RAPESEED OIL SPRAY DEVELOPMENT OF DIESEL IDI SPRAY NOZZLE UNDER AIR MOVEMENT INFLUENCE

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ABSTRACT

Rapeseed oil (RO) spray has very slow atomization due to its high viscosity nature. Although high injection pressure, high ambient temperature and combination of nozzle can promote faster atomization of rapeseed oil spray, another factor that was not discussed is the effect air movement that could positively influence RO spray development. To study the effect of air movement, in particular to generate the swirl (air movement inside the chamber), a swirler was used. Images were captured using a nano-spark shadowgraph photography technique and also high speed video imaging. Macrostructures of diesel sprays such as spray tip penetration length, spray shape, spraycone angle were obtained. Microstructures, such as droplet distribution and size were also studied. Result shows that IDI nozzle rapeseed oil spray has a narrow spray cone angle. The average droplet size is around 20~25µm. The large size of rapeseed oil droplet require assistant to improve atomization and results shows rapid air movement in chamber successfully improve atomization.

Keywords: diesel engine, alternative fuel, rapeseed oil, sustainable energy, fuel injection, spray.

INTRODUCTION

In has been proven from the results of previous study that RO spray has very slow atomization due to its high viscosity nature [1-3]. Although high injection pressure, high ambient temperature and combination of nozzle geometry with piston cavity design and suitable injection strategy can promote faster atomization of RO spray[4-9], another factor that was not discussed is the effect air movement that could positively influence RO spray development.

It should also be stated that the diesel spray injector used in previous experiments [8,9]is for the use of DI diesel engine, which generally use the concept offast fuel – slow air mixing. This is due to the fact that DI diesel engine has to force the fuel to penetrate highly compressed air, the fuel need to be of high velocity. In contrast, as the fuel is injected directly to the spray chamber, air movement is relatively slow and quite limited. On the other hand, IDI diesel engine uses a different air mixing strategy, which is slow fuel – fast air mixing. IDI diesel engine usually designed to have a prechamber (small space to initiate air fuel mixing) that the spray is injected into. Air movement inside the combustion chamber is amplified as it move through the prechamber where it will mix with the fuel before making it way to the main combustion chamber. This process made effective fuel air mixing possible. The fast movement of air mitigates the need of high velocity spray jet, which make IDI diesel engine not requiring high injection pressure fuel delivery system.

This study focuses on the use of RO in IDI diesel engine. As the usage of alternative fuel (in this case, RO) is not limited to one type of engine only (DI and IDI diesel engine)[10-11], the study of any viable condition that could help to improve the spray atomization is commendable. In addition, the usage of RO in IDI diesel engine was strongly suggested to be actually more suitable then DI especially when considering the possibility of injector choking which can be a major problem when using RO to DI diesel engine. As IDI diesel engine spray use the pintle-type nozzle, this risk is largely reduced.

Experiment setup

Figure-1 shows the experimental setup of shadowgraph photography. The experimental system is the same as previous work [7]. It is composed of spray chamber, rapid compression machine (RCM), fuel injection device and optical system. A rapid compression machine was used to create diesel atmosphere in the spray chamber. The spray chamber has two quartz windows in diameter of 60mmfor the access of nano-spark light to a still camera. The spray chamber was filled with inert gas mixture of nitrogen and argon to prevent spray ignition. When ambient temperature reaches designated temperature after termination of rapid compression, fuel was injected into the spray chamber and spray behavior was taken by the optical system. All the images taken by films were scanned and changed to digital pictures. Then using in house algorithm system developed by Yatsufusa [8], the image is analyze and spray fuel droplet can be verified.

To study the effect of air movement, in particular to generate the swirl (air movement inside the chamber), a swirler was used. This swirler is fixed inside the chamber as shown in Figure-2, just after the stop ring. It functions by carefully guiding the inert gas that is propelled by the rapid compression machine to move into the chamber in an angle (α)which will produce fast air movement (swirl). At the same time, as inert gas is being compressed inside the chamber, high ambient temperature also is generated.

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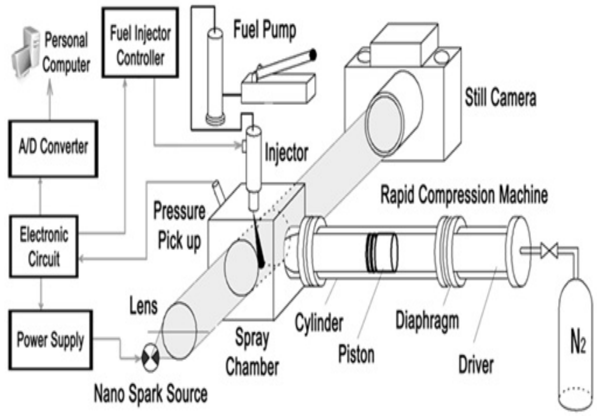

Figure-1. Schematic diagram of nano spark shadow graphy method.

To confirm the swirl speed, trial experiment by using tracer particle inserted in the chamber was done. Highest velocity about Vs=60m/s measured at location of 2/3 of the chamber radius. This is approximately around r=15~20mm. In contrast, when the swirl is located near the outside spray wall chamber, the swirl speed decrease.

It should be stated as this experiment was a joint research with a commercial company, the specification on the IDI nozzle is not available for publication due to legal issue. However, the result theoretically should reflect the characteristic of RO spray development when injected using IDI nozzle that available for commercial use.

In addition, a few alterations was also done particularly on the optical arrangement and the light source to accommodate shadowgraph high speed video camera imaging, to capture a more visible cloud-like dense droplet region as the current direct photography high speed video produce low contrast image; making this region difficult to identify.

RESULT AND DISCUSSION

Figure-3(a) shows IDI RO spray image for injection pressure P_{inj}=40MPa, chamber ambient temperature T_i=298K at t=1ms and t=2ms after start of injection. It can be seen that RO spray form a stick like appearance throughout the spray formation. This particular characteristic shows that atomization process seems to be retarded for RO spray. In addition, the spray liquid core has a heterogeneous liquid distribution, making the confirmation of spray main jet to be difficult. Referring to the magnified image, it can be observed that spray droplet form along the spray boundary from upper to lower section.

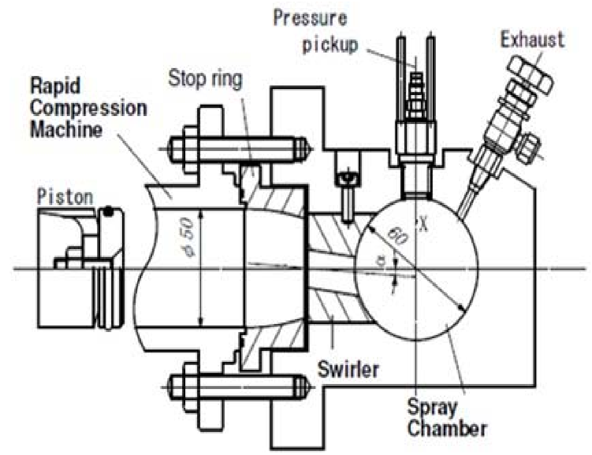

Figure-2. Cross section of spray chamber with swirler inserted between rapid compression machine and spray chamber.

With high ambient temperature, shown in Figure-3(b) at T_i=700K, it can be observed that RO penetrate easier. When compared to T_i=298K at t=1ms, the penetration length shows significant increase, and also droplet formation can be seen at the boundary region, which is not existed before. However, when refer to the magnified image, droplet size still relatively big. The stick like appearance still visible in IDI nozzle RO spray with under-developed branching structure can be seen in some section of the spray especially at the spray downstream.

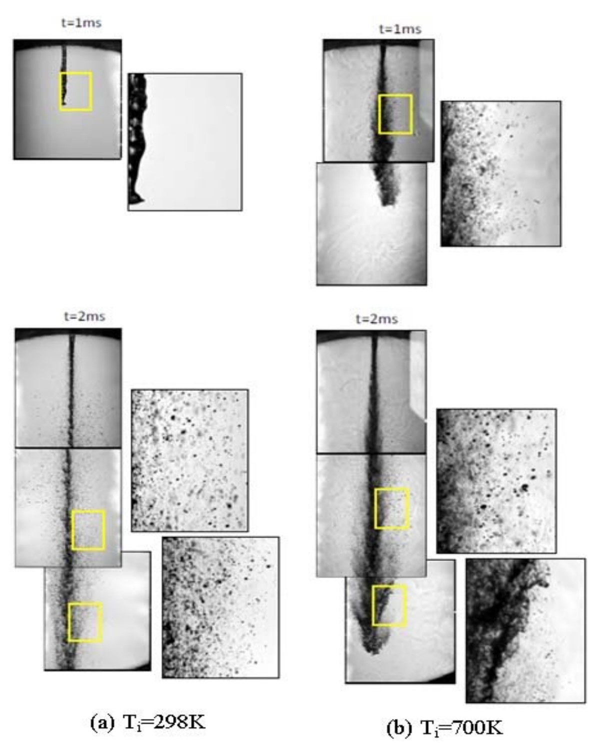

Figure-3. IDI nozzle rapeseed oil spray development image. (P_{inj}=40MPa).

To study more of spray development characteristics of RO, the images in Figure-3 were analyze by in-house image analysis system. The result is shown in Figure-4 (a) & (b). This result shows the spray boundary outline shown by the red line and spray liquid core progression shown by the blue line.

Figure-4(a) shows that RO has very narrow region of high density liquid core. With progression in time, the spray outline seems to expand further from the center axis. However, the high density liquid core region still remains narrow and in certain location, can be seen to be detached. In addition, the spray outline analysis is influence by the large droplet that formed along the boundary region, such making the spray outline to appear expanding.

In Figure-4(b), with increase in ambient temperature, the high density liquid core region seems to become larger, but still narrow when compared to GO. The outer spray outline also expands further outward from the nozzle center axis. This suggest high ambient temperature promote atomization. In general, the spray penetration length also becomes shorter, suggesting higher atomization rate.

Using the images taken, image analysis for droplet sizing and distribution was done. Similar to method used in previous chapter, the spray is divided into section, in this case, into 3 sections, namely upper, middle and lower. All droplets diameters, D are characterized by representative grouping in every 5µm and N is the droplet count number.

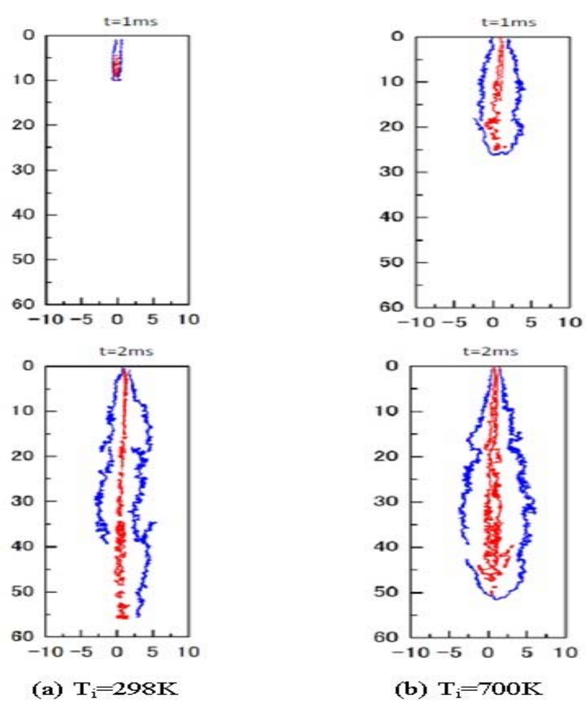

Figure-4. IDI nozzle rapeseed oil spray development, core and boundary progression.(Pinj=40MPa).

Figure-5(a) shows IDI nozzle RO spray droplet distribution. As shown in Figure-3(a), atP_{inj}=40MPa, T_i=298K and t=2.0ms, the spray upper and middle section has a large droplet size with average of 20-25µm at middle section. This indicates that even with longer injection time, RO spray still have problem to produce small diameter size droplet.

Figure-5(b) shows droplet distribution of IDI nozzle RO spray at high ambient temperature of T_i=700K. When compared T_i=298K, the total droplet number count was reduced. This suggests atomization is faster with higher ambient temperature. In particular, the middle section average droplet size was reduced with the highest frequency of 15-20µm. It also can be observed that at lower section, very little number of droplet visible for sizing.

Next, we will study the effect of high speed swirl to the spray development process in IDI nozzle spray, for RO and GO. The experiment parameter were done at injection pressure of P_{inj}=40MPa, with the ambient temperature of T_i=700K.The swirl speed is Vs=60m/s around the vicinity of 20mm, which translate to 2/3 distance from the chamber center and move counter clock wise. The spray was injected downward to the chamber with the spray injector located straight above the chamber center.

Figure-6 shows the spray development of RO spray for IDI nozzle inside chamber with air movement. Injection pressure was P_{inj}=40MPa and ambient temperature was T_i=700K.From the image, IDI spray forms a circular spray path along the spray chamber due to air movement with the spray main body retaining downward direction. At t=2.0ms, the spray also seems to expand outward from the main body spray through the whole spray length, which suggests fuel dispersion due to swirl and the spray tip has made a 1/2 circle. At t=3.0, the dense droplet region still visible in the image which suggested that the spray is under fuel-air mixing process and partially being vaporized especially at the spray tip. At t=4.0ms, the spray tips made a full circle; with the spray injection is completed and the main spray body was now not visible and at t=5.0ms, the spray has fully vaporized with most of the droplet dense region is now not visible.

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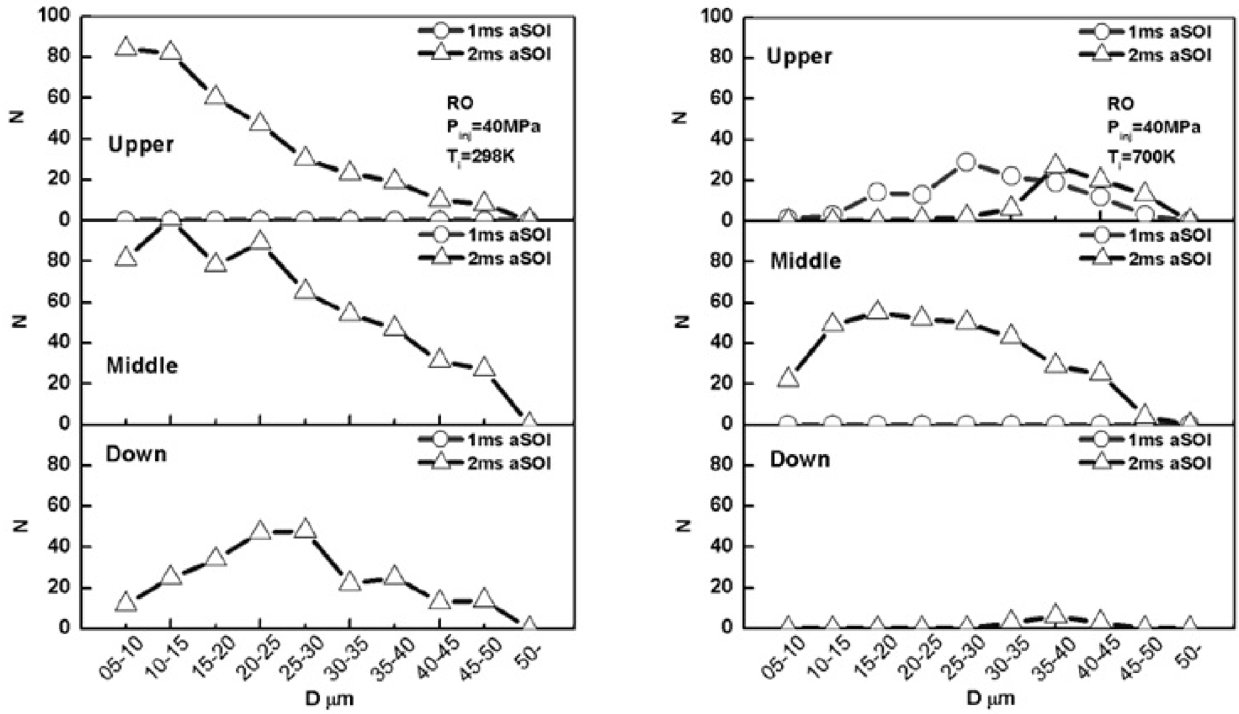

(a) T_i=298K (b) T_i=700K

Figure-5. Droplet size distribution of IDI nozzle rapeseed oil spray.(Pinj=40MPa).

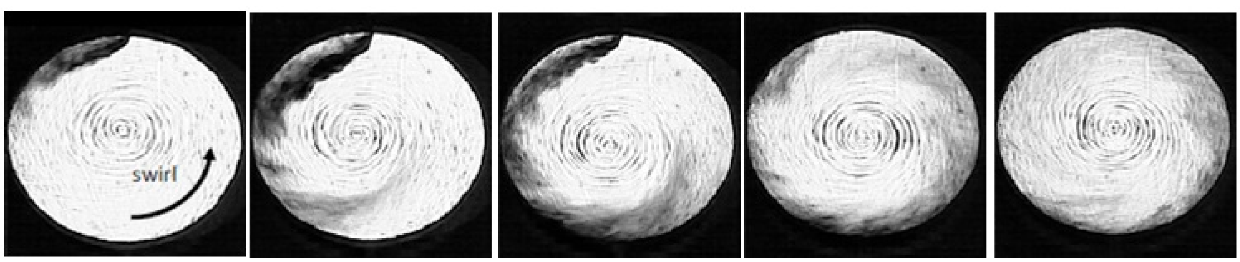

Figure-6. IDI nozzle rapeseed oil spray development under swirl influence (P_{inj}=40MPa, T_i=700K).

Further comparison on the effect of air movement to RO spray can be made in the form of comparison of free jet spray to spray under swirl condition. Results of IDI nozzle under swirl condition, when compared to the previous free jet images, clearly show the different of spray boundary fuel-air mixing. On free jet spray, RO spray forma very narrow cone angle, while under swirl condition, the spray expend outward from center axis due to the dispersion of fuel from air movement. This in turn, increases air entrainment inside the spray body, expand the spray boundary and eventually effect the spray atomization.

CONCLUSIONS

To conclude this chapter, a study was made to characterize the IDI nozzle RO spray development and the effect of air movement to spray development. A comparison on RO spray under swirl condition and free jet spray was also made. The result here would like to note the possibility of IDI engine injection system which incorporate high air movement strategy to be use for RO, which has been proven to have significantly better atomization than without the assistance of air movement.

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