Secondary Pneumatic Atomization at Sieves for high Liquid Flow Rates at low Gas Pressures

P. Walzel*, S. Groom and F. Landwehr

University of Dortmund
Department of Chemical Process Engineering
Chair of Mechanical Process Engineering
*p.walzel@ct.uni-dortmund.de

Abstract

Pneumatic nebulizers of different designs are commonly used to generate fine sprays with mean droplet diameters of $D < 50\ \mu m$. For comparatively large liquid flow rates of $\dot{M}_l > 50\ kg/h$ nebulizers with external mixing as well as prefilming nozzles are applied. In order to achieve the desired droplet size range of $D < 50\ \mu m$ gas pressures of $\Delta p_g = 0.5 \cdot 10^5$ Pa are usually necessary. Nozzles with internal mixing require even higher gas pressures of approx. $\Delta p_g = 1 \cdot 10^5$ Pa for suitable operations [1]. Larger liquid flow rates $\dot{M}_l$ can be sprayed with larger nozzle diameters d. As a consequence at constant liquid to gas mass flow ratio $\mu = \dot{M}_l / \dot{M}_g$ and constant gas pressure Δp_g the mean droplet size however also increases [2]. A finer spray from larger liquid mass flow rates then can be formed only by increasing the gas pressure Δp_g. This option leads to a further reduction of the commonly moderate efficiency of the above mentioned pneumatic nebulizers.

In context to first investigations it should be clarified whether a sufficient atomization of large liquid quantities can take place also with low gas pressures. Therefore a comparatively coarse pre-atomization is applied in a first step. Afterwards the droplets are accelerated by a gas flow towards a sieve, where secondary disintegration of the droplets occurs. At sieves with relatively large areas it is easier to maintain the necessary distances between the droplets otherwise only possible by the large spray angle [3]. Atomization procedures are more effective, when the primary drops are already small [4]. At nozzles with internal mixing, running at liquid to air mass ratio of $\mu \approx 1$ and $\dot{V}_g / \dot{V}_l \approx 500$ an foam like flow is hardly probable. Rather a flow regime with a continuous gas phase and a disperse liquid phase, i.e. as droplets exists. Such flow conditions can deliberately best be realized by a pre-atomization with a pressure atomizer in a very defined manner.

1. Disintegration of droplets on orifices and nozzles

The disintegration of primary droplets in nozzles and orifices at moderate gas velocities was examined in detail e.g. in [5, 6]. Within a range of Gas-Weber-number $We_g = w_g^2 \cdot D_0 \cdot \rho_g / \sigma$ $10 < We_g < 100$ droplets of low viscous liquid disintegrate into secondary droplets with dimensions of $D_0/20 < D < D_0/10$, when the droplets pass an orifice together with a gas. The process of disintegration occurs at low We_g due to bag breakup, at higher Gas- Weber-number by stamen bag breakup. The fragmentation process to some degree shows a stochastic behaviour. Increasing the Gas-Weber-number $We_g > 30$ does not decrease the droplet size considerably. Thus, monosized droplets with e.g. $D \approx 100$ µm could first be generated with capillaries of $d \approx 50$ µm by the Rayleigh-mechanism. Afterwards the droplets could be disintegrated into secondary droplets of approx. $10\ \mu m < D < 20\ \mu m$ at orifices with diameters of e.g. $D \approx 0.5$ mm. At a Gas-Weber-number of $We_g = 15$ and a liquid to gas mass ratio of $\mu = 0.3$ a comparatively high efficiency of $e = 12\,\mu\,\sigma/(D_{32}\ w_g^2\ \rho_l) \approx 1 \cdot 10^{-3}$ seems to be possible for this kind of pneumatic nebulizers. For efficiencies of atomizers see also [4]. This method is applicable, however comparatively complex in principle, since each capillary must be aligned to the centers of its corresponding orifice hole.

2. Secondary atomization on sieves

A more pragmatic way to this method applies the atomization of the liquid into droplets by a common pressure nozzle. The comparatively large primary droplets together with the gas pass a sieve or a perforated plate. In contrary to nozzles with internal mixture a favourable jet divergence and a smaller spray density originate not only after the nozzle, but already within the mixing zone of gas and liquid. A part of the spray directly strikes the mesh wires of the sieve, respectively the webs of the plate. The disintegration of these droplets occurs by the effect of impact [7]. Another part of the spray is detached from the sieve surface, respectively from the plate surface by the gas stream. A further part of droplets may disintegrate by the bag breakup mechanism. In total a complex process results, whose total effect on the secondary spray was to be examined by means of different sieves, pre-atomization conditions and gas pressures.

3. Experimental setup

Fig. 1 represents the experimental setup. The orifice as well as the sieves were mounted at the end of a tube with an inner diameter of $d_T = 120$mm. The gas was supplied to the tube by a fan. The shared-edged orifice acting as a holder for the sieves inserts had a diameter of $d_B = 50$ mm. Pressure nozzles were mounted inside the tube in order to pre-atomize the liquid, as shown in Fig. 1b. The distance a_{ON} between the nozzle and the sieve, the perforated plate resp., is given by the spray angle and by the diameter of the orifice. An optimum distance a_{ON} is characterised by an entire primary spray coverage of the sieve surface. Too large distances a_{ON} lead to the impact of a part of the primary spray on the orifice edges. The liquid is deposited at this position and then forms comparatively large drops. According to this aspect the pressure nozzle was mounted at a distance $a_{ON} = 45$ mm in front of the sieve surface on the tube axis.

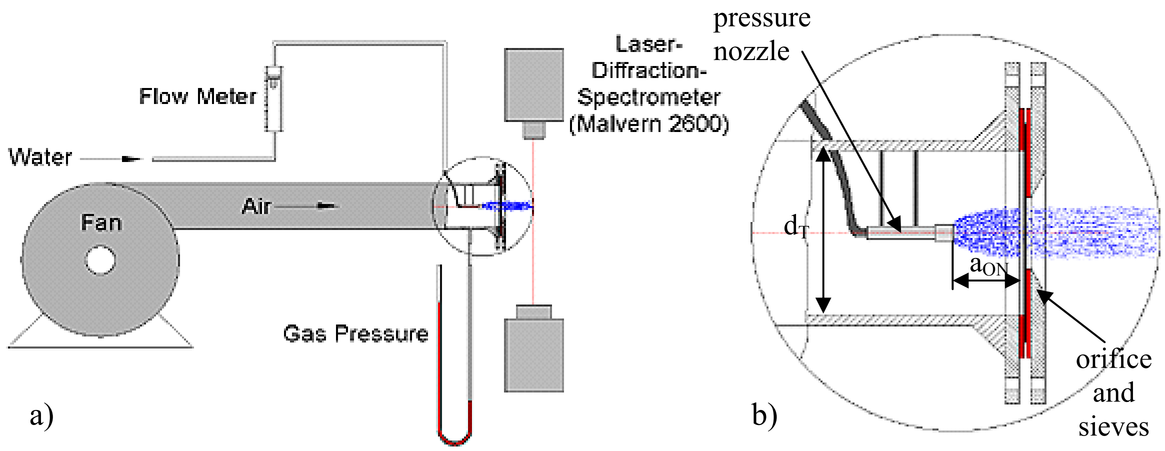


Fig. 1: a) Experimental setup; b) detailed sketch of the orifice geometry and the pressure nozzle (pre-atomization)

For the experiments two different pressure nozzles were used for primary atomization. The commercial Full Cone Nozzle VCN (Schlick, model 553, size 0) with a nozzle diameter of $d_N = 1.2$ mm is shown in Fig. 2a. It was operated at liquid pressures of $\Delta p_l = 2{\cdot}10^5$, $4{\cdot}10^5$ and $6{\cdot}10^5$ Pa. The own built Multi-Jet Nozzle (MJN) is illustrated in Fig. 2b. With a lithographic etched perforated plate (from Stork-Veco, pitch t = 0.8 mm, thickness 0.25 mm, hole diameter $d_h = 100$ µm) laminar micro jets of approximately 200 µm in diameter were generated at the applied liquid flow rates. To provide a divergent spray angle the perforated plate was bent to form a calotte with a radius of $r \approx 20$ mm.

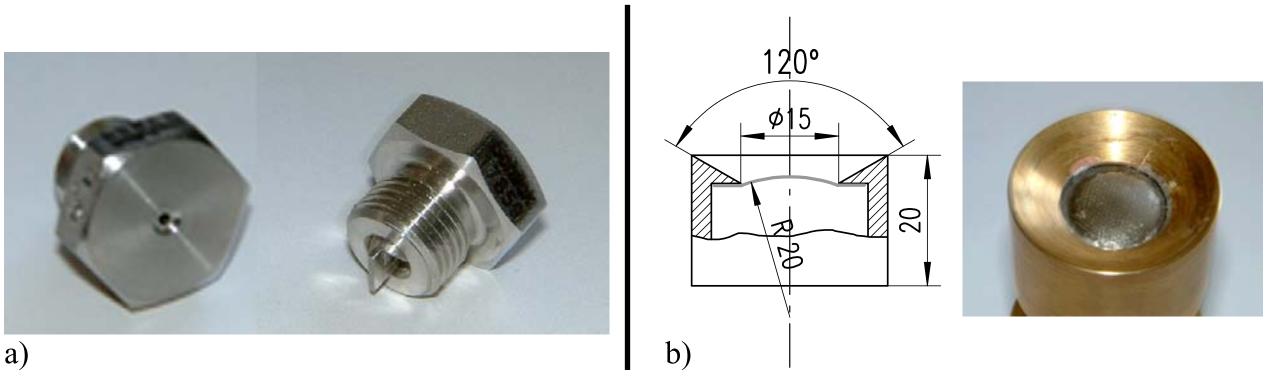


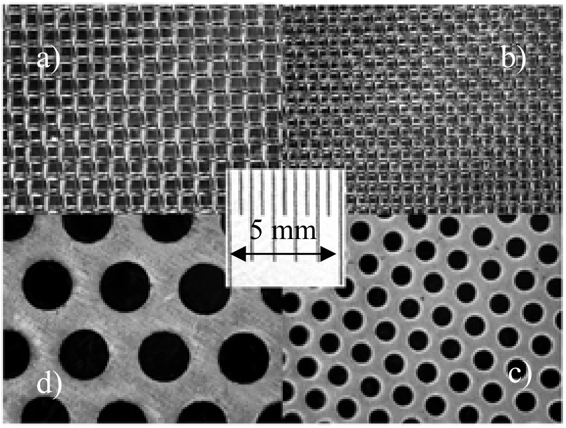
Fig. 2: Applied pressure nozzle for primary atomization a) photos of the commercial Full Cone Nozzle VCN; b) sketch of cross section and photo of the Multi-Jet Nozzle (MJN)

In contrast to the VCN at the Multi-Jet Nozzle the liquid volume flux was controlled instead of the pressure. Tab. 1 shows the operating conditions of the pre-atomizers.

Tab. 1: Operating conditions of the pre-atomizer

Full Cone Nozzle (VCN)	**Multi-Jet Nozzle**
$\Delta p_l = 2{\cdot}10^5$ Pa ÷ 35 l/h	$\dot{V}_l = 20\ l/h$
$\Delta p_l = 4{\cdot}10^5$ Pa ÷ 53 l/h	$\dot{V}_l = 40\ l/h$
$\Delta p_l = 6{\cdot}10^5$ Pa ÷ 64 l/h	$\dot{V}_l = 60\ l/h$

Fig. 3 illustrates the different sieves and perforated plates as tested in our examination.



a) sieve-1, mesh width w = 0,6 mm
free area ratio $\alpha = A_p/A_t = 0,56$

b) sieve-2, mesh width w = 0,35 mm
free area ratio $\alpha = A_p/A_t = 0,49$

c) perforated plate-1, hole diameter d_h = 0,8 mm
free area ratio $\alpha = A_p/A_t = 0,26$

d) perforated plate-2, hole diameter d_h = 2,0 mm
free area ratio $\alpha = A_p/A_t = 0,30$

Fig. 3: Photos of the tested sieves and perforated plates. A_p is the passable area, A_t is the total area of the sieves or plates

The gas discharge coefficients $c_D = \dot{V}_g /(A_t\ \alpha \sqrt{2 \cdot \Delta p_g / \rho_g}) \approx 0{,}9$ measured for all of the sieves and plates as presented in Fig. 3 result in a good agreement with the data well-known from the literature [8]. A substantial change in c_D due to the additional primary drop impact to the sieve surface could not be detected at the applied liquid to gas mass flow ratios of $\mu < 0.4$.

4. Measurements of mean drop size

The measurements of the drop size were conducted by means of a Laser-Diffraction-Spectrometer (Malvern 2600). In Fig. 4 the Sauter mean diameter D_{32} is presented after complete secondary disintegration as a function of the liquid to gas mass flow rate ratio at Δp_g = 7500 Pa for different sieves and perforated plate as shown in Fig. 3.

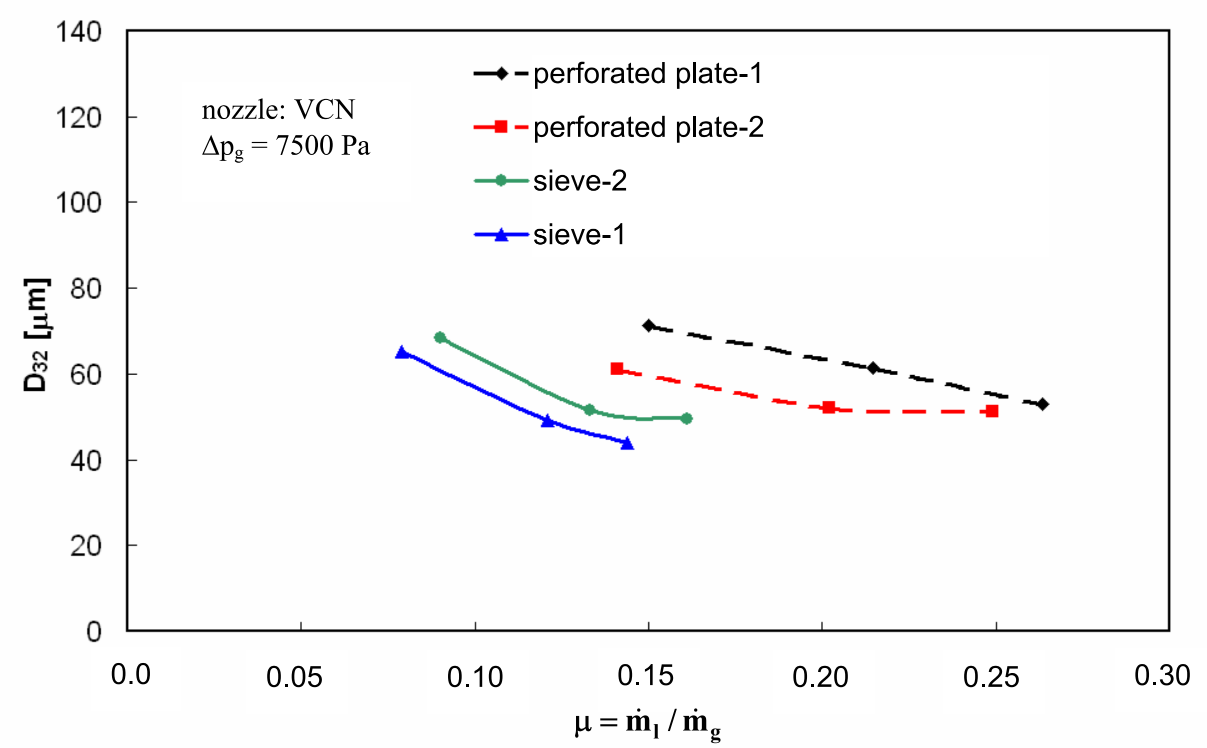


Fig. 4: Sauter mean diameter vs. liquid to gas mass ratio μ at Δp_g = 7500 Pa. Primary atomizer is a Full Cone Nozzle VCN and different sieves and perforated plates were tested

The comparison of the two sieves shows that a larger mesh width w leads to finer secondary drops. A similar relation could be recognized in case of the perforated plates. Thus, a clear dependence between the secondary droplet size and the geometrical dimension of the mesh width w, respectively the hole diameter d_h of the perforated plates, cannot be recognized. However, the ratio of the free area α has a substantial influence on the secondary drop formation. As indicated in Fig. 4 the Sauter mean diameter decreases with an increasing ratio of the free area ratio α. Perforated plates with even larger free area ratios $\alpha \geq 0.4$ may produce smaller secondary droplets compared to the sieves with already relative larger free area ratios of $\alpha = 0.49$ or $\alpha = 0.56$.

Fig. 5 compares the droplet size distributions Q_3 of the primary and the secondary spray at a gas pressure of $\Delta p_g = 9000$ Pa. The FCN forms a primary spray with a Sauter mean diameter of $D_{32} = 212$ µm at liquid pressure of $\Delta p_l = 2 \cdot 10^5$ Pa.

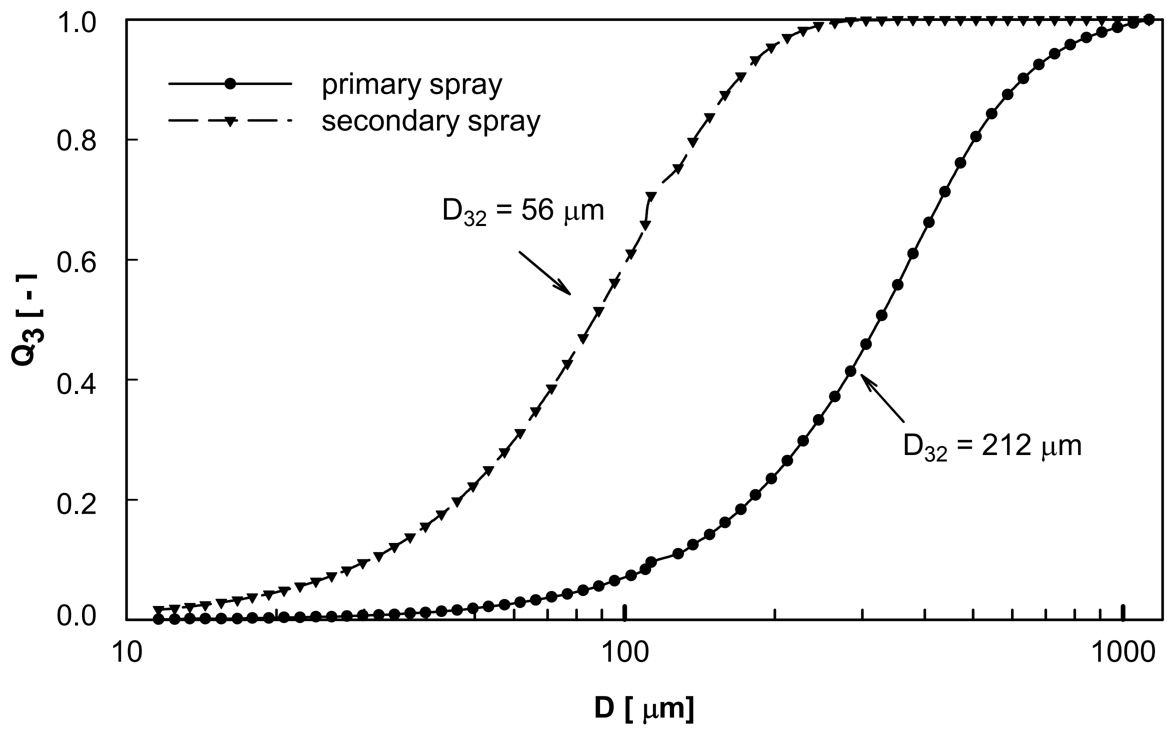


Fig. 5: Drop size distributions Q_3 for the primary and the secondary spray produced by the FCN For the secondary atomization a sieve was used with a mesh width of w = 0,6 mm at gas pressures of Δp_g= 9000 Pa

The primary drop size can be reduced to D_{32}=56 µm by means of a sieve with a mesh size of w = 0.6 mm and a comparatively low gas pressure of $\Delta p_g = 9000$ Pa. This means a reduction of the droplet size to a quarter of primary droplet size.

Fig. 6 is a plot of the secondary drop size depending on the gas pressure when a perforated plate with $d_h = 0.8$ mm is mounted to trigger secondary break-up. The Sauter mean diameter D_{32} is plotted as a function of the liquid volumetric flow density at the sieve $S_l = \dot{V}_l / A_O$. This method of secondary droplet disintegration allows liquid volumetric flow densities up to $S_l = 33$ m^3/(m^2 h). The VCN was used for pre-atomization here. The gas pressure Δp_g was varied from 5000 Pa up to 12000 Pa.

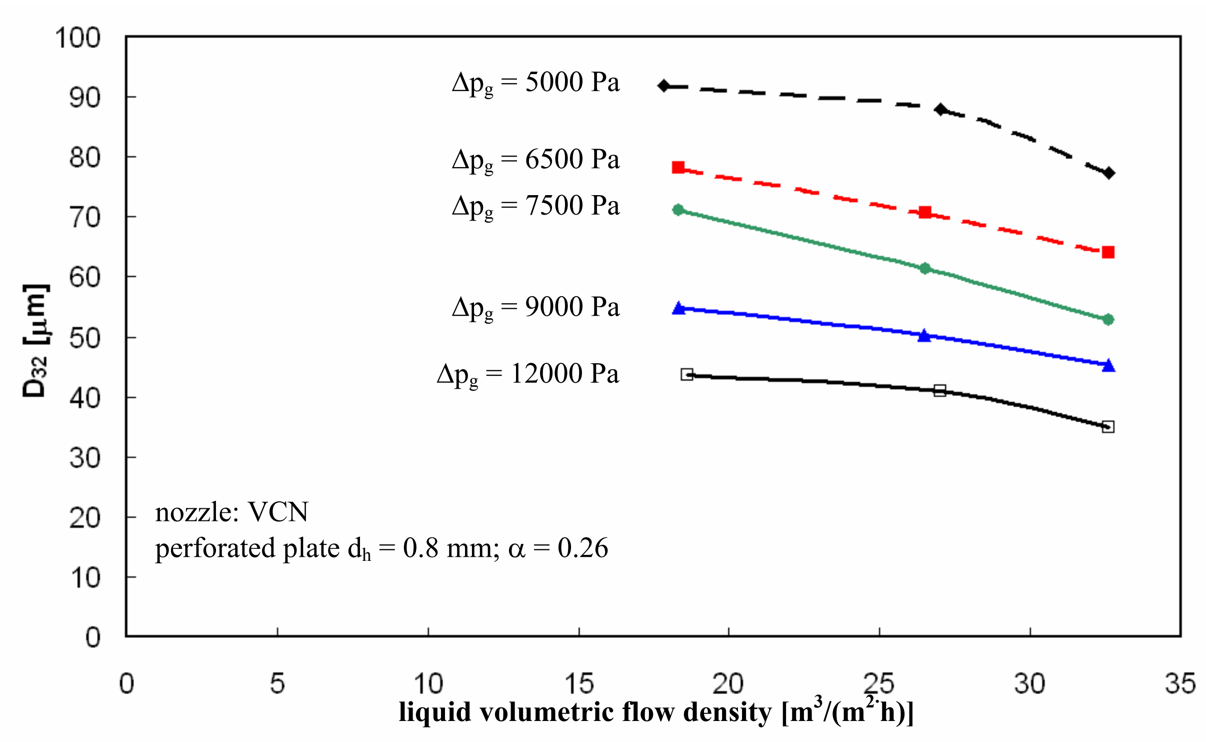


Fig. 6: Sauter diameter D_{32} of the secondary spray depending on the liquid volumetric flow density at the sieve S_l for different gas pressures Δp_g. The perforated plate with d_h = 0.8 mm and the VCN was used

As usual for pneumatic atomizer, a higher gas pressure drop leads to smaller mean droplet sizes D_{32}. In contrast, a decrease of the mean droplet size at increasing liquid to gas mass flow ratios is unusual at constant gas pressures. However, at VCN the increasing liquid flow results in a decreasing primary droplet size. Due to the finer pre-atomization the secondary mean droplet size also follows this trend.

Within the entire field of applied liquid flow rates the Multi-Jet Nozzle produces laminar liquid jets. These always atomize within the Rayleigh-regime to primary drops with a diameter of about 200 µm. The Sauter mean diameter D_{32} of the secondary spray is presented in Fig. 7 depending on the liquid to gas mass flow ratio and for different gas pressures. The perforated plate-1 with d_h = 0.8 mm again was used. In the case of the MJN the Sauter mean diameter D_{32} of the secondary spray increases with increasing liquid to gas mass flow ratio as expected for pneumatic nebulizers. The primary liquid jets disintegrate by the Rayleigh-mechanism within the described operating range as in Tab. 1. As a consequence the primary droplet size is more or less independent of the liquid flow rate when the MJN is applied as a pre-atomizer. Due to the higher liquid to gas mass flow ratio the secondary droplets become larger at equal gas pressures. At relatively low gas pressures of $\Delta p_g = 1.4\cdot10^5$ Pa the drop size can be reduced to 1/5 of the primary drop size.

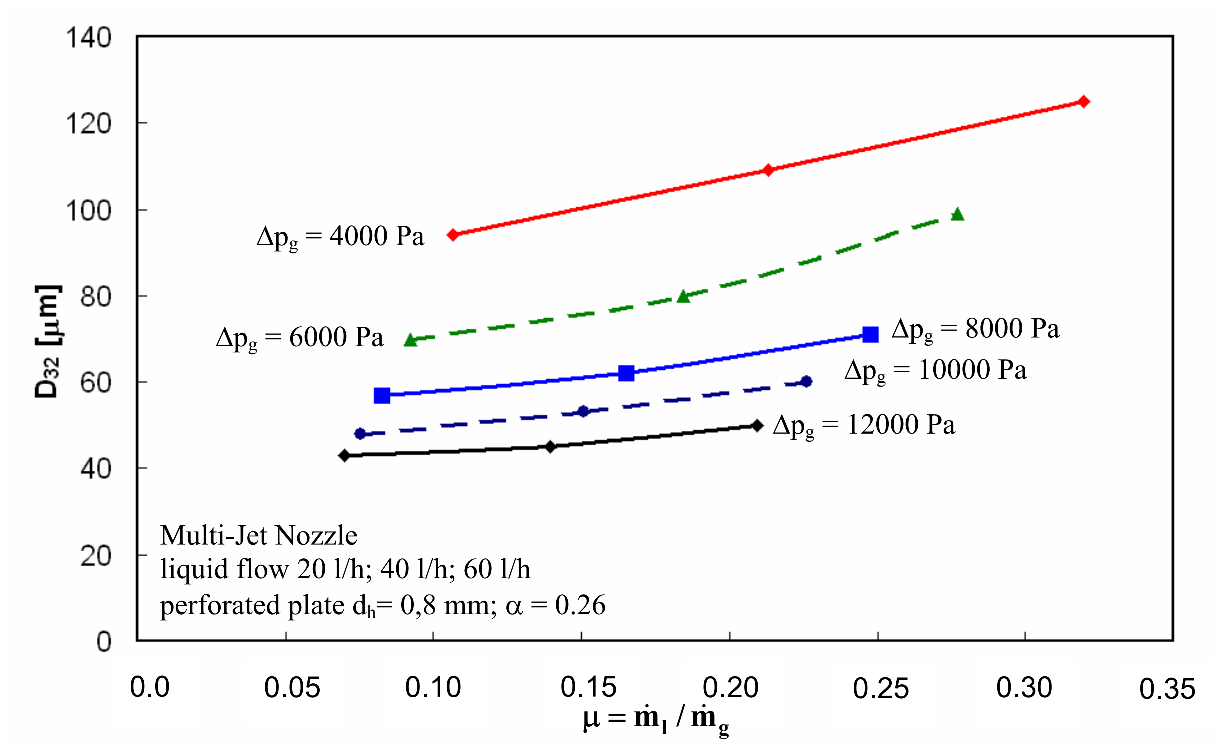


Fig. 7: Sauter mean diameter D_{32} of the secondary spray depending on the liquid to gas mass flow ratio μ for different gas pressures Δp_g: The perforated plate-1 with $d_h = 0.8$ mm and the MJN was assembled

With the method of secondary atomization at sieves and perforated plates efficiencies up to $e = 12\,\mu\,\sigma/(d_{32}\,w_g^2\,\rho_l) \approx 4.8 \cdot 10^{-4}$ were achieved as shown in Fig. 8. This lies within a considerable range for pneumatic atomizer. Highest efficiencies were observed at the sieve-1 with a mesh width w = 0.6 mm and a free area ratio of $\alpha = 0.56$.

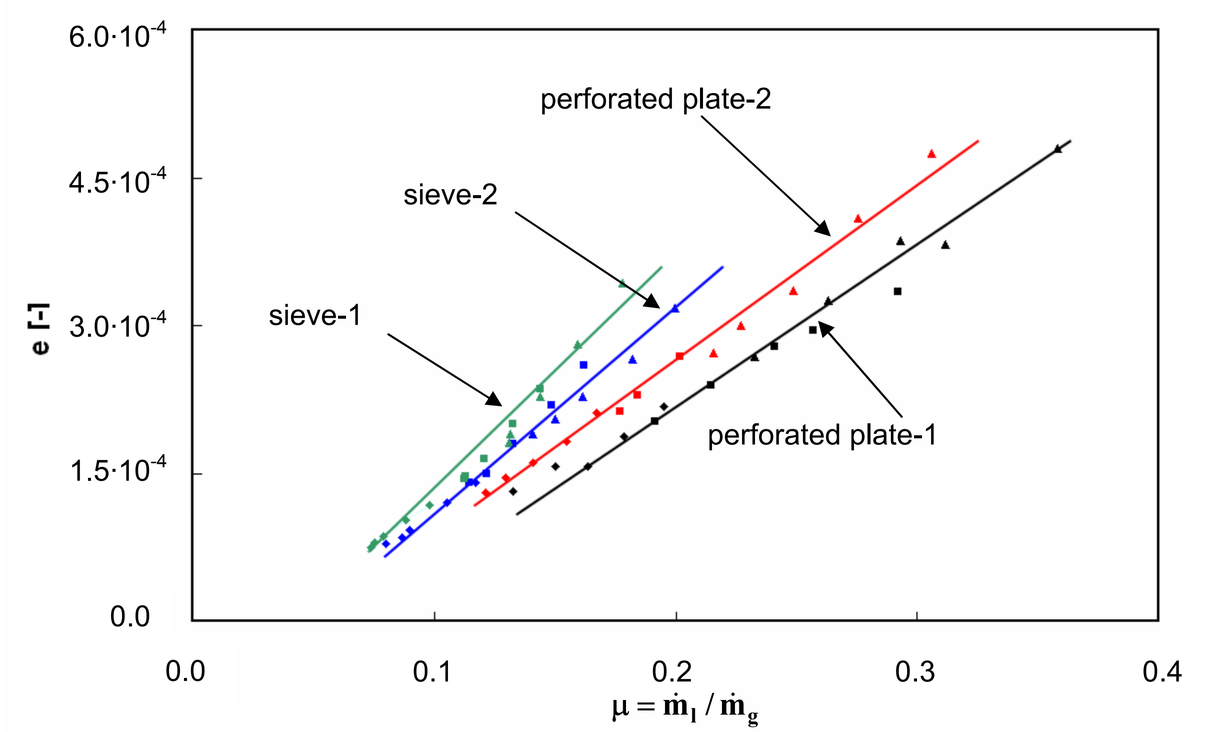


Fig. 8: Efficiencies e of droplet generation by means of different sieves and perforated plates

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