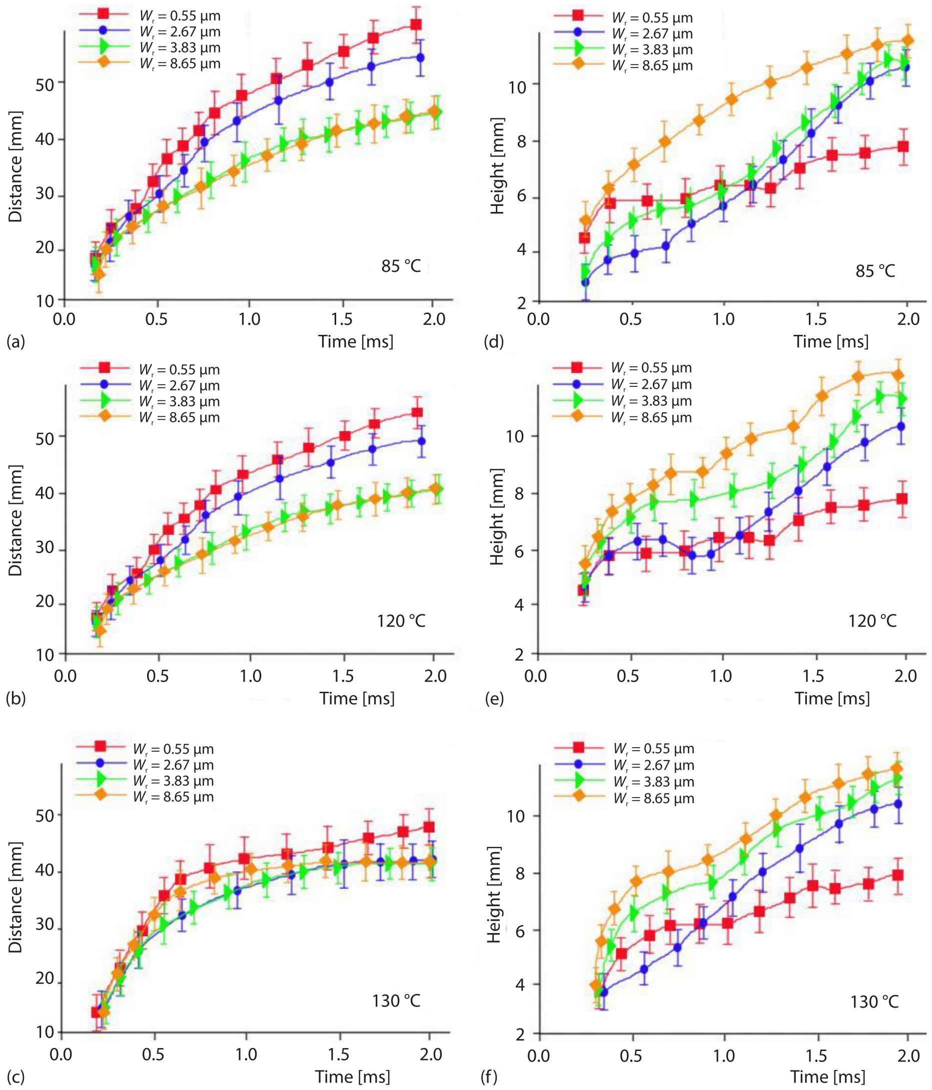

Figure 13. (a)-(c) represents the radial penetration distance of –35 # diesel doing spray under different conditions and (d)-(f) represents height's comparison of spray impingement under different conditions with –35 # diesel

distance of the spray. When the wall temperature rises, the air near the wall will be heated to a certain extent because the temperature difference between the wall and the spray is reduced. This heating reduces the thickness of the boundary-layer and increases the velocity gradient of the air. Compared with the cold wall, the boundary-layer flow on the hot wall is faster and more stable, so the influence of roughness on the horizontal propagation is weakened, and the horizontal spreading distance of the spray is reduced.

In addition, with the increase of wall roughness and the rise of the contact wall temperature, the height of the spray wall will gradually increase, but the difference of spray wall height caused by roughness will decrease. This shows that the variation of wall roughness and temperature will affect the droplet behavior after impact spray. Higher roughness and temperature difference will increase the droplet hydrodynamics effect and increase the droplet height after hitting the wall. However, with the increase of roughness and temperature, the forces on the droplets on the wall become more similar, resulting in a gradual decrease in the difference in the height of spray impact due to roughness.

Effect of wall temperature on the characteristics of spray impingement

The injection pressure is set to 80 MPa and the injection duration is 1 ms, the roughness of the –35# civil diesel fuel on the wall is 3.83 μm, fig. 14 shows the horizontal expansion of spray at different wall temperatures. Through image comparison, as time goes on, the outward expansion form of spray along the wall direction under different wall temperature is similar, and the development front of spray gradually becomes sharp and thin. In the macro image, it is not observed that with the change of wall temperature, the development distance of spray impinging on the wall in the horizontal direction will change significantly at the same time point.

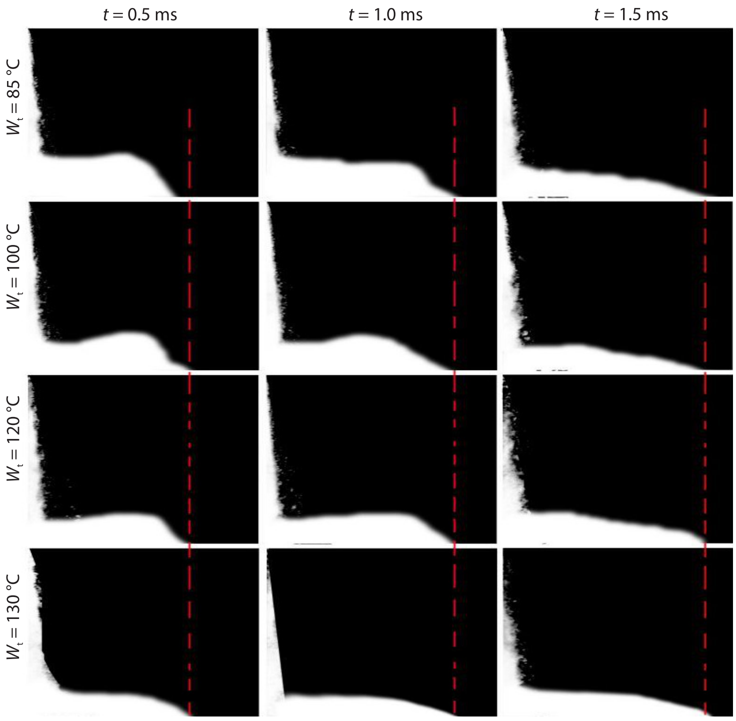

Figure 14. Comparison of the influence of wall temperature on the radial penetration distance of spray

Under the condition of changing the wall temperature (85 °C, 100 °C, 120 °C, and 130 °C), the impact of spray impingement on the height of the wall can be shown in the fig. 15, the macro image shows that with the rise of the wall temperature, the height of spray impingement will decrease, but this rule is not obvious, and there are still fluctuations at some time points.

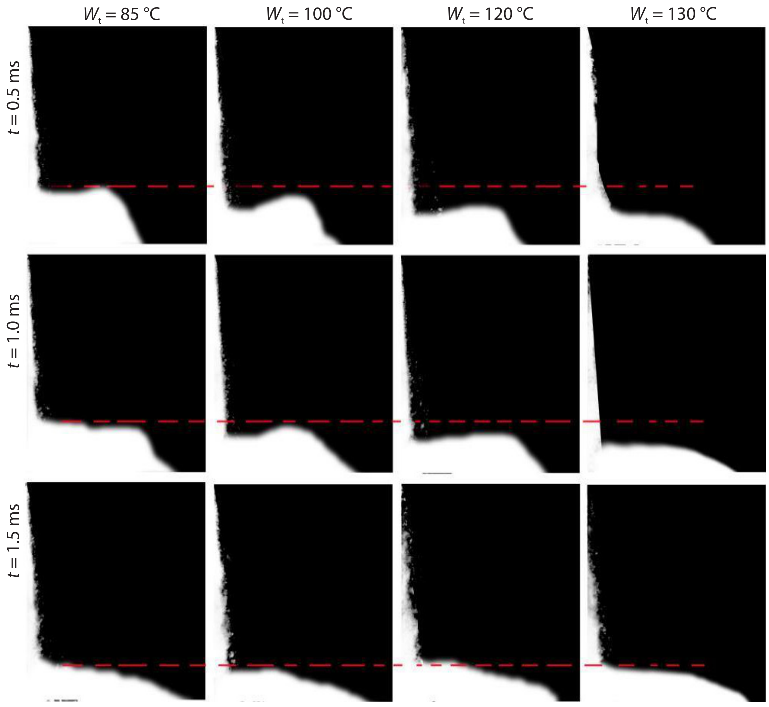

Figure 15. Comparison of influence of wall temperature on spray impingement height

In figs. 16(a)-16(d), when the wall roughness is small (W_r = 0.55 μm and W_r = 2.67 μm), there is a phenomenon in the horizontal development of spray impingement, that is, with the increase of wall temperature, and the horizontal development distance of spray decreases, further observation shows that the lower the wall temperature, the longer the forward development duration of spray. When the wall roughness increases (W_r = 3.83 μm and W_r = 8.65 μm), the development of spray impingement in the horizontal direction has no obvious effect under the change of wall temperature. The test results show that under different wall temperatures, the distribution of each curve basically coincides, and spray points will appear partial separation at the beginning of the impingement and at the end of the spray, however, the position relationship of these separation spray points is not the same as that generated by the wall temperature change with small roughness.

In figs. 16(e)-16(h), the influence of different roughness changes on the spray impingement height is more obvious, when the roughness is constant, the influence of wall temperature on the spray impingement height is not obvious. Under the condition of low wall roughness (W_r = 0.55 μm), there is a trend that the height of spray impingement increases with the rise of wall temperature, but when the wall roughness rises, the time goes on, and the height of spray impingement under each roughness condition is basically the same. Compared with the reference data in the previous section, for –35# diesel fuel, the influence of wall roughness on spray impingement height is stronger than that of wall temperature on spray impingement height in the whole experiments. In practical application, the horizontal development and separation of spray can be improved by optimizing the wall processing technology, controlling the wall temperature and roughness.

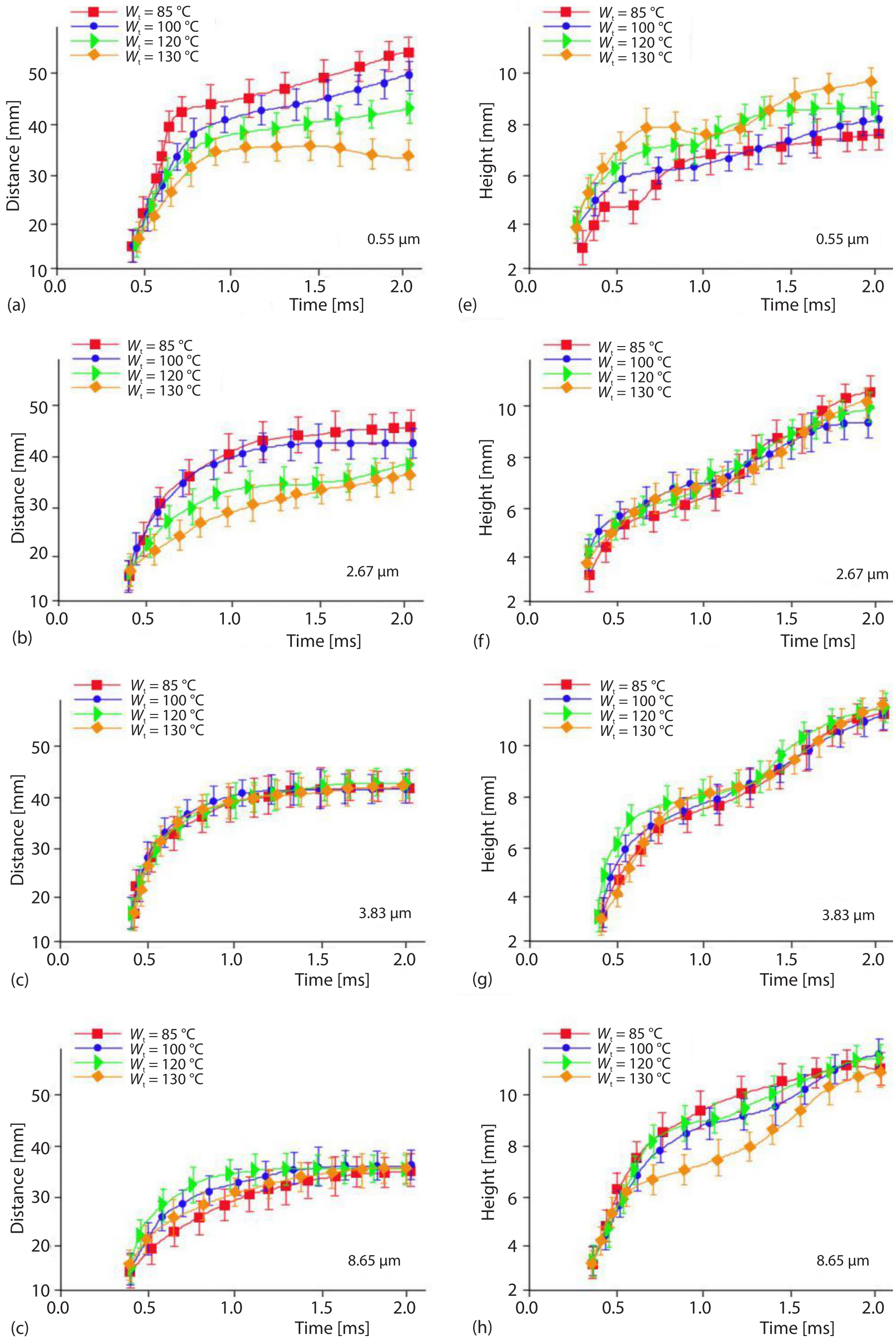

Figure 16. (a)-(d) represents the radial penetration distance of –35# diesel doing spray under different conditions and (e)-(h) represents height's comparison of spray impingement under different conditions with –35# diesel

According to the aforementioned experimental results, it can be concluded that under the condition of small wall roughness, the horizontal development distance of spray gradually decreases with the increase of wall temperature, and the duration of spray forward development will be longer. This shows that the small wall roughness means that the liquid film formed on the wall is relatively flat. When the temperature rises, the air-flow near the wall will rise after being heated to form a strong convection, which will prompt the spray to mix with the air-flow faster. As the droplet thermal evaporation rate increases, the liquid phase heat transfer between adjacent droplet decreases, resulting in a smaller distance for spray horizontal development, because the droplet is more likely to evaporate rapidly. In addition, the phenomenon of thermal convection prolongs the time for droplets to evaporate after the wall impact, resulting in a longer duration for the spray to develop forward.

However, when the wall roughness increases, the change of wall temperature has no obvious effect on the spray development in the horizontal direction. In addition, under different roughness conditions, the influence of wall temperature on the height of spray impact is not obvious. This shows that larger wall roughness means that there is more drag and turbulence along the droplet's transport path. The concave-convex structure of these rough surfaces causes turbulent layers to form, resulting in a larger gradient of turbulent velocity leaving the droplet. Therefore, the change of wall temperature has no obvious effect on the horizontal development of spray. For the spray wall impact height, larger wall roughness will increase the droplet collision probability and impact energy loss, while the wall temperature has limited influence on it, because the temperature change cannot significantly change the interaction between the droplet and the wall.

Conclusions

As an important power equipment, Diesel engine has attracted much attention in fuel utilization efficiency and exhaust emissions, this paper focuses on the phenomenon of fuel spray impingement, we design a visual constant volume spray impingement test system, and adjust according to different factors, and test the spray impingement after adjustment as follows.

- The results show that the injection speed and the background gas pressure are adjusted by the droplet Weber number during the wall impact process. When the injection speed is 50 mg/ms, 90 mg/m, and 140 mg/ms, the spray wall impact time points are 1.2 ms, 0.8 ms, and 0.4 ms, respectively. When the background gas pressure is 2.5 MPa, 2.0 MPa, and 1.5 MPa, respectively, the time points of spray impingement on the wall are 0.86 ms, 0.72 ms, and 0.63 ms, respectively, indicating that the greater the injection speed and the lower the background pressure, the greater the diffusion distance of impingement on the wall.
- The diffusion distance of spray in the horizontal direction after wall collision needs to consider the wall roughness and wall height at the same time, the increase of temperature or wall roughness will weaken the influence of another condition on the diffusion distance of spray;
- The impingement height of spray is limited by the test conditions and data collection, and the results have some volatility, but it can be clearly seen that the impingement height is affected by the wall roughness.

Nomenclature

d – distance from spray to wall collision, [m]
h – reflection height
l – collision diffusion distance
W_r – roughness of combustion chamber wall surface, [μm]
W_t – wall temperature, [°C]

Contribution

Authors Chutao Lai and Xiaokai Zhou equally contributed to this work.

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