5. Combustion of liquid fuels

5.1 Atomization of fuel

Liquid fuels such as gasoline, diesel, fuel oil light, fuel oil heavy or kerosene have to be atomized and well mixed with the combustion air before burned. Therefore nozzles are used. Nozzles are divided into two groups: Pressure atomizers and twin-fluid atomizers.

5.1.1 Pressure atomizers

Pressure atomizers are divided into turbulence nozzles and liquid sheet nozzles. At both types of nozzles the energy from the liquid pressure is converted into kinetic energy and a small part of it into forming new surface. To increase the flow rate at a pressure atomizer, the liquid pressure has to be increased. This influences the drop properties of the spray generated.

Turbulence nozzles

Turbulence nozzles are used for fuel injection at diesel engines. The turbulence is generated by the high fuel velocity. The fuel jet leaving the nozzle breaks up into small drops very soon in a short distance after the nozzle outlet. The smaller the nozzle outlet is, the smaller the generated drops are. Thereby has also taken into account that the flow rate at a constant fuel pressure decreases with smaller outlet diameter. Usual fuel pressures are above 1400 bar. The spray pattern of such a nozzle is a full cone.

In 1974 Hiroyasu and Katoda found the equation

\[ d_{32} = 2330 \cdot \rho_L^{0.121} \cdot V_B^{0.131} \cdot \frac{\Delta p_B}{\rho_B}^{0.135} \] (5-1)

for calculating the Sauter-Mean-Diameter for diesel injection nozzles. Thereby \( \rho_a \) is the air density, \( V_f \) the fuel volumetric flow and \( \Delta p_f \) the pressure difference at the nozzle. The fuel volumetric flow can be replaced by the equation

\[ V_B = u \cdot A = \frac{2 \cdot \Delta p_B}{\rho_B} \cdot \frac{\pi}{4} \cdot D^2 \] (5-2)

Thereby \( \rho_f \) is the fuel density and \( D \) the nozzle outlet diameter. The following equation achieved

\[ d_{32} = 2362 \cdot \frac{\rho_L^{0.121}}{\rho_B^{0.655}} \cdot \frac{D^{0.262}}{\Delta p_B^{0.0695}} \] (5-3)

The variables has to be used in SI-units. The Sauter-Mean-Diameter is the diameter of a drop whose ratio of volume to surface area is the same as that of the entire spray.

Liquid sheet nozzles

Liquid sheet nozzles are used in gasoline injection and for the atomization of fuel oil light in household burners. Thereby the pressure operation range is between 10 bar and 200 bar. Liquid sheet nozzles generate a hollow cone spray pattern. The construction of this type of nozzles is like this, that a liquid sheet is formed. This sheet breaks up into drops.
With increasing fuel flux the regimes of border contraction, aerodynamic wave break up and turbulent break up are passed through. At border contraction the sheet is limited by a border bulk. At this border bulk the spreading speed is the same as the contraction speed. The border bulk breaks up into large drops. With increasing fuel flux slight turbulent sheets begin oscillating by the influence of aerodynamic forces. The amplitude of the oscillation rapidly increases downwards the fuel sheet and break up is started. Liquid filaments are formed. As shown in Fig. 5-1, they break up into small drops. This process is called aerodynamic wave break up. At further increase of fuel flux the break up regime is dominated by fluid turbulence. The fuel sheets disintegrate like any turbulent jet after a short distance behind the nozzle outlet. Examples for such type of nozzles are shown in Fig. 5-2. Thereby \( M_f \) is the mass flux of fuel.

In fuel atomization, swirl atomizers are often used. At this type of nozzles the fuel sheet is formed by a fuel twist generated inside the nozzle (Fig. 5-2b). A decrease of nozzle outlet diameter leads to a finer spray but also to a reduction of fuel flux. By axial move of the inner cone the outlet area can be changed at the nozzle shown in Fig. 5-2a. At fuel oil light household burners there is a limiting minimum diameter for the nozzles outlet to prevent a blocking of the nozzle outlet by particle pollution inside the fuel. To achieve a fine spray a minimum fuel pressure has to be kept. Therefore a lower limit of burner power of around 15 kW exists. A smaller viscosity of the fuel promotes the disintegration of the fuel and the formation of smaller drops. Due to this fuel oil light is preheated before atomized. Fuel oil heavy has to be preheated before atomization.

Jasuja found in 1979 the equation

\[
\frac{d_{32}}{D} = 2.25 \cdot \sigma_f^{0.25} \cdot \frac{\mu_f^{0.25} \cdot M_f^{0.25}}{\rho_f^{0.5}} \cdot \frac{\Delta \rho_f^{0.5} \cdot \rho_L^{-0.25}}{\mu_f^{0.5} \cdot \rho_L^{0.25}}, \tag{5-4}
\]

for calculation of Sauter-Mean-Diameter. Thereby \( \sigma_f \) is the fuel surface tension, \( \mu_f \) the fuel viscosity and \( M_f \) the fuel mass flux. The variables are used in SI-units.

### 5.1.2 Twin-fluid atomizers

At twin fluid atomizers the energy from the atomization gas (dynamic pressure, relative velocity) is used to disintegrate the bulk liquid. Fig. 5-3 shows a prefilming nozzle. The mass flow of atomization gas is \( M_g \). At this type of nozzle a wall film of fuel is formed inside the nozzle. This film breaks up into drops at the lower edge by the influence of the air flow. The type of nozzle shown in Fig. 5-3 is used for kerosene atomization in jet turbines. Lefebvre found 1984 the equation

\[
\frac{d_{32}}{D} = 0.48 \left( \frac{\sigma_f}{\rho_f \cdot u_R \cdot D} \right)^{0.4} \left( 1 + \frac{M_g}{M_L} \right)^{0.4} + 0.15 \left( \frac{\mu_f^2}{\sigma_f \cdot \rho_f \cdot D} \right)^{0.5} \left( 1 + \frac{M_g}{M_L} \right), \tag{5-5}
\]

for calculating the Sauter-Mean-Diameter.

Fig. 5-4 shows the so called external mixing twin fluid atomizers. At this type of nozzles the atomization gas is mixed external with the liquid. Fig. 5-5 shows an internal mixing twin fluid atomizer with a internal mixing of gas and liquid.

Fig 5-6 shows a nozzle for high power applications. Two different air flows are used for atomization. The twisting film air presses the fuel oil from the lance onto the inner cone. The
fuel oil discharges as a film at the surface of the cone. The atomization gas flow through the slit between the inner and the outer cone. Twin-fluid atomizers have a larger outlet area than pressure atomizers. They are more firm for plugging. For fuel oil heavy and high power burners twin-fluid atomizers are favored. For fuel oil heavy water steam is used as atomization gas.

![Aerodynamic ware break up](image1)

**Fig. 5-1:** Aerodynamic ware break up

![Liquid sheet nozzles](image2)

**Fig 5-2:** Liquid sheet nozzles

![Prefilming nozzle](image3)

**Fig. 5-3:** Prefilming nozzle
Fig. 5-4: External mixing twin fluid atomizers

Fig. 5-5: Internal mixing twin fluid atomizers

Fig. 5-6: Example of twin fluid nozzle for high power
Fig. 5-7:

Fig. 5-8: