

The effect of injector boost current on fuel spray characteristics

Keisuke Komada*¹, Manabu Saito², Hironobu Ueki³

¹Fukuoka Institute of Technology, 3-30-1 Wajiro-higashi, Higashi-ku, Fukuoka, Japan

²IRS, 19-8 Shinjuku-cho, Higashimatsuyama, Saitama, Japan

³Nagasaki University, 1-14 Bunkyo-machi, Nagasaki, Japan

*Corresponding author: komada@fit.ac.jp

Abstract

A laser 2-focus velocimeter (L2F) was used for the measurements of the velocity and size of droplets in diesel fuel sprays injected from a solenoid type diesel injector. The L2F had a micro-scale probe which consists of two foci. The focal diameter was about 3 micro meters, and the distance between two foci was 20 micro meters. The fuel was stored once in a common rail and was injected intermittently to the atmosphere. The diameter of the nozzle orifice was 0.15 mm. The injection pressure was set at 60 MPa, and the boost current of the injector needle opening was changed from 12 to 20A. The L2F measurement was conducted at the spray center, 10 mm downstream from the nozzle exit. The velocity of droplets increased with time at the early period of injection under both boost current conditions. Spray tip droplets under low boost current were observed at the L2F measurement position later than under high boost current. The needle opening speed is considered to become lower due to the decrease of the boost current. The size of droplets under the condition of lower boost current was smaller than the one under the condition of high boost current at the early period of injection. The investigation indicated that the turbulence inside the nozzle was increased because the period of seat contraction was extended.

Keywords

Diesel spray, Droplets, Velocity, Size, Laser measurement, Boost current

Introduction

Appropriate control of the combustion in diesel engines are necessary for the improvement of thermal efficiency and the reduction of exhaust emissions. The fuel injection system was investigated theoretically [1] and experimentally[2], and changing the spray characteristic was attempted by the control of injection rate[3] and the control of the needle valve in the case of the piezo injector[4]. The effect of temperature and pressure of the surrounding air on the spray behaviour were reported[5]. Phase Doppler Anemometer was effectively applied for the measurements of the velocity and size of droplets inside sprays[6-9]. However, it is difficult to identify each droplet near the nozzle exit due to surrounding high number density droplets. There are few reports about the effect of injector drive current on the spray characteristics.

Laser 2-focus velocimeter(L2F) can measure the velocity and size of droplet in the spray near the nozzle region due to the micro scale measurement volume. In the present study, the effect of drive current of injector on the spray characteristics was investigated by using the L2F.

Experimental setup

Figure 1 shows the light probe of the L2F. The focus length L in the direction of optical axis is about 20 μm , the focus diameter F is 3 μm , and the distance S between two foci is 20 μm . L2F can discriminate each droplet in the dense droplet region, because L2F has micro-scale measurement volume. Figure 2 shows the measurement principle of the velocity and size of droplets. The upper half of Figure 2 shows the cross-section of the L2F probe. When a droplet passes through both upstream and downstream foci, time-of-flight t_1 , time-of-scattering t_2 on the upstream focus and time-of-scattering t_3 on the downstream focus are measured by a digital counter with a clock of 700 MHz. The velocity of droplet can be calculated by dividing the distance S between two foci with the measured time-of-flight t_1 , that is

$$u = \frac{S}{t_1} \quad (1)$$

The relation used for the estimation of droplet size is that the ratio of the time-of-flight and the time-of-scattering corresponds to the ratio of the distance S between two foci and the droplet size dp plus the focus size F . The time-of-scattering is estimated by averaging two time-of-scattering. The droplet size dp can be estimated by

$$d_p = u \cdot \frac{(t_2 + t_3)}{2} - F \tag{2}$$

Figure 3 shows the measurement system of fuel sprays using the L2F. The light source is a laser diode which has a maximum power of 100mW and a wave length of 830nm. A non-spherical lens, which has a focal length of 8 mm and a numerical aperture of 0.5, is adopted as the condenser lens. The optical system has a length of 350mm including the light source. The backscattering light of a droplet at the focus is guided to a Si - APD (Silicon Avalanche Photo Diode), and the light is converted into an electrical signal. The clock signal with a frequency of 10MHz was used for recording the time when a droplet passed through the upstream focus. This means that the period of the minimum window for each data is 0.1μs. The time-of-flight and time-of-scattering are measured by the digital counter which is mainly constituted by a FPGA (Field Programmable Gateway Array). Diesel fuel pressurized by the high pressure pump was stored in the common rail. The common rail was used to control the injection pressure. Injection conditions such as the injection timing and the injection duration were controlled by the injector driver. The coordinate z is the distance along the spray axis from the nozzle exit, the coordinate y is the distance along the laser axis from the spray center, and the coordinate x is perpendicular to y and z-axes. The x-axis indicates the radius from the spray center in the plane where y is zero. Two foci of the L2F probe were set in such a way that the direction from the upstream focus to the downstream focus was adjusted to the spray axis.

Table 1 shows the experimental conditions. The diesel fuel spray which was injected intermittently into the atmosphere by using a 6-hole injector nozzle. The orifice diameter of the injector was 0.15 mm and the rail pressure was set at 60 MPa. The frequency of injection was 3Hz. Measurement plane was located at 10 mm from the nozzle exit, and the measurement positions were x = 0, 0.4, 0.8, 1.2 and 1.6mm. The measurement was conducted during 90-470 injections, and the number of droplets observed was 20,000.

Figure 4 shows the waveforms of the current applied on the injector. The time window is set to 0.03 ms. The horizontal axis shows the elapsed time after start signal of injection. The boost current(BC) is that the current is for opening the needle valve. The value of boost current was set at 12 and 20A. In the case of BC = 20A, the value of current increased and decreased rapidly between T = 0 and 0.2ms. After that, the change of current was small until T = 0.4ms. On the other hand, the value of current increased between T = 0 and 0.4ms in the case of BC = 12 A. The current gradient at BC = 12 A was smaller than the one at BC = 20 A in the period between T = 0 and 0.1ms. After T = 0.4 ms, the difference of current between both cases of BC was small.

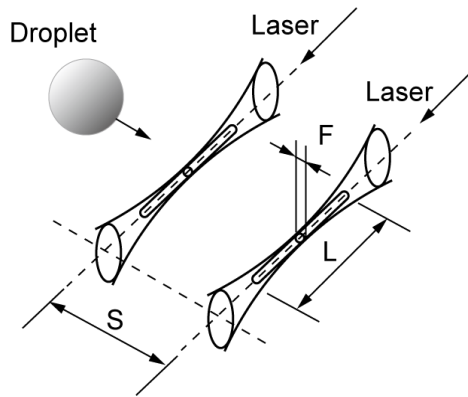


Figure 1. Measurement probe of L2F

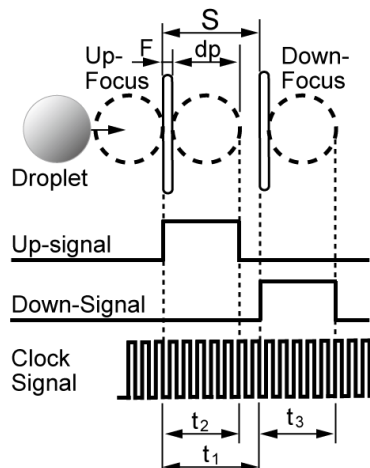


Figure 2. Time-of-flight and time-of-scattering

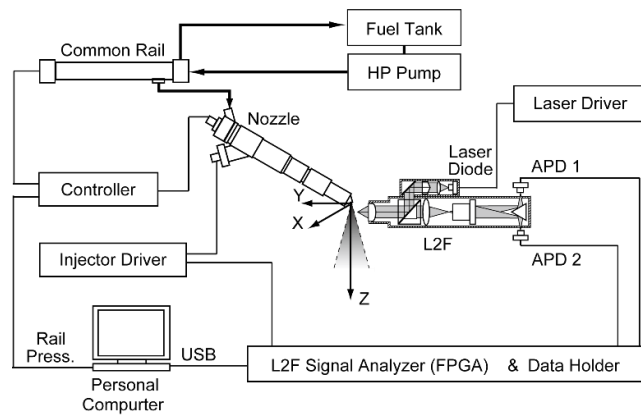


Figure 3. Fuel spray measurement system

Table 1. Measurement conditions

Injector Specification	
Hole diameter [mm]	0.15
Number of hole [-]	6
Test Condition	
Rail pressure [MPa]	60
Ambient pressure [MPa]	0.1
Ambient temperature [K]	296
Injection interval [ms]	330
Measurement positions	
x [mm]	0, 0.4, 0.8, 1.2, 1.6
y [mm]	0
z [mm]	10

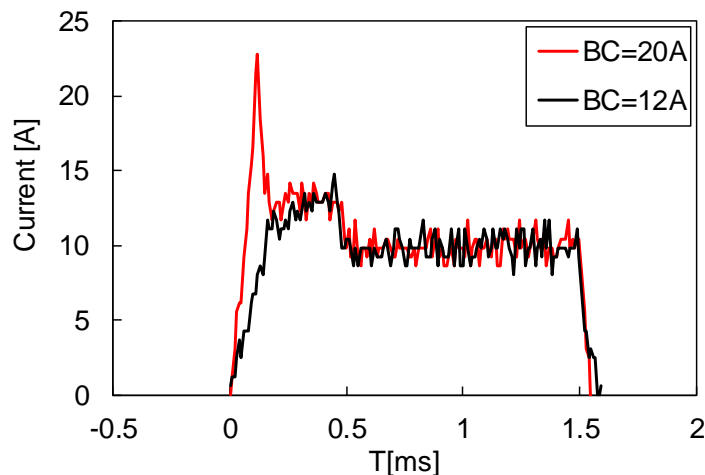


Figure 4. Injector drive current waveform

Results and discussion

Figure 5(a) shows the time variation of arithmetic mean velocity of droplets in the case of BC = 20 A. The time window of 0.05 ms. The horizontal axis shows the elapsed time after the start signal of injection. The measurement position were $x = 0, 0.4, 0.8, 1.2$ and 1.6 mm. In the case of $x = 0.4$ mm, the velocity of droplets increased between the time when the spray tip passed at the measurement position and $T = 1.0$ ms, and the change of velocity was small between $T = 1.0$ and 1.9 ms. The velocity of droplets decreased after $T = 1.9$ ms. The velocity of droplets changed because the flow rate of fuel changed with the close and open of needle valve. In the cases of $x = 0.8, 1.2$ and 1.6 mm, the change of velocity was small between the time when the spray tip passed at the measurement position and $T = 1.9$ ms.

Figure 5(b) shows the time variation of arithmetic mean size of droplets. The size of droplets decreased between $T = 0.6$ and 0.7 ms in each measurement position. Droplet breakup was seemingly enhanced because of the increase of turbulence inside the nozzle. In the case of $x = 0.4$ mm, the size of droplets increased between $T = 0.7$ and 1.0 ms, and the change of size was small between $T = 1.0$ and 1.9 ms, and the size of droplets decreased after $T = 1.9$ ms. In the cases of $x = 0.8, 1.2$ and 1.6 mm, the change of size was small between the time when the spray tip passed at the measurement position and $T = 1.9$ ms.

Figure 6(a) show the time variations of velocity at $x = 0$ mm under the conditions of $BC = 12$ and 20 A. The plots of $BC = 20$ A was already shown in Figure 5(a). The velocity of droplets increased to about 180 m/s in a period from $T = 0.55$ to 0.8 ms in the case of $BC = 20$ A just after the start of injection. On the other hand, the velocity of droplets increased to 170 m/s in a period from $T = 0.85$ to 1.15 ms in the case of $BC = 12$ A. These periods are defined as the early stage for two conditions of BC respectively. The rate of increase in the case of $BC = 12$ A was smaller than that in the case of $BC = 20$ A. The opening speed of injector needle valve seemingly decreased with the decrease of BC in the early stage. The temporal changes of velocity were small in the subsequent period until $T = 1.9$ ms in both cases of BC . These periods are defined as the middle stage. The injection duration in the case of $BC = 12$ A was shorter than that in the case of $BC = 20$ A, and the effect of BC on the velocity of droplets were observed until the end of the middle stage. The velocity after the middle stage in the case of $BC = 12$ A was nearly the same as that in the case of $BC = 20$ A. The start of injection is considered to be delayed with the decrease in BC .

Figure 6(b) show the time variations of size at $x = 0$ mm. The size of droplets similarly decreased once in different time phases and increased in the early stage in both cases of BC . The size difference between 2 cases decreased with the time in the middle stage, and the sizes decreased in almost the same route after $T = 1.9$ ms.

Figure 7(a) show the spatial distributions of velocity in the case of early stage. The horizontal axis shows the distance from the spray center. The velocity of droplets at the spray center was higher than the one at the spray periphery in both cases of BC . The velocity of droplets in the case of $BC = 12$ A was nearly the same as the one of $BC = 20$ A in each measurement positions.

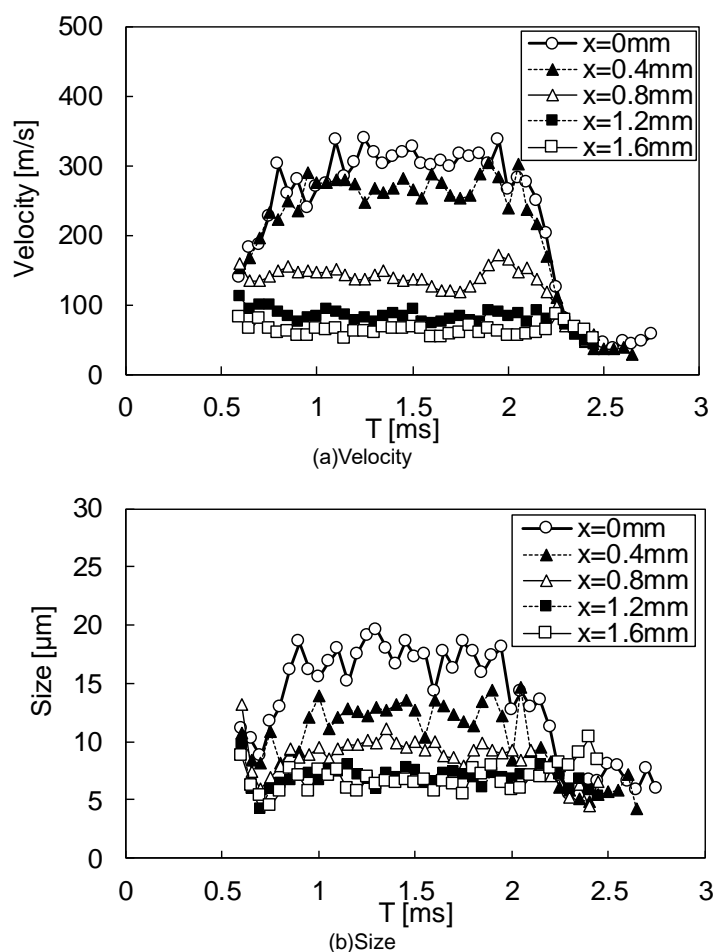


Figure 5. Time variation of velocity and size; $BC = 20$ A

Figure 7(b) show the spatial distributions of size in the case of early stage. The size of droplets at the spray center was larger than the one at the spray periphery in each BC. The size of droplets in the case of BC = 12 A was smaller than the one in the case of BC = 20 A at each measurement position. The decrease in the opening speed of needle valve is considered to extend the period of the seat contraction which leads to the turbulence of fuel flow inside the nozzle. The results demonstrate that the enhancement of droplet breakup caused by the turbulent flow appears over almost whole section of the spray.

Figure 8(a) and (b) show the spatial distributions of the velocity and the size in the case of middle stage. The velocity and size of droplets at the spray center were higher and larger than those at the spray periphery in each BC. This indicates that the effect of BC does not remain in the spray in the period of middle stage.

Conclusions

A laser 2-focus velocimeter (L2F) was applied for the measurement of diesel fuel sprays injected from a 6-hole solenoid injector. The boost currents were set at 12 and 20 A. The measurement was conducted at 10 mm downstream from the nozzle exit under a rail pressure of 60 MPa. Results were as follows.

- (1) The rate of increase in the droplet velocity was decreased with the decrease in the rate of increase of boost current in the period of early stage of injection.
- (2) The change in the increase rate of droplet velocity with the boost current indicates that the opening speed of the injector needle valve decreased with the decrease of boost current in the period of early stage of injection.
- (3) The injection duration in the case of lower boost current was shorter than in the case of higher boost current. The size of droplets similarly decreases once in different time phase and increased in the early stage in 2 cases. The size difference between 2 cases decreases with time in the middle stage of injection.
- (4) The droplet size in the case of lower boost current was smaller than higher boost current over almost whole section of the spray in the period of early stage of injection.

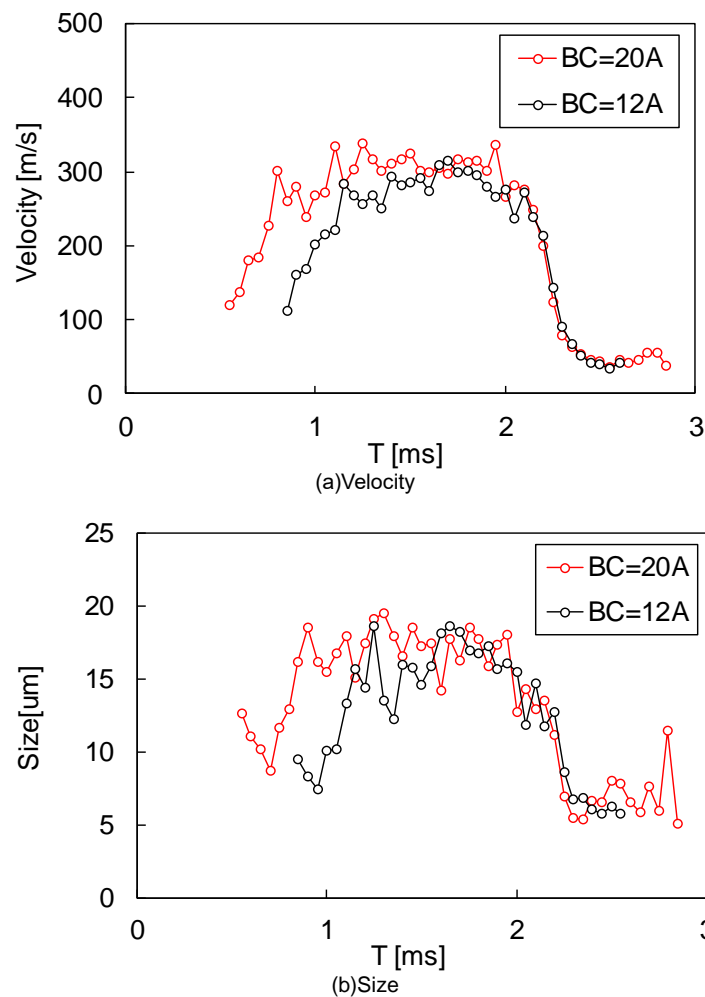


Figure 6. Time variation of velocity and size; $x = 0$ mm

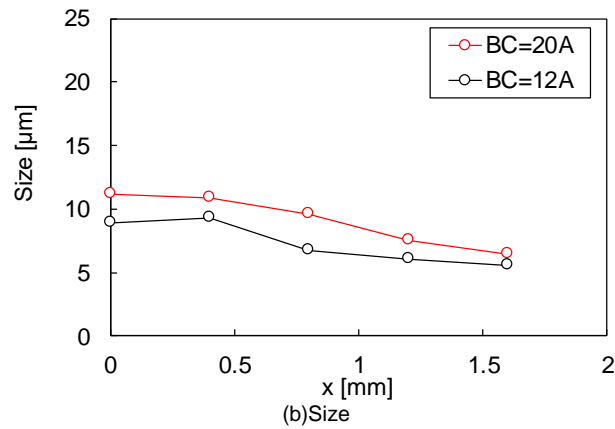
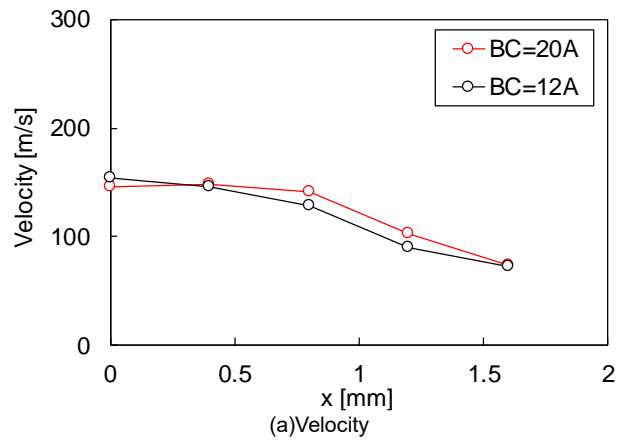


Figure 7. Spatial distributions of velocity and size; Early stage

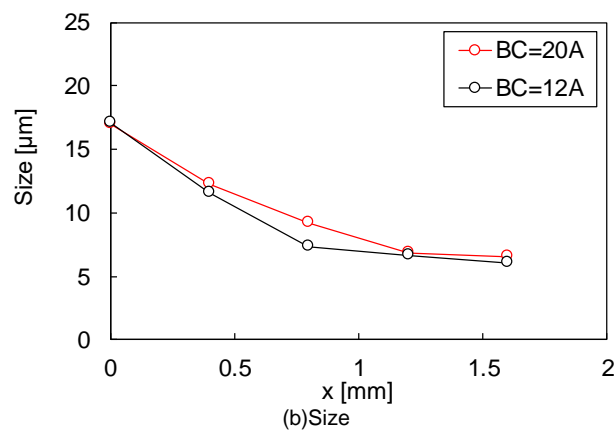
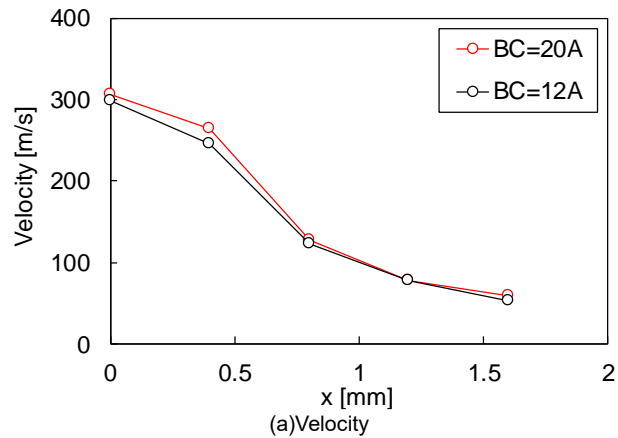


Figure 8. Spatial distributions of velocity and size; Middle stage

References

- [1] JP. Beierer, K. Huhtala M. Vilenius, “Experimental Study of the Hydraulic Circuit of a Commercial Common Rail Diesel Fuel Injection System”, SAE Paper, No.2007-01-0487, (2007), pp.131-142
- [2] J. Lee, K. Min, K. Kang, C. Bae, “Hydraulic Simulation and Experimental Analysis of Needle Response and Controlled Injection Rate Shape Characteristics in a Piezo-driven Diesel Injector”, SAE Paper, No.2006-01-1119, (2006), pp.99-107
- [3] K. Tanabe, S. Kohketsu, S. Nakayama, “Effect of Fuel Injection Rate Control on Reduction of Emissions and Fuel Consumption in a Heavy Duty DI Diesel Engine”, SAE Paper, No.2005-01-0907, (2005), pp 1-11
- [4] G. Dober, S.Tullis, G. Greeves, N. Milovanovic, M. Hardy, S. Zuelch, “The Impact of Injection Strategies on Emissions Reduction and Power Output of Future Diesel Engines”, SAE Paper, No.2008-01-0941, (2008), pp.183-191
- [5] Hayato, Y., Takashi, S., Hiroshi, M., Makoto, M., Koji, K.: Research of the DI Diesel Spray Characteristics at High Temperature and High Pressure Ambient, SAE Paper No. 2007-01-0665 (2007), 169-181
- [6] Payri. R., Tormos. B., Salvador. F.J., Araneo. L., “Spray droplet velocity characterization for convergent nozzles with three different diameters”, Fuel, vol.87, No.15-16(2008), pp. 3176-3182
- [7] Lacoste, J., Crua, C., Heikal, M., Kennaird, D., Gold, M., “PDA Characterisation of Dense Diesel Sprays Using a Common-Rail Injection System”, SAE Paper ,No.2003-01-3085 (2003), pp. 2074-2085
- [8] Takeda, T., Okumura, N., Senda, J., “Study on Droplet Measurement of Unsteady Diesel Spray Using Phase Doppler Anemometry (PDA)”, Proc. ICLASS-2006, (2006), pp. 1-5
- [9] Hung C.C., Martin J.K., Koo J.Y., “Injection Pressure Effects Upon Droplet Behavior in Transient Diesel Sprays”, SAE Paper, No.970053 (1997), pp. 168-181