SUBTASK3.4B
Investigate Dynamic Spray Characteristics by Image Processing

IEA-TLM
September 17, 2008
Capri, Italy

3.4B-III (IKI)

Spray from a Thin Plate Nozzle with several tens micrometer holes

Norihiko IKI

Energy Technology Research Institute,

National Institute of Advanced Industrial Science and Technology (AIST)

Outline

1. Introduction
2. Atomization of liquid fuel injector of small gas turbine
3. Spray of a planar plate nozzle
4. Conclusion

Characteristics of ceramics in a gas turbine

Advantages of ceramics

(1) Ceramic parts enable high temperature operation without cooling devices.

(2) Increase of turbine inlet temperature

(3) Narrow tip clearance of a turbine blade is available due to low thermal expansion coefficient

(4) Low density and high strength at high temperature is proper for high rotating speed of rotor

(5) Abradable shroud technique is available

A ceramic gas turbine can achieve high thermal efficiency without cooling system of turbine blades.

Disadvantages of ceramics

(1) High cost

(2) Fragile

(3) Broken by stress concentration

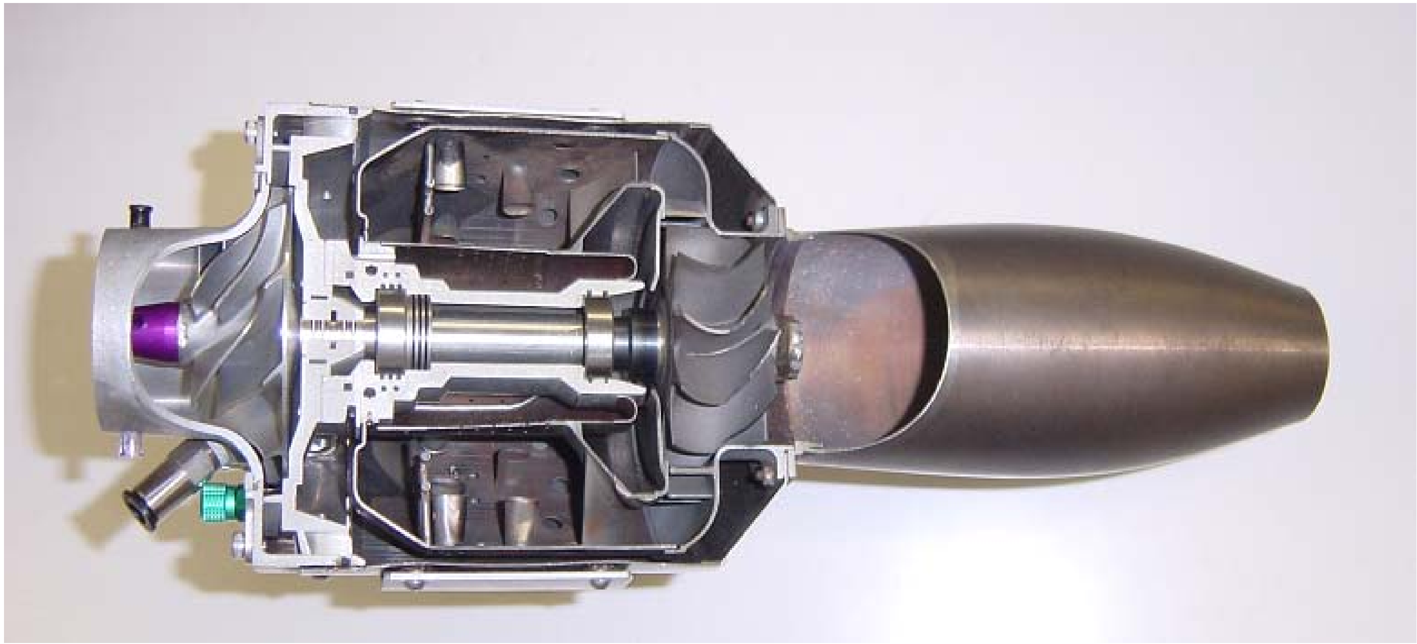
These disadvantages can be overcomed by mass production and suitable design for ceramics.

Efficiency and TIT of small ceramic gas turbines

- **35% of electric efficiency**
  - In many situations, running cost of a micro gas turbine cogeneration can be lower than that of a diesel engine cogeneration if the electric efficiency of micro gas turbine becomes 35%. (Tsuchiya et. al.)
  - Target of the 100kW CGT project was 40% of electric efficiency and 1350°C of turbine inlet temperature.
  - Therefore 1,200°C class micro gas turbine will be able to achieve 35% of electric efficiency by regenerative cycle.
- **Substitution for a burner**
  - Turbine exit temperature of 1,200°C class small gas turbine reaches to 1,000°C. That is to say, 1,200°C class simple cycle can supply 1,000°C exhaust gas.
  - Therefore a small simple gas turbine can replace with burners for furnace, incinerator etc. if price of a small simple gas turbine goes down to several 1,000US dollars.
- **Hybrid structure of ceramics and metals**
  - Full ceramic type gas turbine is expensive and it is not essential factor for 1,200°C class system.
  - A hybrid type gas turbine of ceramics and metals is reasonable.

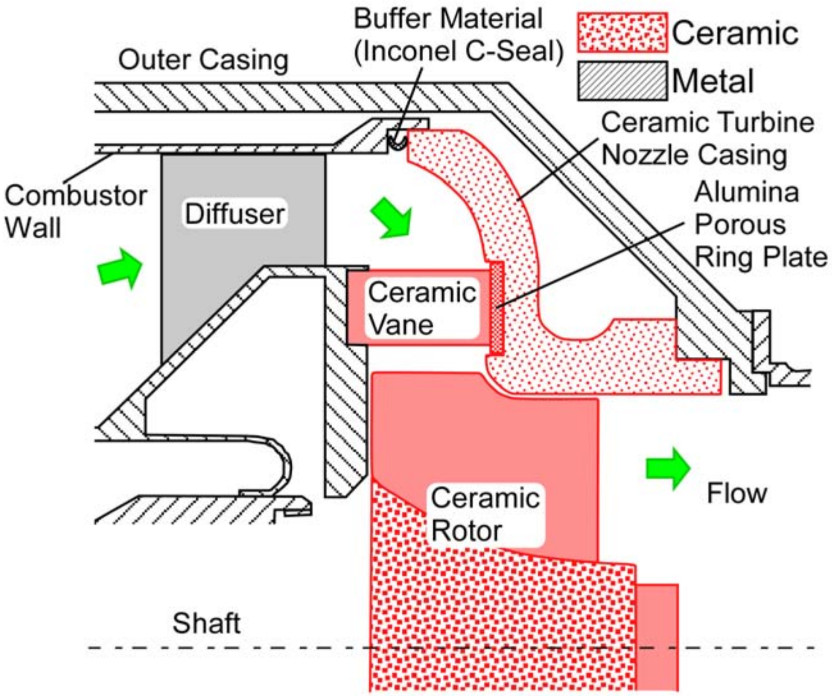
Mini jet engine

- AIST studies micro gas turbine with ceramic parts and metal parts using Sophia J-850.
- Design for a model aircraft
- Employment of the automobile turbocharger technology .
- Simple structure that installs a combustor between a turbine and a centrifugal compressor.
- Expands in application to education field, research and development field, UAV (Unmanned Aerial Vehicle) etc.



Small gas turbine with ceramic rotor

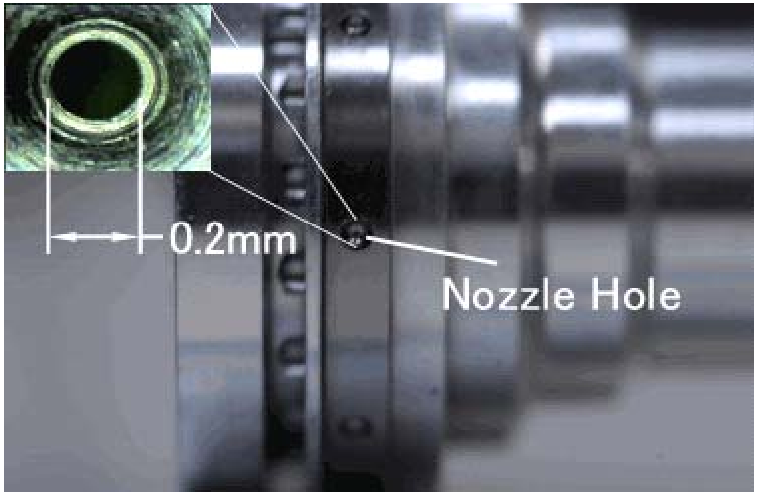
- AIST studies micro gas turbine with ceramic parts and metal parts using Sophia J-850.
- However liquid fuel cannot burn completely in a combustor of a mini jet engine in several cases such as starting condition.
- Atomization phenomena of fuel injector are not clear yet.
- Spray characteristics of a fuel injector is one of important factors for a combustor and it influences the performance of a jet engine.
- Therefore AIST investigates pressure atomization of fuel injector of a mini jet engine as the first step of improvement of combustion in a mini jet engine combustor.

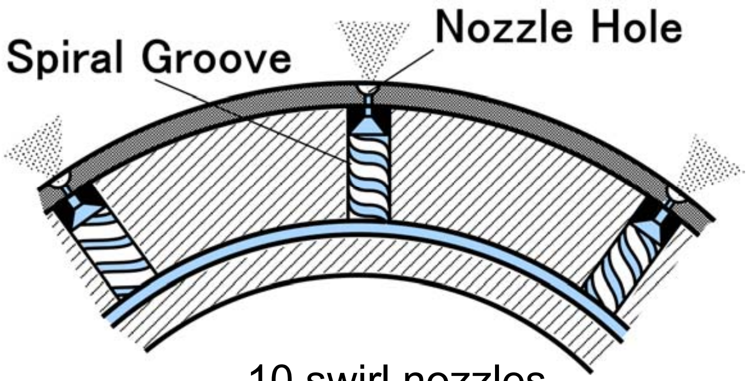


Outline

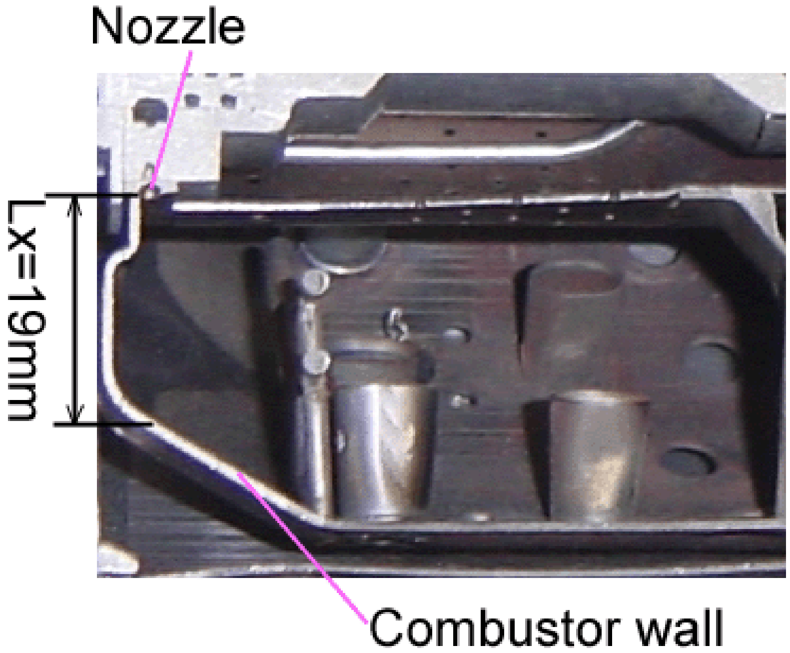
1. Introduction
2. Atomization of liquid fuel injector of small gas turbine
3. Spray of a planar plate nozzle
4. Conclusion

Fuel Injector



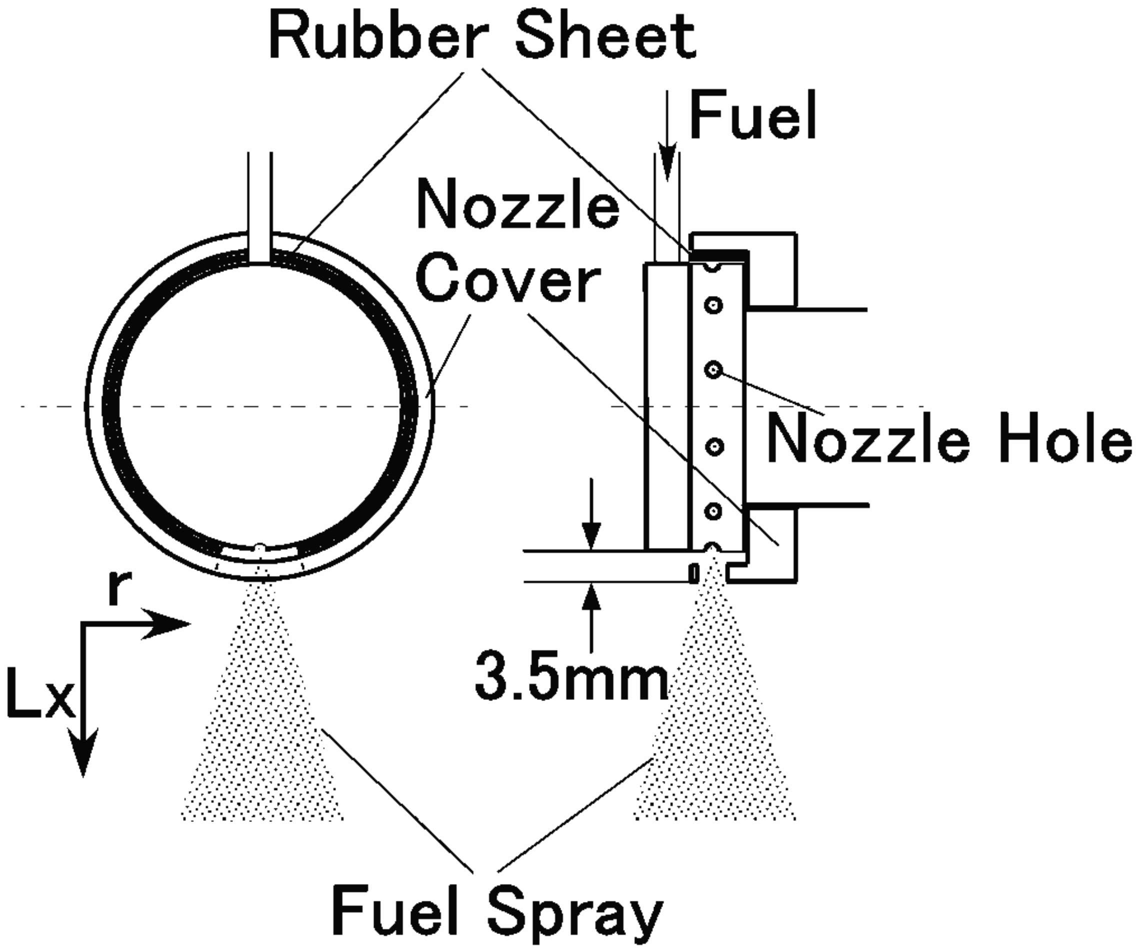


10 swirl nozzles



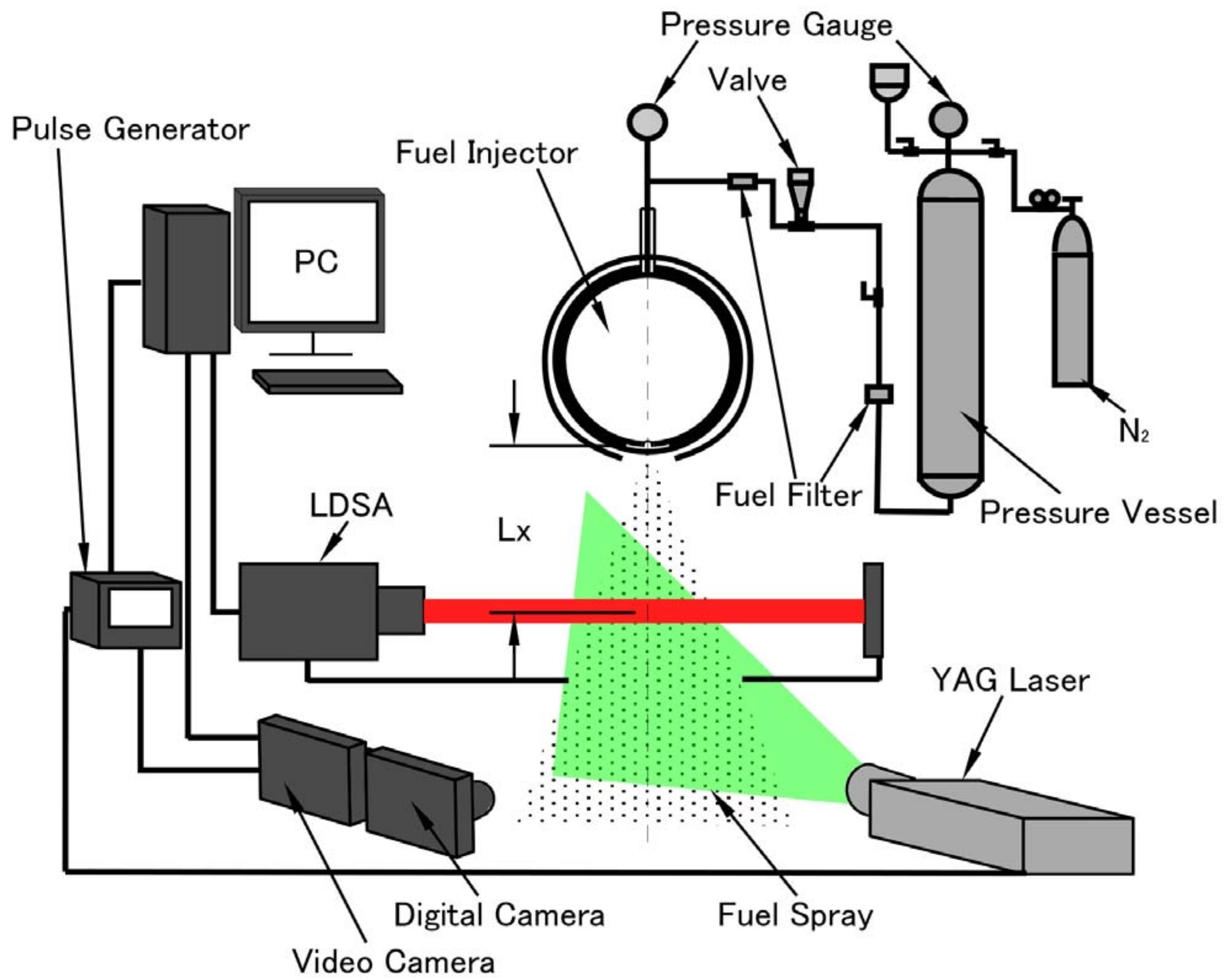
- The fuel injector has 10 nozzle holes in the craters on the peripheral ring of the bearing housing.
- The inner diameter of each nozzle hole is about 0.2mm.
- The fuel flow rate of the nozzle is below 0.2g/s at the ignition condition
- Liquid fuel is swirled in two spiral grooves and it is injected from the nozzle hole in the center of the crater.
- Injected fuel makes solid cone spray.

Experimental Apparatus for Spray Characteristics



- A nozzle cover with rubber sheet is fabricated for the observation of the spray from the single nozzle hole .
- The area in 3.5mm from the nozzle hole exit is invisible by the nozzle cover.
- The test fuel is Sophia Turbo Jet Fuel (70% kerosene -30 % white gasoline) and kerosene.
- Injection pressure ***Pi*** is from 0.01 to 0.2MPa.
- The fuel is injected vertically down ward in the atmospheric pressure.
- The fuel flow rate is measured by its volumetric method and the discharge coefficient is calculated from the measured flow rate and 0.2mm of the diameter of the nozzle hole .

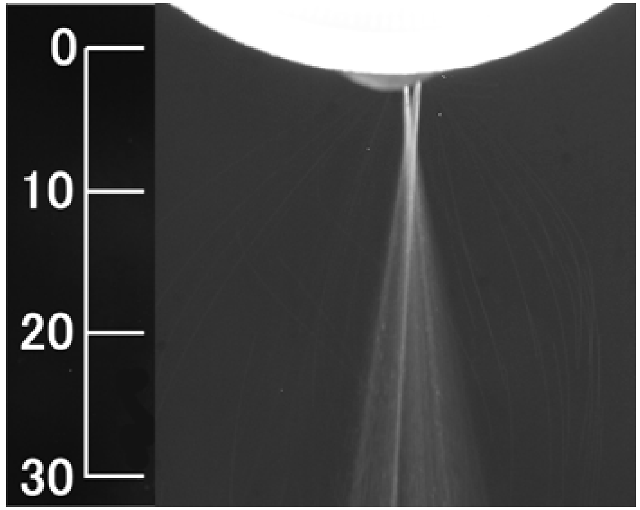
Experimental Apparatus for Spray Characteristics



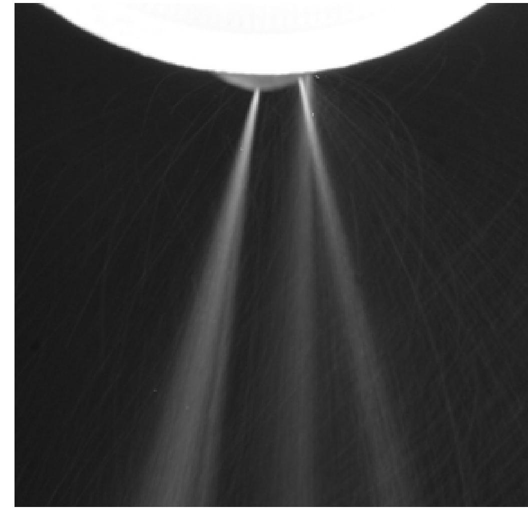
- Spray from one nozzle is investigated by flash photography, Laser Diffraction and PIV.
- Flash photographs of fuel spray at various injection pressure Pi were taken with YAG laser sheet and a digital still camera.
- Sauter mean diameter of the fuel spray is measured by laser diffraction method with LDSA 1500A.
- Velocities of droplets were measured by PIV method.

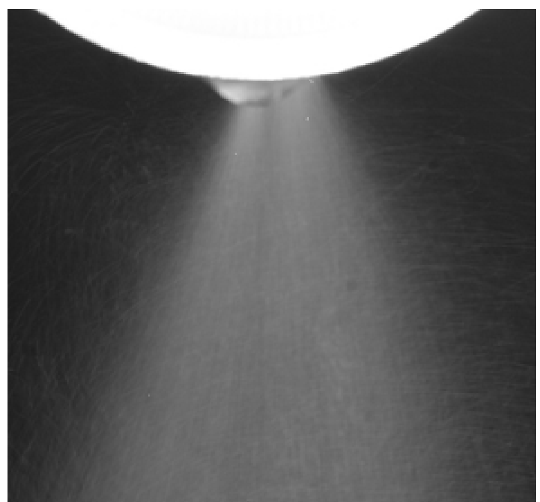
Spray of Original Fuel (Kerosene 70% - Gasoline 30%)

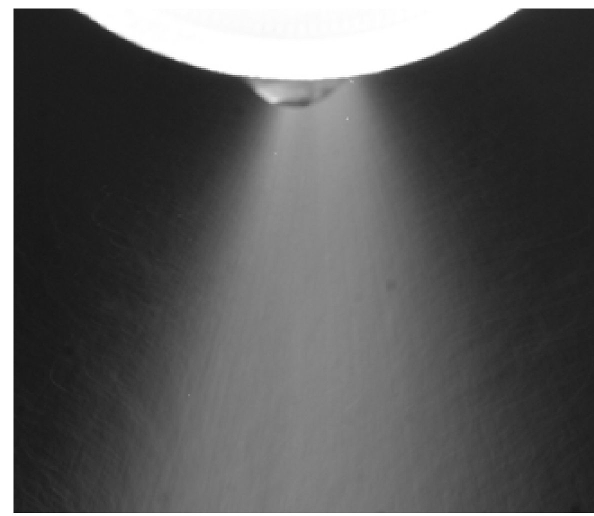
Two liquid columns of original fuel are observed when injection pressure ***Pi*** is below 0.05 MPa.
It seems reasonable that these two liquid columns derived from two grooves in the nozzle hole.



(a) **Pi** *= 0.02 MPa*


(b) **Pi** *= 0.05 MPa*


(c) **Pi** *= 0.10 MPa*

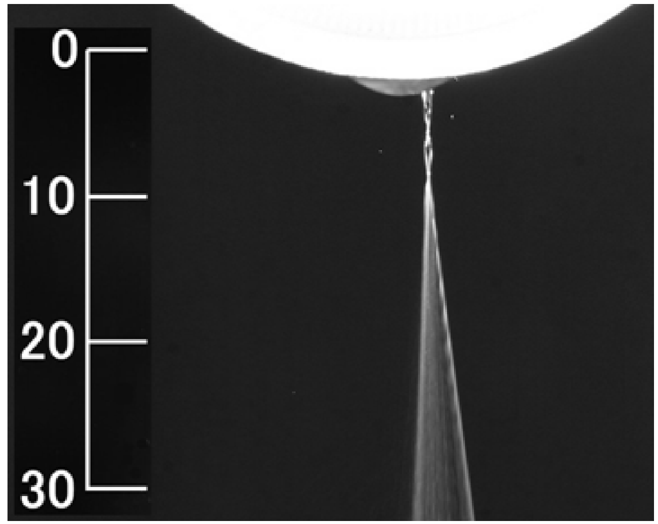

(d) **Pi** *= 0.15 MPa*

Spray of Kerosene

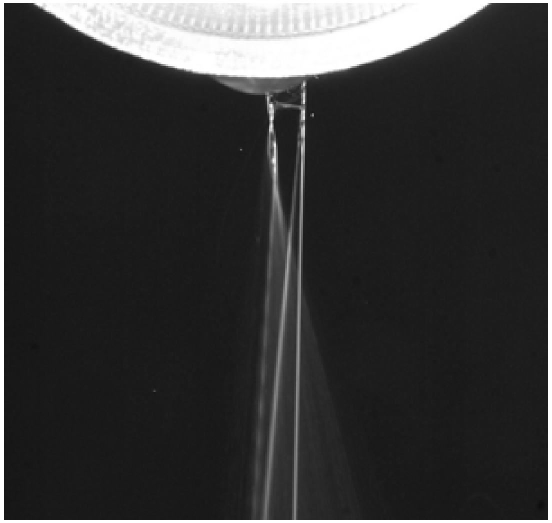
Two liquid columns of kerosene fuel are observed more clearly than those of original fuel. Gasoline in original fuel accelerates disintegration and evaporation of fuel.

Since injection pressure ***Pi*** is below 0.05MPa at ignition condition of the mini jet engine, it is more difficult to start up the mini jet engine with kerosene than those with original fuel.

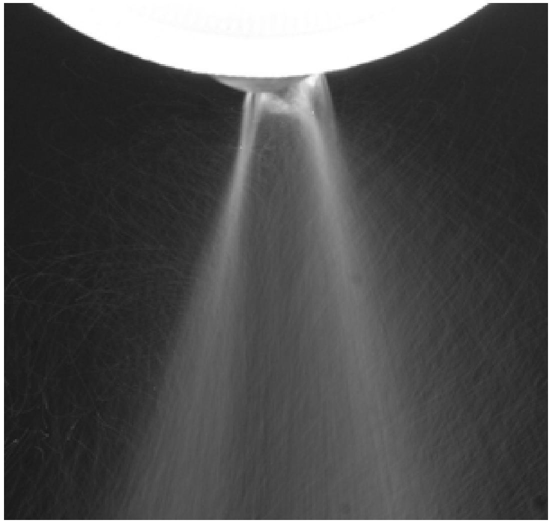
It is clear that the improvement of the fuel injector becomes more important issue for utilization of kerosene.



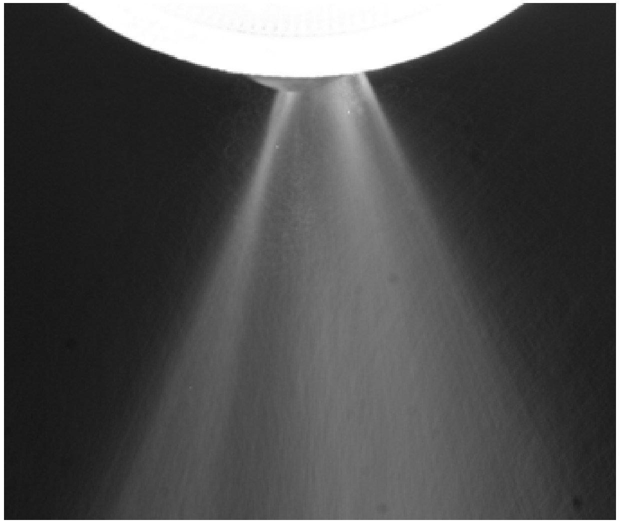
(a) **Pi** = 0.02 MPa



(b) **Pi** = 0.05 MPa



(c) **Pi** = 0.10 MPa



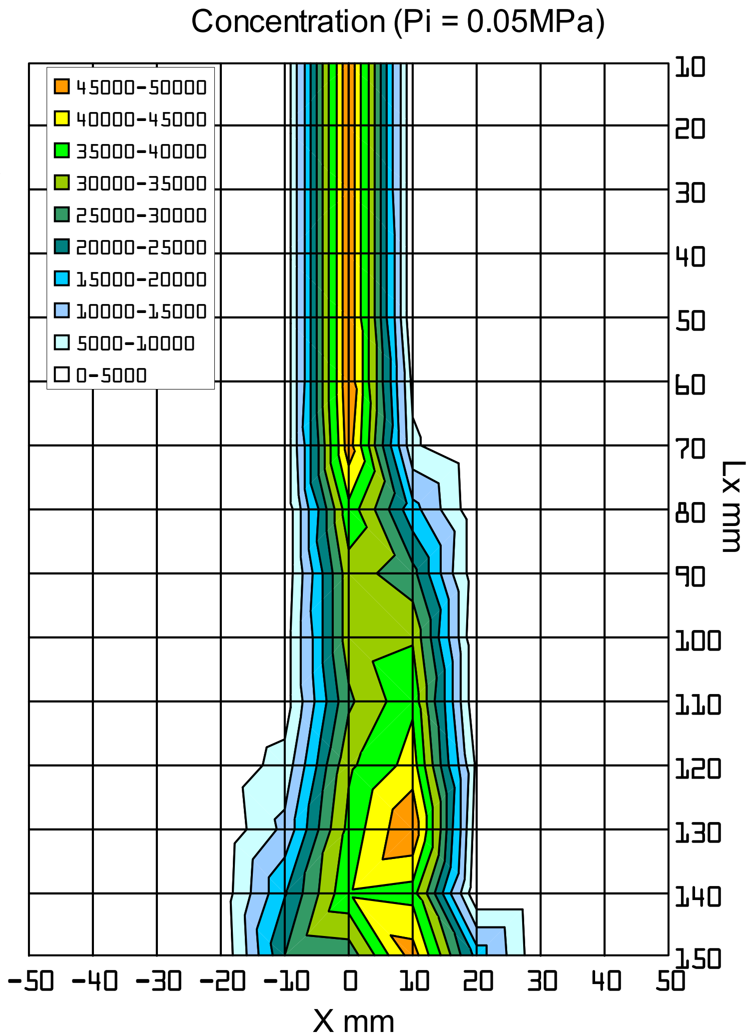
(d) **Pi** = 0.15 MPa

Concentration and SMD of Kerosene Spray at ***Pi*** *= 0.05 MPa*

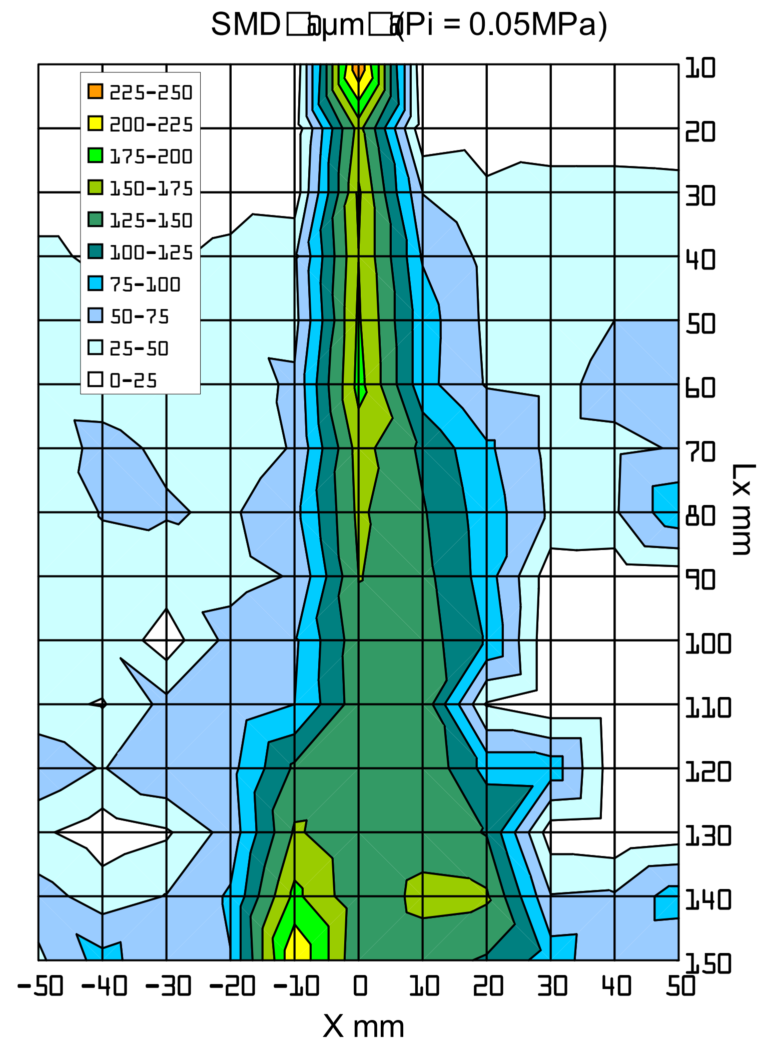
The concentrations are measured along the laser optical path by laser diffraction method with LDSA 1500A.

The area where concentration is over 10000 is observed around X = 0mm and it almost agrees with the area where ***SMD*** is over 125 micrometers.

Kerosene jets dose not expand widely and disintegrates mainly into large droplets. Especially it is hard to evaporate Lx<20mm.



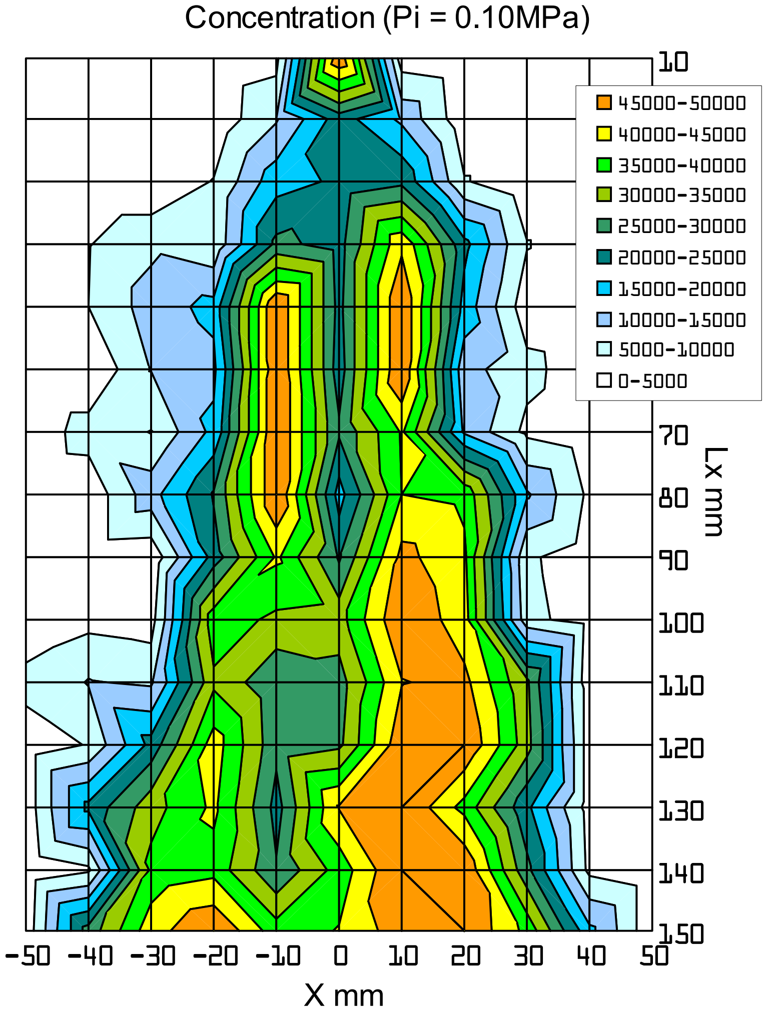
(a) Concentration



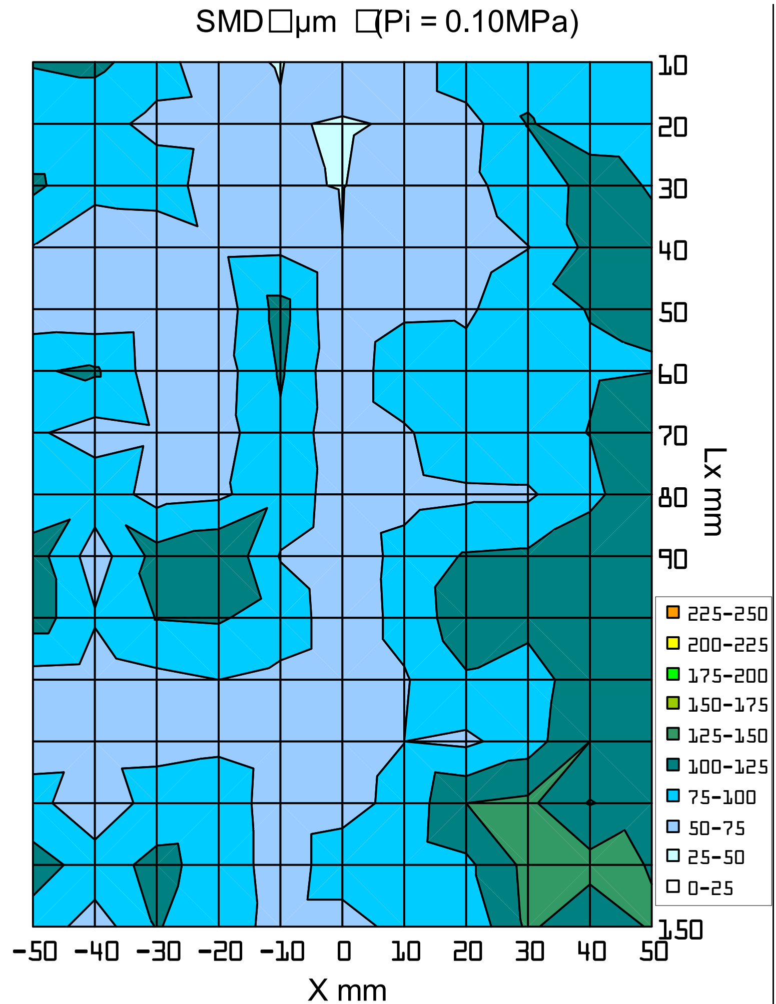
(b) ***SMD***

Concentration and SMD of Kerosene Spray at ***Pi*** *= 0.10 MPa*

When ***Pi*** is 0.10MPa, kerosene jet expands widely but ***SMD*** is over 50 micrometers at Lx=20mm.



(a) Concentration



(b) ***SMD***

Outline

1. Introduction
2. Atomization of liquid fuel injector of small gas turbine
3. Spray of a planar plate nozzle
4. Conclusion

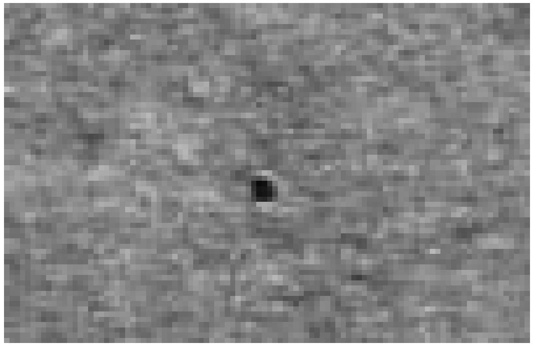
Plate nozzles with several tens micrometer holes

Disintegration phenomena of thin liquid jet were investigated with planar nickel plate nozzles as basic research of liquid atomization with a hole with a diameter of several tens micrometers.

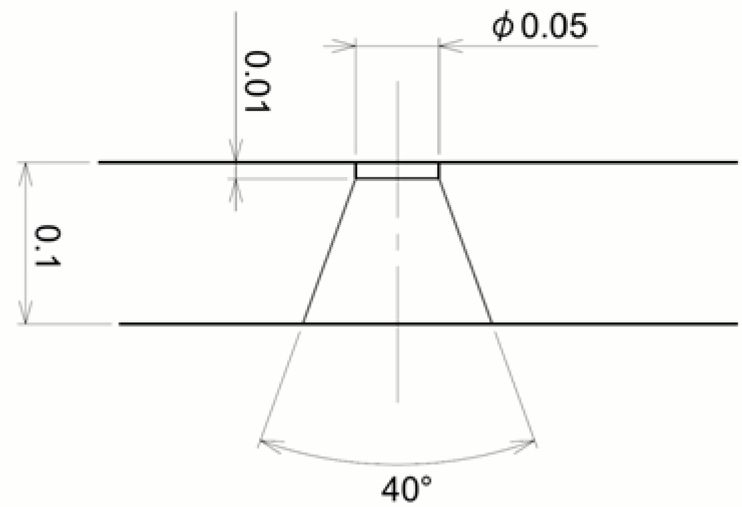
This investigation is considered to be as a first step of development of the multi-holes fuel injectors fabricated by Micro-Electro-Mechanical-Systems (MEMS) technologies.

2 types of nozzles are prepared.

- Thin plate nozzle
    - fabricated by electroforming process.
    - The thickness of the nozzle is 0.02mm.
    - Nozzle hole diameter ***Dn*** :0.01-0.07mm
    - Fluorine coating on the both sides.
- Plate nozzle fabricated by press working
    - thicker than the thin plate nozzle
    - ***Dn*** = 0.05mm
    - Fluorine coating is not processed.



(a) Thin plate nozzle fabricated by electroforming



(b) Plate nozzle fabricated by press working

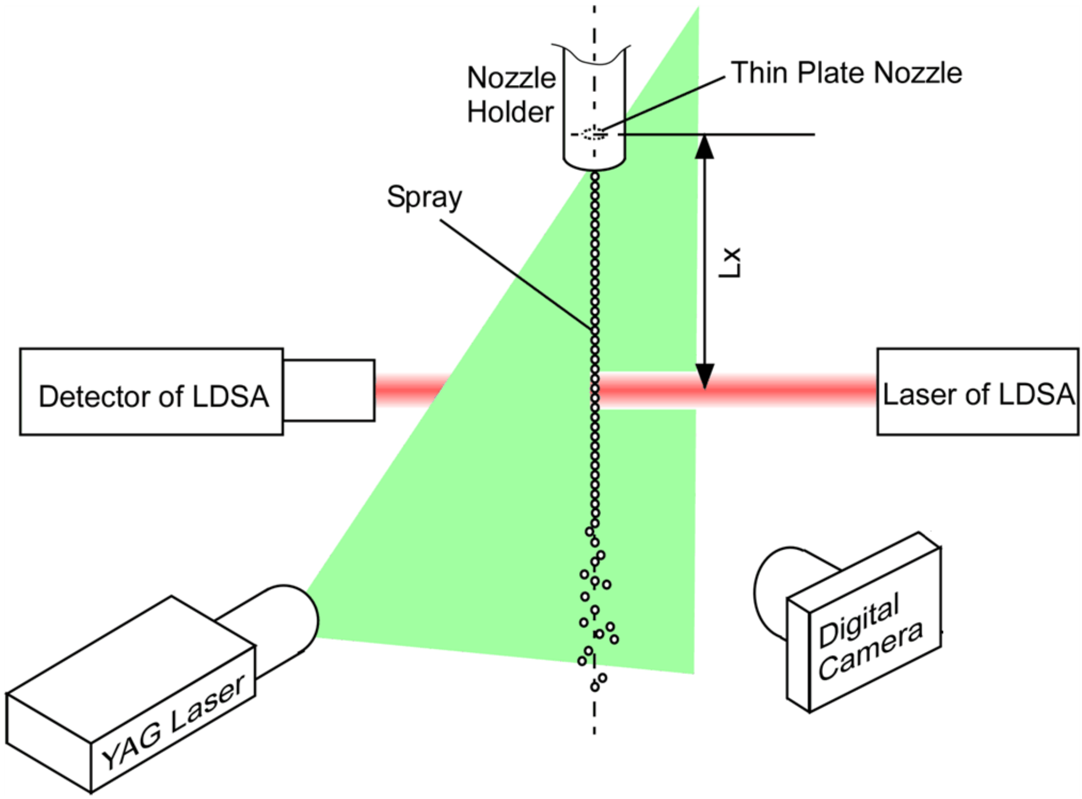
Experimental apparatus

Ion exchanged water is sprayed vertically downward into static atmospheric air.

Injection pressure ***Pi*** is from 0.1 to 2.0MPa.

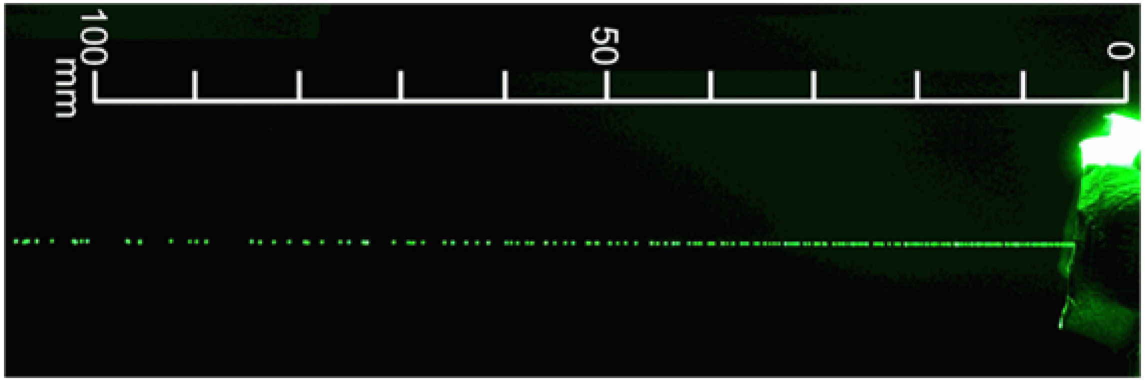
Photographs of disintegration phenomena of the water jets are taken by digital camera and laser sheet of YAG laser.

The Sauter mean diameters ***SMD*** were measured by laser diffraction method.

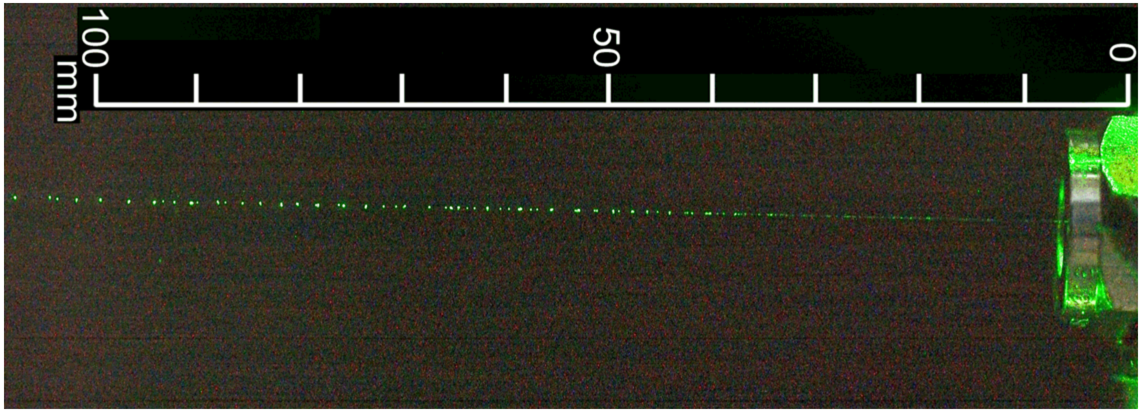


Spray with plate nozzle

Water jet already disintegrates into small droplets array where ***Lx*** (distance from the nozzle hole exit) is 10mm.
The interval of the droplets array becomes larger with ***Lx***.

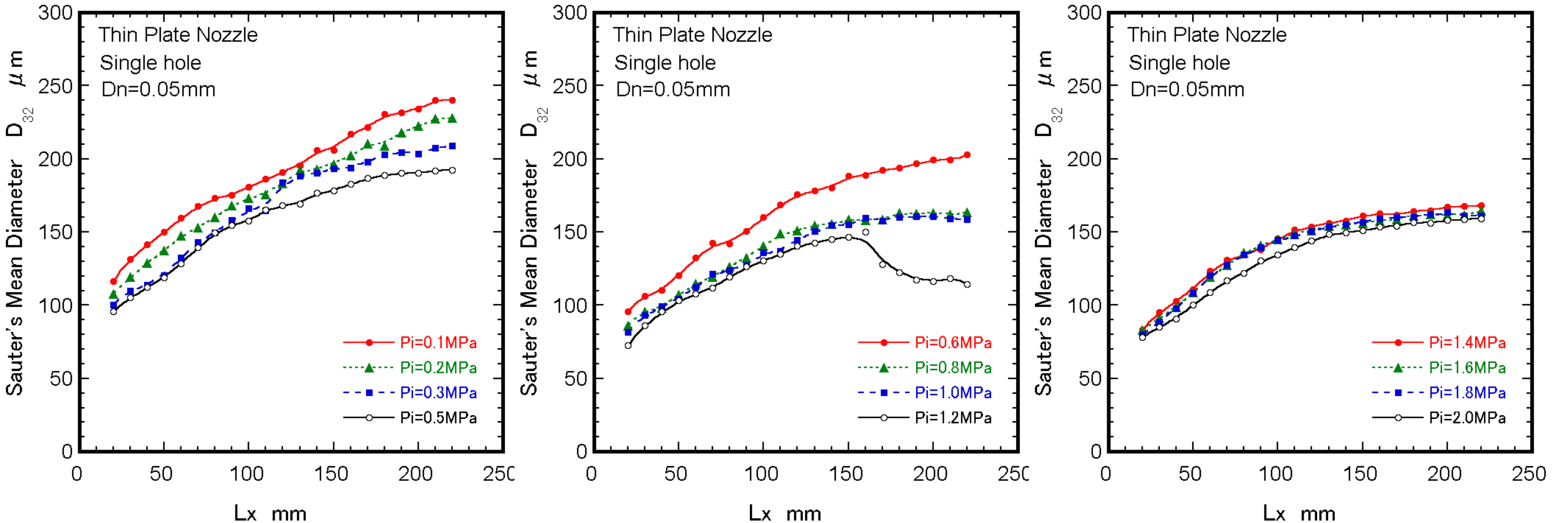


(a) Thin plate nozzle fabricated by Electro- forming
*(**Dn** = 0.03 mm, **Pi** = 0.06 MPa)*



(b) Planar plate nozzle fabricated by press working
*(**Dn** = 0.05 mm, **Pi** = 0.05 MPa)*

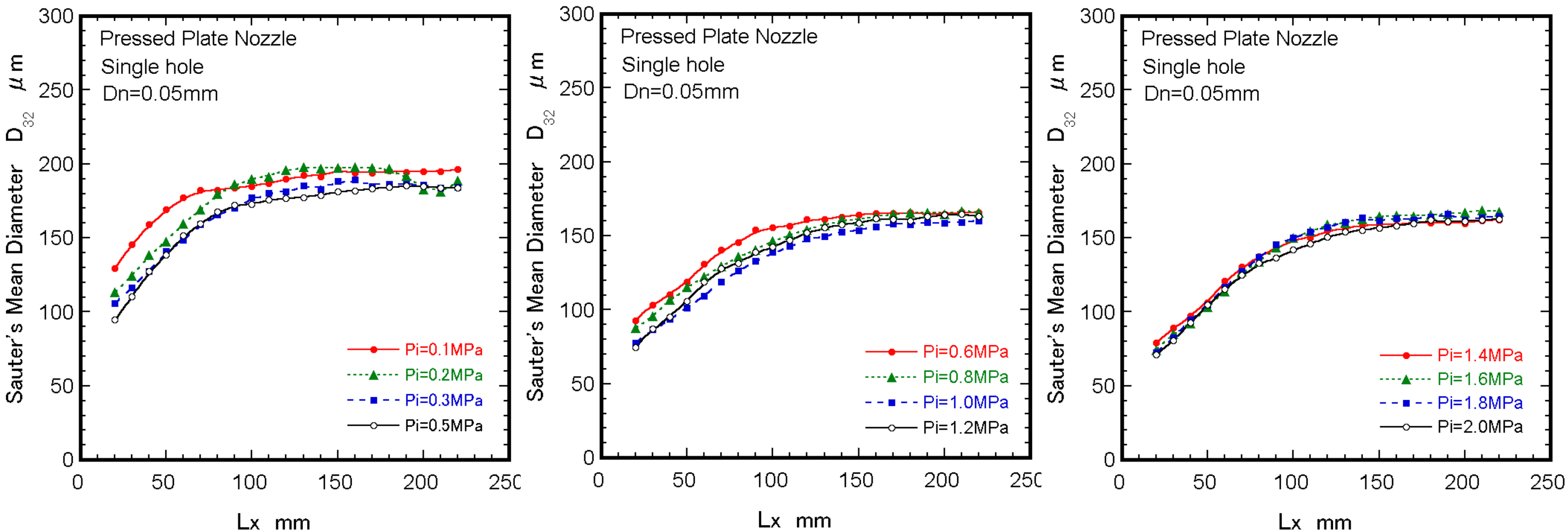
SMD with thin plate nozzle



(a) ***Pi****=0.1-0.5MPa* *(b)* ***Pi****=0.6-1.2MPa* *(c)* ***Pi****=1.4-2.0MPa*

SMD with thin plate hole nozzle mainly increase gradually with ***Lx***.

SMD with plate nozzle fabricated by press working



(a) ***Pi****=0.1-0.5MPa* *(b)* ***Pi****=0.6-1.2MPa* *(c)* ***Pi****=1.4-2.0MPa*

SMD near nozzle hole exit with the nozzle fabricated by press working is as almost same as that with thin plate nozzle fabricated by electroforming.

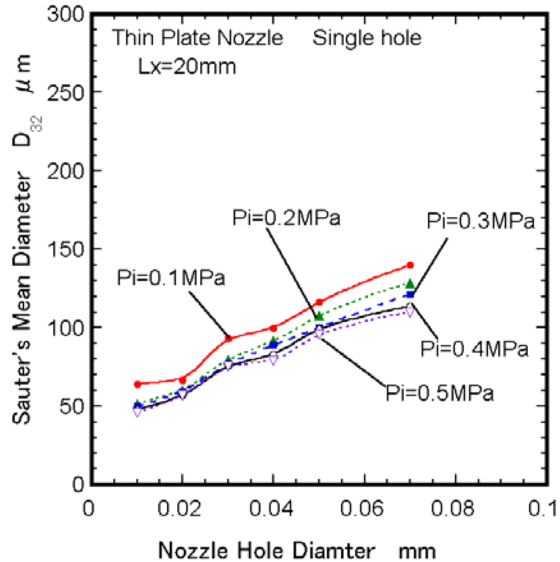
SMD of thin plate nozzle near nozzle exit with increase of *Dn*

Figures show the variation of ***SMD*** near nozzle exit with increase of ***Dn***.

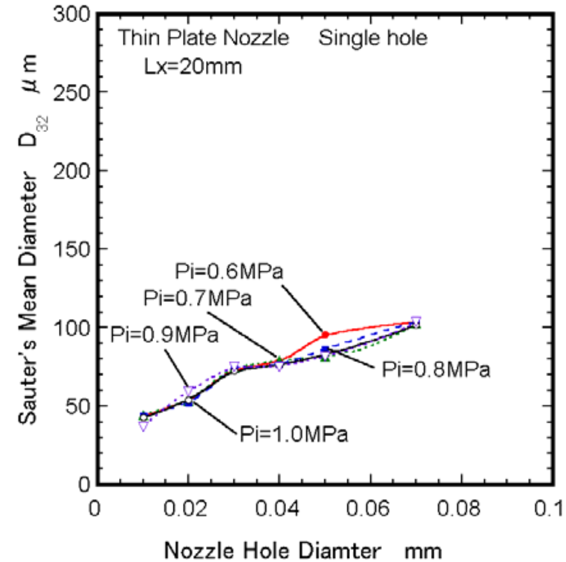
At low injection pressure ***Pi***, ***SMD*** increase monotonously with ***Dn*** and ***SMD*** decrease with ***Pi***.

At higher ***Pi***, ***SMD*** becomes almost independent on ***Pi*** as shown in (c).

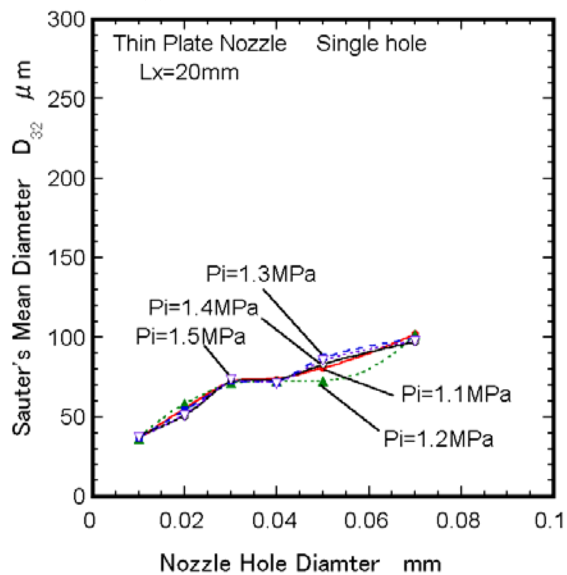
At high ***Pi***, the rising curve of ***SMD*** inflects at ***Dn***=0.03mm.



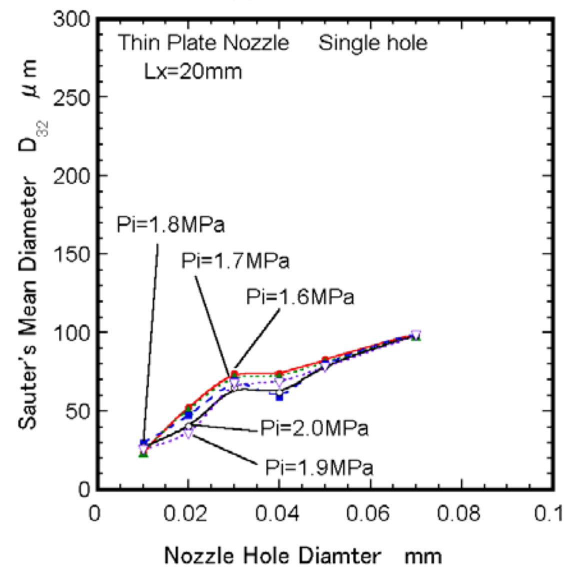
(a) ***Pi***=0.1-0.5MPa



(b) ***Pi***=0.6-1.0MPa



(c) ***Pi***=1.1-1.5MPa



(d) ***Pi***=1.6-2.0MPa

Outline

1. Introduction
2. Atomization of liquid fuel injector of small gas turbine
3. Spray of a planar plate nozzle
4. Conclusion

Conclusions

- The fuel spray of mini jet engine is investigated for fuel switching to kerosene. Two liquid columns of kerosene fuel are observed more clearly than those of original fuel. It is more difficult to start up the mini jet engine with kerosene than those with original fuel.
- The planar plate nickel nozzles are fabricated using electroforming process or press working. Ion exchanged water is sprayed vertically downward into static atmospheric air. ***SMD*** near nozzle hole exit with the nozzle fabricated by press working is as almost same as that with thin plate nozzle fabricated by electroforming.

SUBTASK 3.4B
INVESTIGATE DYNAMIC SPRAY CHARACTERISTICS BY IMAGE PROCESSING

Contributor: Japan National Committee for IEA/CRD Implementing Agreement on Energy Conservation and Emission Reduction in Combustion (JECC). Tokyo JAPAN

Description:

The technical goal of the present report is to develop spray measuring techniques with high spatial and temporal resolution of size, velocity vector and local density by means of interferometry, light scattering, density image, and fluorescence techniques which are applicable for investigations in combustion systems.

The technical goal of the present report is to clarify the disintegration phenomena with thin plate nozzles as basic research of liquid atomization. This investigation is considered to be as a first step of development of the multi-holes fuel injectors fabricated by Micro-Electro-Mechanical-Systems (MEMS) technologies, especially the fuel injector for continuous combustion such as gas turbine combustor.

Spray development and ambient flow field were observed and measured under various back pressure conditions. The main purpose of the study is to obtain the basic knowledge related with making good mixture for improving the combustion of direct injection engines.

Other research was performed about image analysis tools for high-speed videography. This program is in yet basic state, but fundamental analysis menus are provided. It was verified that application to ultra high-speed video recording system such as Shimadzu's could be done. In addition more general movie file (AVI files in Windows OS) can be handled by this program.

Accomplishments:

The fuel spray of mini jet engine is investigated for fuel switching to kerosene. Two liquid columns of kerosene fuel are observed more clearly than those of original fuel. It is more difficult to start up the mini jet engine with kerosene than those with original fuel.

The planar plate nickel nozzles are fabricated using electroforming process or press working. Ion exchanged water is sprayed vertically downward into static atmospheric air. ***SMD*** near nozzle hole exit with the nozzle fabricated by press working is as almost same as that with thin plate nozzle fabricated by electroforming.

The employed injectors were swirl-type, and form sprays into a pressure vessel in which the pressure was set to 0.1 MPa and 1.1 MPa. Visualization of the spray behaviors was conducted using a high-speed video camera, and obtained time-series images enabled the PIV measurement of spray-induced ambient flow motion. As a result, relationship of back pressure conditions with sprays and ambient flow was clarified.

Plans:

The work planned for next year will be follows:

Ultra high-speed video recording analysis will be applied to spray particles.

Publications:

Iki, N., "Water Spray from Several Tens Micrometer Holes", ILASS-Asia, 155-159, 2007

Kobayashi, Y., Ishima, T. and Obokata, T., "Spray Characteristics of a High-Pressure Swirl Injector for DISI Engines under High Ambient Temperature and Pressure Conditions", SAE 2008 world congress in Detroit, SAE paper NO. 2008-01-0130, 1-8, 2008

Kobayashi, Y., Ishima, T. and Obokata, T., " Characteristics on Intermittent Fuel Spray by Swirl Injector under High Back Pressure and High temperature Conditions", IEA Combustion Agreement Fuel Spray Work Shop 2007 in Detroit

Similar work elsewhere:

None Known

Milestone Chart:

CY-85 -86 -87 -88 -89 -90 -91 -92 -93 -94 -95 -96
□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□
+ + + + + o o o
A B C D E F G H

-97 -98 -99 -100 -001 -002 –003 -004 -005 -006 -007 -008
□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□
o o o o o o o o
I J K L M N O P

+ Task completed
o Task will be completed

A: Refinement the homodyne techniques to yield the information on particulate formation
B: Development of holographic techniques for apray combustion.
C: Improve the two frame holographic system.
D: Design the quadruplet frame holographic system.
E: Improve the image processing techniques.
F: Develop new holographic system for frame recording/
G: Improve the LLS high-speed photographic system.
H: Develop new high intensity incoherent flash light system.
I: Improve visual technique for soot clouds.
J: Improve fringe counting system.
K: Complete simple high-speed photo-recording system.
L: Develop new holographic recording techniques for small particle field.
M: Application of Linear Scan Camera System to Particle analysis
N Development of Versatile Motion Analysis Program for Ultra high-speed videography
O Application of Interferometric Laser Imaging Technique (ILI) to the Spray Behavior in a Swirling Hot Air Flow
P High speed digital video analysis for spray droplets sizing and vector field in combustion flows

Contact for Further Information:

Prof. Naoki Yokoyama
Research Institute of Science and Technology, Tokai University
Kitakaname 1117, Hiratsuka, Kanagawa, 259-1292 JAPAN
E-mail: nao@rist.u-tokai.ac.jp

SUBTASK3.4B

Investigate Dynamic Spray Characteristics by Image Processing

3.4B-III (IKI)

Spray from a Thin Plate Nozzle with several tens micrometer holes

N. Iki*, National Institute of Advanced Industrial Science and Technology (AIST), Tsukuba, Ibaraki, Japan

3.4B Objective

The present task is to observe disintegration phenomena of thin liquid jet with the thin planar nickel plate nozzles fabricated by electroforming process. The task will be performed by laser assisted optical techniques by laser induced fluorescence techniques and by high speed movies as well.

3.4B-II (Iki) Scope

The technical goal of the present report is to clarify the disintegration phenomena with thin plate nozzles as basic research of liquid atomization. This investigation is considered to be as a first step of development of the multi-holes fuel injectors fabricated by Micro-Electro-Mechanical-Systems (MEMS) technologies, especially the fuel injector for continuous combustion such as gas turbine combustor.

3.4B-III (Iki) Accomplishment

The fuel spray of mini jet engine is investigated for fuel switching to kerosene. Two liquid columns of kerosene fuel are observed more clearly than those of original fuel. It is more difficult to start up the mini jet engine with kerosene than those with original fuel.

The planar plate nickel nozzles are fabricated using electroforming process or press working. Ion exchanged water is sprayed vertically downward into static atmospheric air. ***SMD*** near nozzle hole exit with the nozzle fabricated by press working is as almost same as that with thin plate nozzle fabricated by electroforming.

****

Contact for further Information:
Task Leader
Prof. Naoki YOKOYAMA
Research Institute of Science and Technology, Tokai University
Kitakaname 1117, Hiratuka, Kanagawa,259-1292 Japan
E-mail: nao@rist.u-tokai.ac.jp

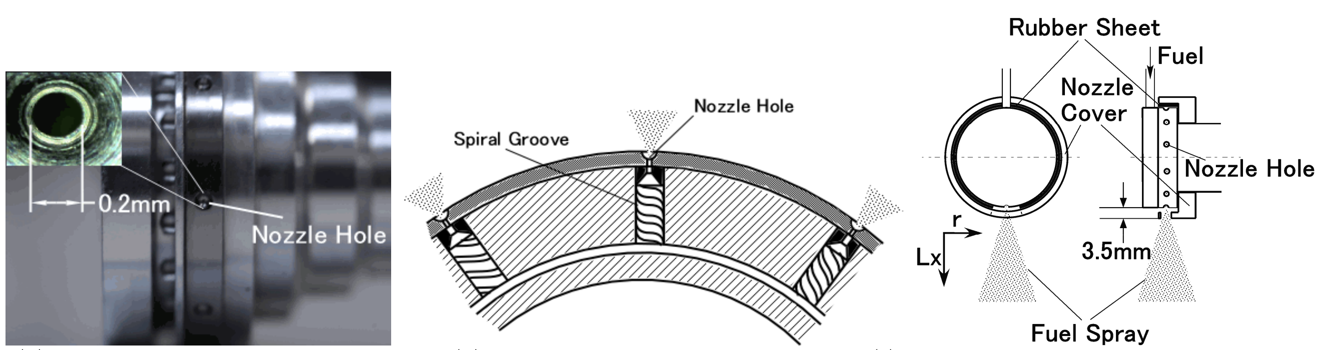
Accomplished Performances

Abstract

The combustor of this small engine has many problems such as unstable ignition, spurt of flame at starting up, unburned combustibles etc. Not only these problems, temperature pattern factor, thermal heat loss, combustion efficiency and pressure loss are common issues for small high-intensity combustors. Therefore the author tries to visualize the mixing processes of fuel and air and combustion phenomena in the small gas turbine combustor. The liquid fuel injector for such a small gas turbine has many problems. The atomization processes with the practical fuel injector for small gas turbine are investigated in order to clarify the technical issues. The fuel switching to 100% kerosene is expected for long time operation of the gas turbine. Therefore improvement of the pressure atomization is important issue. The author considers possibility to adopt a planar plate nozzle with small holes to an internal combustion engine such as gas turbines. If fuel flow rate and injection pressure are limited, there are many variable design parameters which effects on atomization phenomena, such as number of holes, size of holes, hole shape, intervals of holes, hole patterns, etc. The cost of nozzle fabricated by electroforming can be reduced by mass production but it is expensive at development stage. Multi-holes nozzle fabricated by press working is already used for automobile engines. Then 2 types of nozzles are prepared. The first type is fabricated by electroforming process. The thickness of the nozzle is 0.02mm. Nozzle hole diameter ***Dn*** is from 0.01mm to 0.07mm. Fluorine coating is processed on the both sides of the nozzle. The other type is fabricated by press working and thicker than the first type. ***Dn*** is 0.05mm. Fluorine coating is not processed.

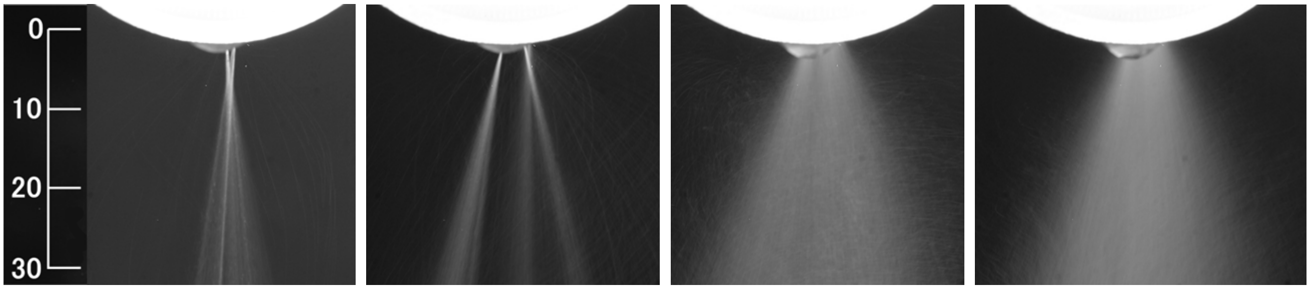
1. Atomization of liquid fuel injector of small gas turbine

The fuel spray of mini jet engine (J-850, Sophia Precision, Co., Ltd.) is investigated. The fuel injector is integrated to the bearing housing and it has 10 nozzle holes on the circumferential wall as shown in fig. 1. Each nozzle has spiral groove inside. Spray from one nozzle is investigated. The original fuel is mixture of fuel 70% kerosene and 30% gasoline but 100% kerosene is expected for long time operation.



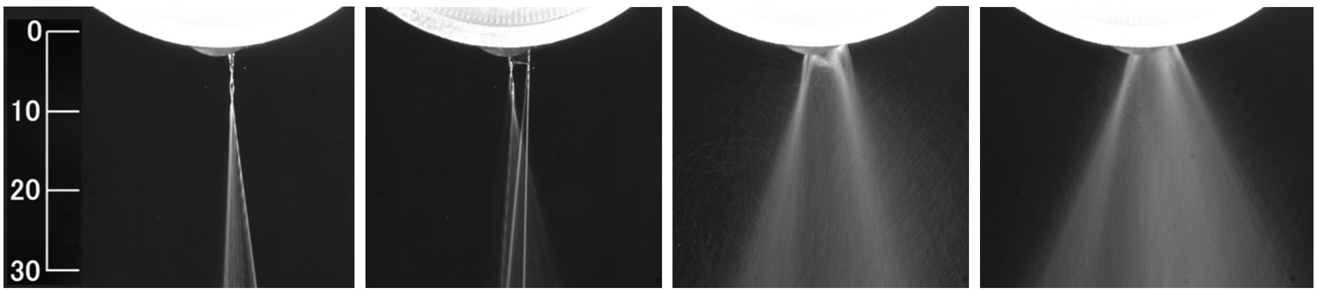
(a) Nozzle Hole of Fuel Injector *(b) Structure of Fuel Injector* *(c) Setting of Spray Observation*

Fig. 1 Experimental Apparatus for Spray Characteristics



(a) ***Pi*** *= 0.02 MPa* *(b)* ***Pi*** *= 0.05 MPa* *(c)* ***Pi*** *= 0.10 MPa* *(d)* ***Pi*** *= 0.15 MPa*

Fig. 2 Spray of Original Fuel (Kerosene 70% - Gasoline 30%)

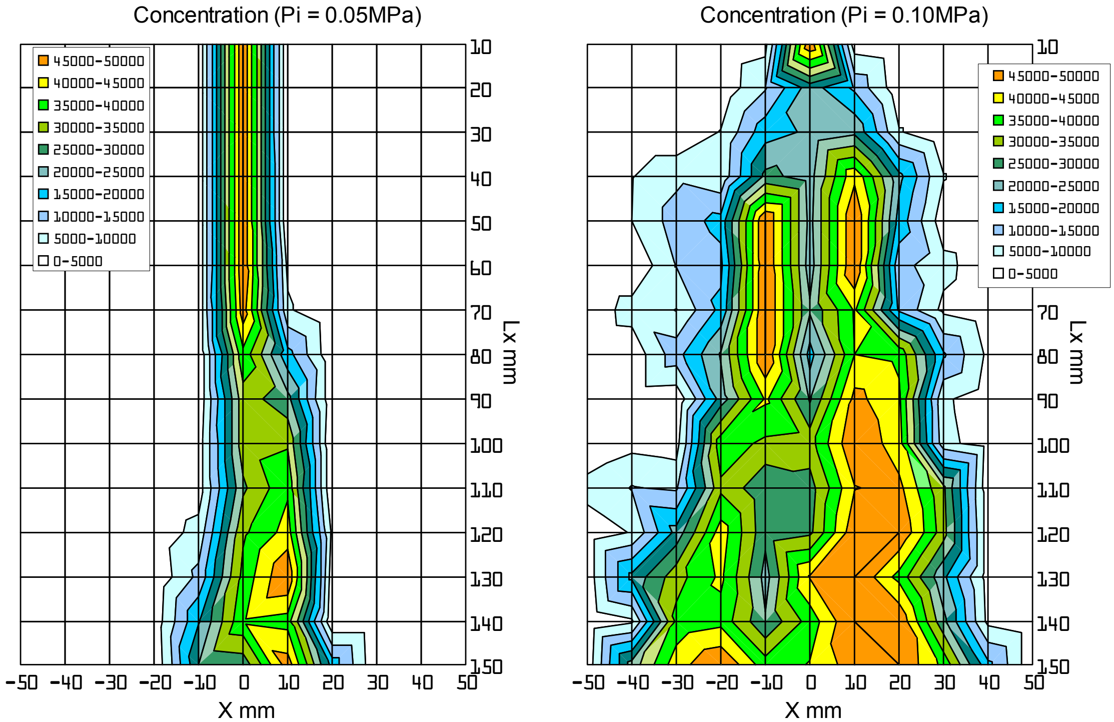


(a) ***Pi*** *= 0.02 MPa* *(b)* ***Pi*** *= 0.05 MPa* *(c)* ***Pi*** *= 0.10 MPa* *(d)* ***Pi*** *= 0.15 MPa*

Fig. 3 Spray of Kerosene

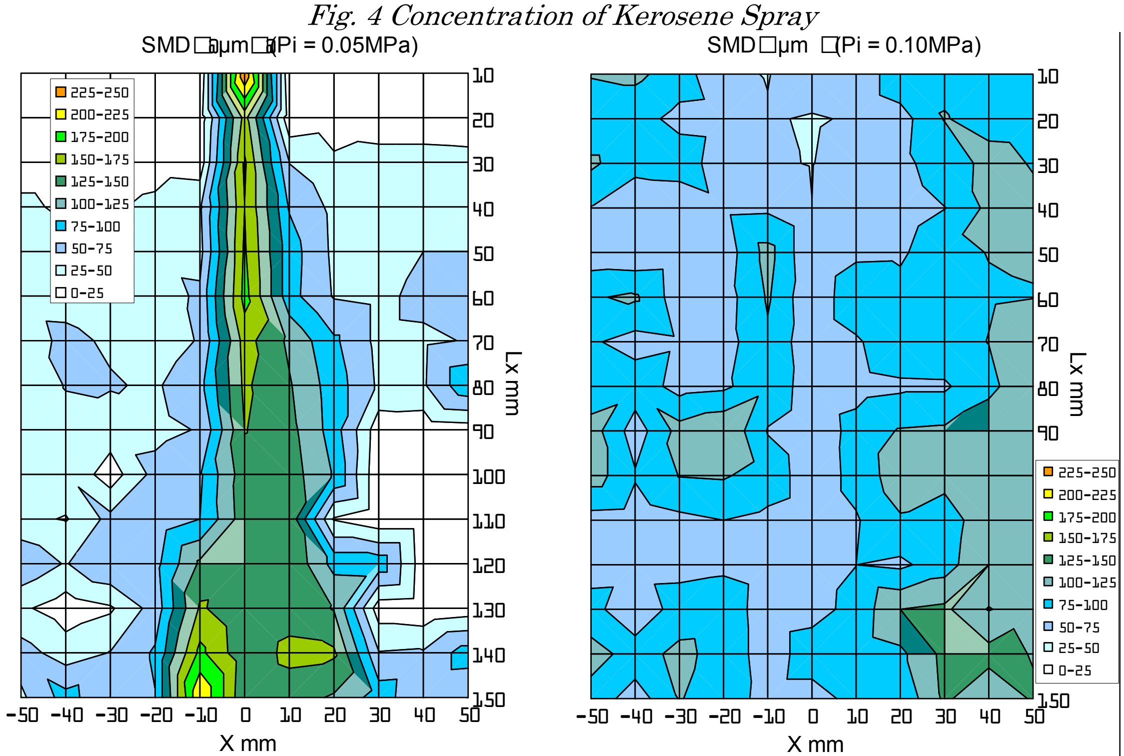
As shown in fig. 2, two liquid columns of original fuel are observed when injection pressure ***Pi*** is below 0.05 MPa. It seems reasonable that these two liquid columns derived from two grooves in the nozzle hole. As shown in fig. 3, two liquid columns of kerosene fuel are observed more clearly than those of original fuel. Gasoline in original fuel accelerates disintegration and evaporation of fuel. Since injection pressure ***Pi*** is below 0.05MPa at ignition condition of the mini jet engine, it is more difficult to start up the mini jet engine with kerosene than those with original fuel. It is clear that the improvement of the fuel injector becomes more important issue for utilization of kerosene.

Figure 4 and 5 shows distribution pattern the concentration and Sauter Mean Diameter ***SMD*** of kerosene spray measured by laser diffraction method with LDSA 1500A. The concentration and ***SMD*** are measured along the laser optical path and the values are not cross-sectional. When ***Pi*** is 0.05MPa, the area where concentration is over 10000 is observed around X = 0mm and it almost agrees with the area where ***SMD*** is over 125 micrometers. The areas where ***SMD*** is below 50 micrometers are observed at X>30mm and X<-30mm where the concentration is below 5000. Kerosene jets dose not expand widely and disintegrates mainly into large droplets. Especially it is hard to evaporate Lx<20mm. When ***Pi*** is 0.10MPa, kerosene jet expands widely but ***SMD*** is over 50 micrometers at Lx=20mm.



(a) ***Pi*** *= 0.05 MPa* *(b)* ***Pi*** *= 0.10 MPa*

Fig. 4 Concentration of Kerosene Spray



(a) ***Pi*** *= 0.05 MPa* *(b)* ***Pi*** *= 0.10 MPa*

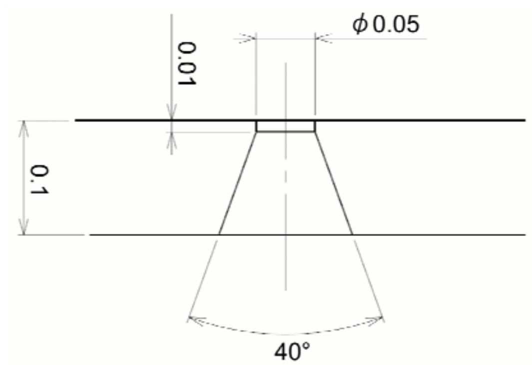
Fig. 5 Sauter Mean Diameter of Kerosene Spray

2. Spray of a planar plate nozzle

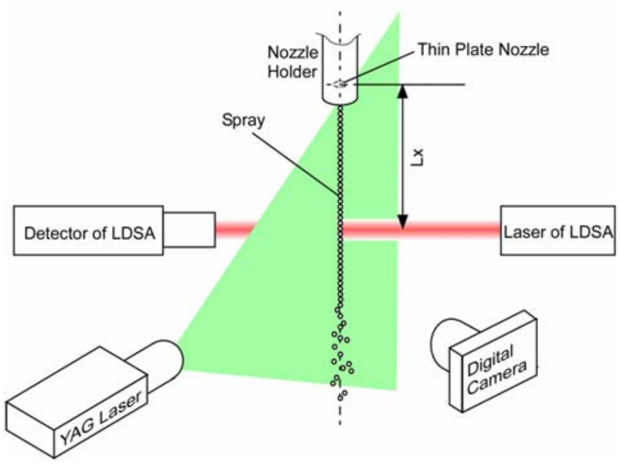
Disintegration phenomena of thin liquid jet were investigated with planar nickel plate nozzles as basic research of liquid atomization with a hole with a diameter of several tens micrometers. This investigation is considered to be as a first step of development of the multi-holes fuel injectors fabricated by Micro-Electro-Mechanical-Systems (MEMS) technologies. 2 types of nozzles are prepared. The first type is fabricated by electroforming process. The thickness of the nozzle is 0.02mm. Nozzle hole diameter ***Dn*** is from 0.01mm to 0.07mm. Fluorine coating is processed on the both sides of the nozzle. The other type is fabricated by press working and thicker than the first type. ***Dn*** is 0.05mm as shown in fig. 6 (a). Fluorine coating is not processed.

Ion exchanged water is sprayed vertically downward into static atmospheric air as shown in fig. 6 (b). Injection pressure ***Pi*** is from 0.1 to 2.0MPa. Photographs of disintegration phenomena of the water jets are taken by digital camera and laser sheet of YAG laser. The Sauter mean diameters ***SMD*** were measured by laser diffraction method.

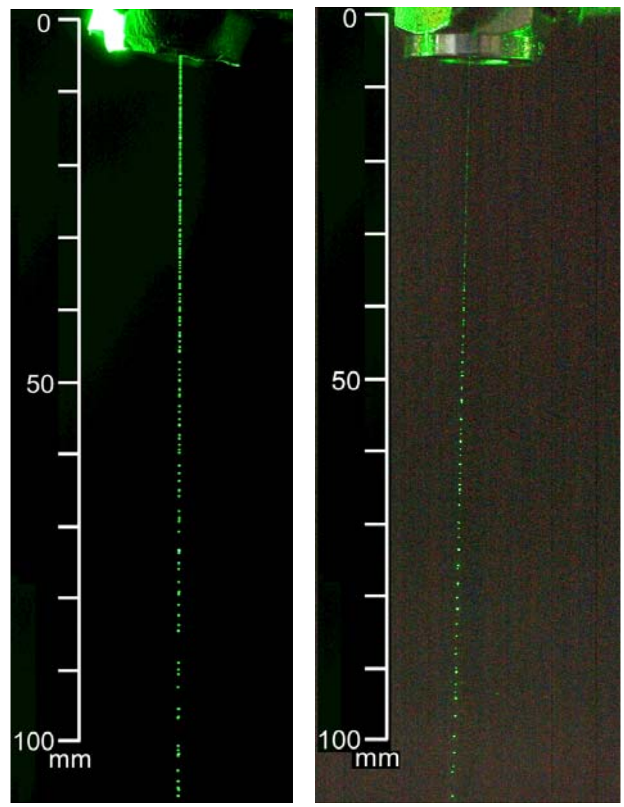
Water jet already disintegrates into small droplets array where ***Lx*** (distance from the nozzle hole exit) is 10mm as shown in fig. 7. The interval of the droplets array becomes larger with ***Lx***. ***SMD*** with thin plate hole nozzle mainly increase gradually with ***Lx*** as shown in fig. 8. ***SMD*** near nozzle hole exit with the nozzle fabricated by press working is as almost same as that with thin plate nozzle



(a) Plate nozzle fabricated by press working



(b) Experimental apparatus
Fig. 6 Experimental apparatus



*(a) Thin plate nozzle fabricated by Electro-forming (**Dn** = 0.03 mm, **Pi** = 0.06 MPa)*

*(b) Planar plate nozzle fabricated by press working (**Dn** = 0.05 mm, **Pi** = 0.05 MPa)*

Fig. 7 Spray with plate nozzle

fabricated by electroforming as shown in fig. 9. At low ***Pi***, ***SMD*** with thin plate nozzle fabricated by electroforming increase monotonously with ***Dn***. At high ***Pi***, the rising curve of ***SMD*** inflects at ***Dn***=0.03mm.

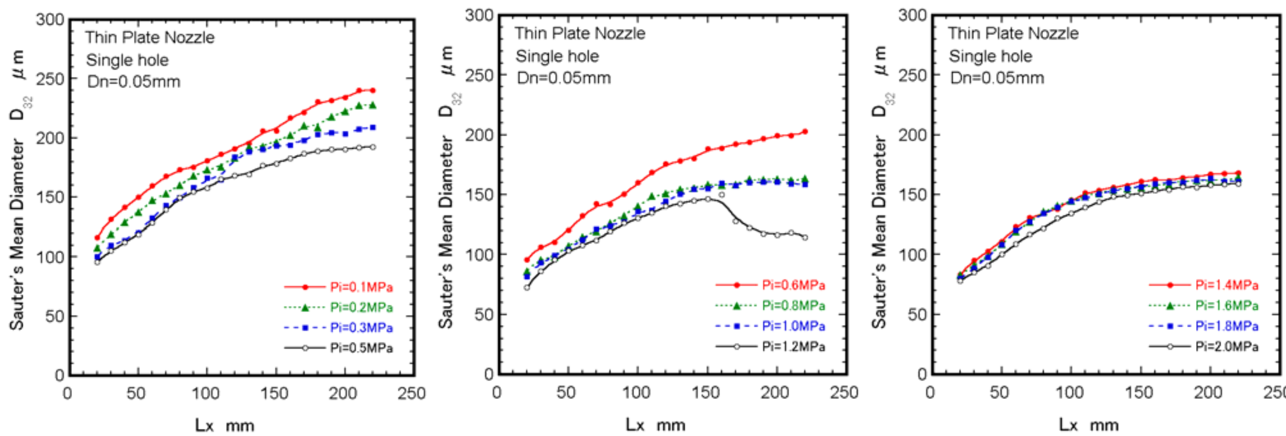
4. Conclusion

The fuel spray of mini jet engine is investigated for fuel switching to kerosene. Two liquid columns of kerosene fuel are observed more clearly than those of original fuel. It is more difficult to start up the mini jet engine with kerosene than those with original fuel.

The planar plate nickel nozzles are fabricated using electroforming process or press working. Ion exchanged water is sprayed vertically downward into static atmospheric air. ***SMD*** near nozzle hole exit with the nozzle fabricated by press working is as almost same as that with thin plate nozzle fabricated by electroforming.

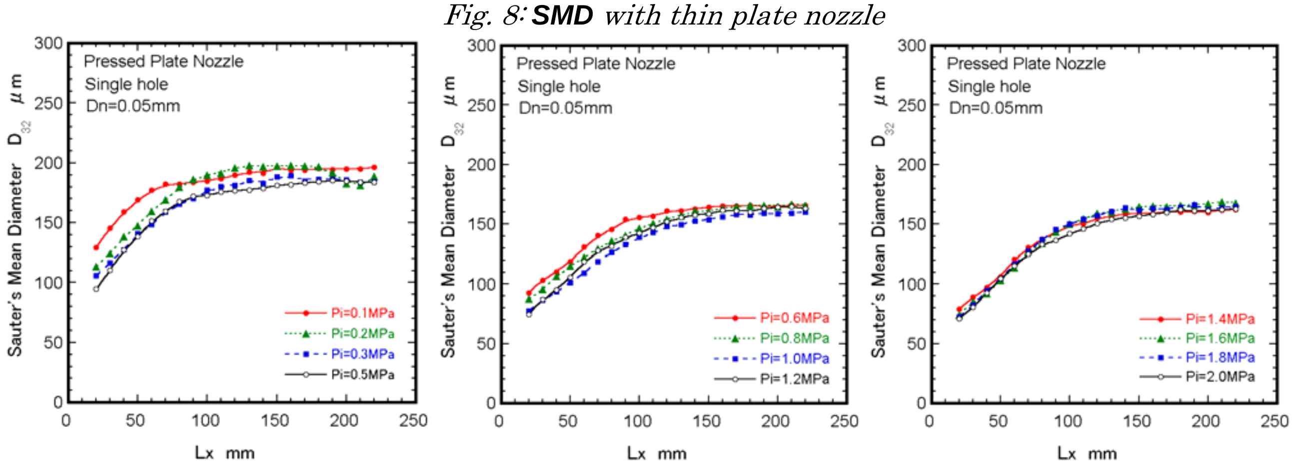
References

Iki, N., "Water Spray from Several Tens Micrometer Holes", ILASS-Asia, 155-159, 2007



(a) ***Pi****=0.1-0.5MPa* *(b)* ***Pi****=0.6-1.2MPa* *(c)* ***Pi****=1.4-2.0MPa*

Fig. 8: ***SMD*** *with thin plate nozzle*



(a) ***Pi****=0.1-0.5MPa* *(b)* ***Pi****=0.6-1.2MPa* *(c)* ***Pi****=1.4-2.0MPa*

Fig. 9: ***SMD*** *with plate nozzle with press working*

SUBTASK3.4B

Investigate Dynamic Spray Characteristics by Image Processing

3.4B--IV (Tsuneaki Ishima, Yoshiyuki Kobayashi and Tomio Obokata.)

Characteristics of spray and its surrounding flow initiated from a swirl spray.

T. Ishima*, Gunma University, Tenjin, Kiryu, Gunma, Japan

Accomplished Performances

Abstract

Spray development and ambient flow field were observed and measured under various back pressure conditions. The main purpose of the study is to obtain the basic knowledge related with making good mixture for improving the combustion of direct injection engines. The employed injectors were swirl-type, and form sprays into a pressure vessel in which the pressure was set to 0.1 MPa and 1.1 MPa. Visualization of the spray behaviors was conducted using a high-speed video camera, and obtained time-series images enabled the PIV measurement of spray-induced ambient flow motion. As a result, relationship of back pressure conditions with sprays and ambient flow was clarified.

1. Experimental setup and experimental conditions

Figure 1 shows a schematic of the experimental setup for visualization of the intermittent spray. A liquid fuel of n-heptane was used for standardization of the fuel and safety of the experiment. The evaporation point of the n-heptane is 371.4 K. The fuel line has a filter, a high-pressure pump and a swirl type fuel injector for direct injection gasoline engine. Valve opening duration and frequency of injection were controlled by an injection time controller. The fuel pressure, valve opening duration and injection frequency were set to 10 MPa, 0.7 ms and 1 Hz, respectively. Under this condition, the spray characteristics can be treated as the independent spray. The constant volume chamber was filled up by N_2 gas for preventing the combustion. The ambient temperatures Ta are set 298 and 423 K. The backpressures BP are 0 and 1.0 MPa in gauge pressure. The origin of the coordinates is the center of nozzle exit. The stream wise and radial directions of the spray are z- and r- axes, respectively. In this experiment, the flow rate inside the pressure chamber is set to

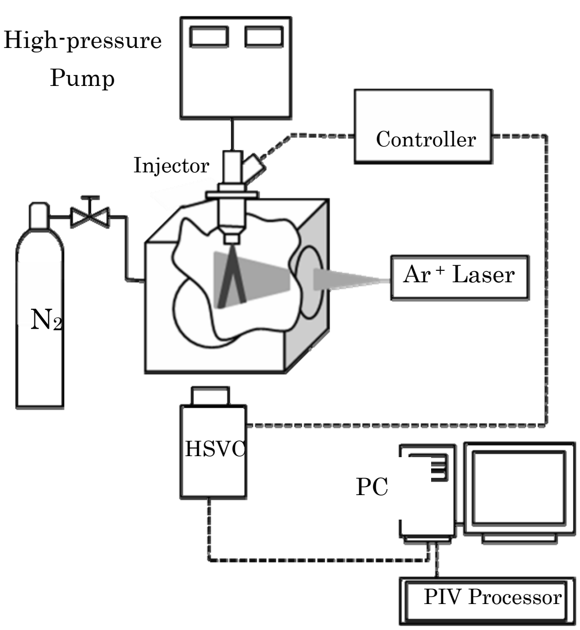


Fig. 1 Experimental setup

30 Nl/min. This condition makes the flow of 0.03 m/s inside the chamber. With this condition, small droplets are suspended in the pressure chamber. In this experiment, these small droplets are treated as the tracer particle of ambient flow.

The visualization was carried out by using a high speed video camera (Photoron APX). The laser sheet is used for illuminating the spray formation. For velocity vector measurements, the PIV system (Dantec Flowmap 2000) is used. All of the frames of the movie by the high speed video camera are translated to the still pictures. Using the pictures, the vector maps are calculated by using PIV processor. The laser is Ar^+ laser (Spectra physics 2007) with 6W of total output power. The high speed video camera setting is shown in Table 1.

Table 1 High speed video camera settings

	Setting I	Setting II	Setting III
Frame rate fps	5,000	10,000	5,000
Shutter speed ms	2	17	33
Image size pixel	640 x 912, 768 x 800	384 x 544, 512 x 512	640 x 912, 768 x 800
Spatial resolution mm / pixel	0.026	0.073	0.026

In the experiment, a laser Doppler anemometer (LDA) is also applied to measure the spray velocity. The LDA can make two-component instantaneous velocity measurement. The laser is Ar^+ laser (Spectra physics 2007) and optical systems (Dantec 57x). A burst spectram analyzer (Dantec F60) is used for processing the Doppler signal.

2. Spray formation and ambient air flow

Figure 2 shows the velocity vector maps with visualized picture. The measurement time is 0.2, 0.6 and 1.0 ms from the injection start. The experimental result under the condition of both of the ambient pressure of 0.1 and 1.1 MPa is appeared. Double scales for spray and ambient air is used. The gray vectors inside the spray picture are LDA data of spray velocity and black vectors are the data for the ambient air.

For the low ambient pressure condition, the ambient velocity is very low at $t = 0.2$ ms. The spray velocity is maximum and it is almost 100 m/s. On the other side, the maximum ambient velocity of 0.3 m/s in negative direction can be observed near the spray injector region. The ambient velocity is increasing with the time, especially upper side of the spray. The ambient air points to the spray core region. At $t = 0.6$ and 1.0 ms, the large vortex can be also observed. The ambient air flows along this vortex.

For the high ambient pressure condition, the spray has narrow width compared with that with low ambient pressure condition. The ambient air can hardly flow. The velocity is rather small compared with that of the low ambient pressure condition. The results show that the air entrainment for the high ambient pressure condition becomes weak. The spray has large vortex at the edge of the spray however it is smaller than that of the low pressure condition.

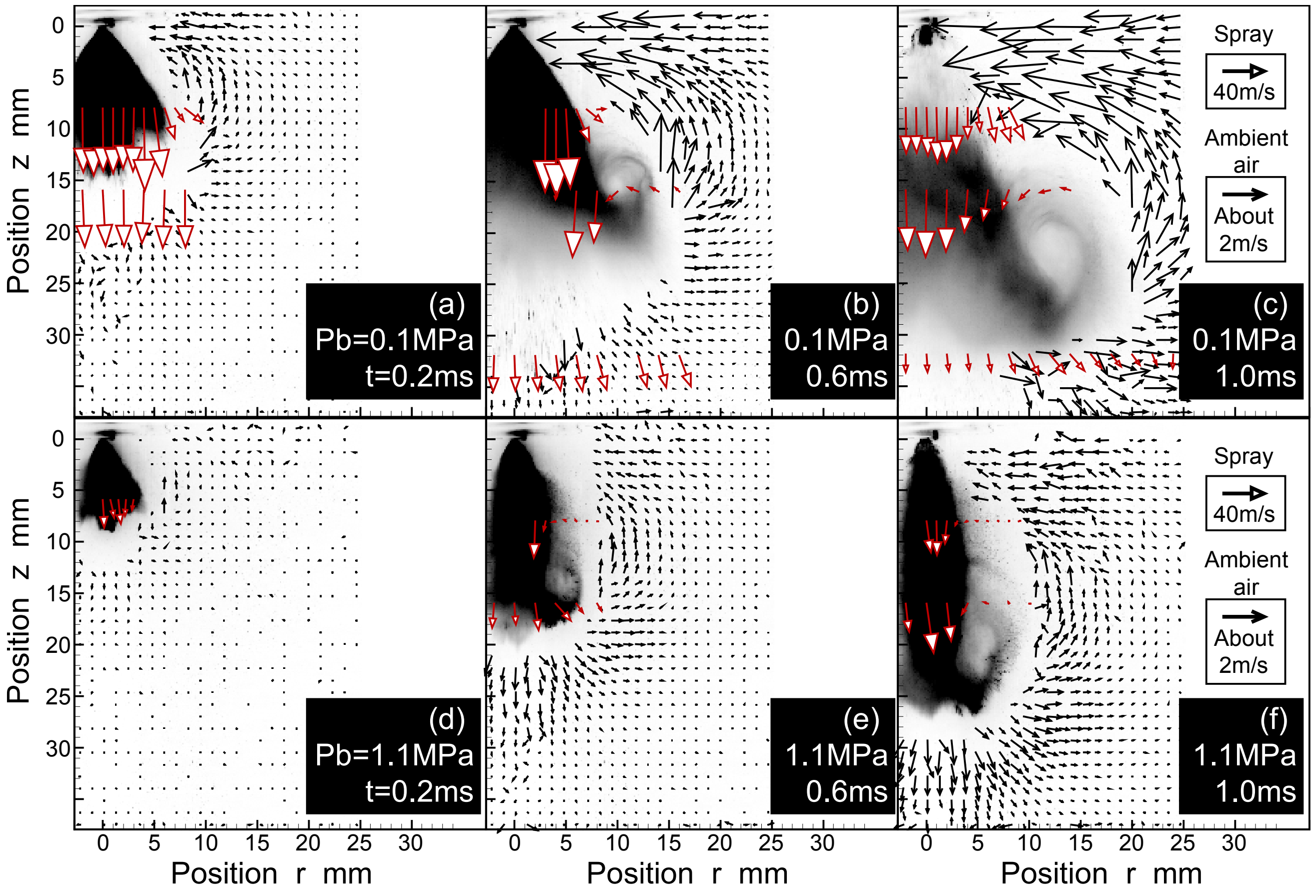


Fig. 2 Spray formation and velocity vectors with two ambient-pressure conditions.

3. Summary

The fuel spray formation with swirl type injector has been studied. The analysis with high-speed video camera can be effective for observing the spray formation and ambient air motion. The vector map of the ambient air motion is obtained by using high-speed video camera and PIV processor. The results show the difference in the spray formation and ambient flow fieled with the ambient pressure condition.

References

Kobayashi, Y., Ishima, T. and Obokata, T., "Spray Characteristics of a High-Pressure Swirl Injector for DISI Engines under High Ambient Temperature and Pressure Conditions", SAE 2008 world congress in Detroit, SAE paper NO. 2008-01-0130, 1-8, 2008

Kobayashi, Y., Ishima, T. and Obokata, T., " Characteristics on Intermittent Fuel Spray by Swirl Injector under High Back Pressure and High temperature Conditions", IEA Combustion Agreement Fuel Spray Work Shop 2007 in Detroit