CASE STUDY

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with passion for microfluidics

Characterization of mp6-micropump-driven vibrating meshes

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Controlled nebulization of different liquids

Active fluid transportation

Medical, LiveScience, Automotive

In strongly growing fields of Medical, Lifescience, Automotive, Aerospace and several other industries, the controlled nebulization of different kinds of liquids by advanced products is tremendously increased. In order to keep the needed devices as small as possible not only pipes, valves and connectors for fluid passage have to be miniaturized. Of even equal importance: the active element for fluid transportation.

For that purpose, we investigated Vibrating Meshes of two different well-known suppliers which were driven by our mp6 micropumps. In addition, we performed several reference experiments for fluid delivery to the mesh. The results demonstrate unbeatable advantages, which recommend the mp6 micropump for that task.
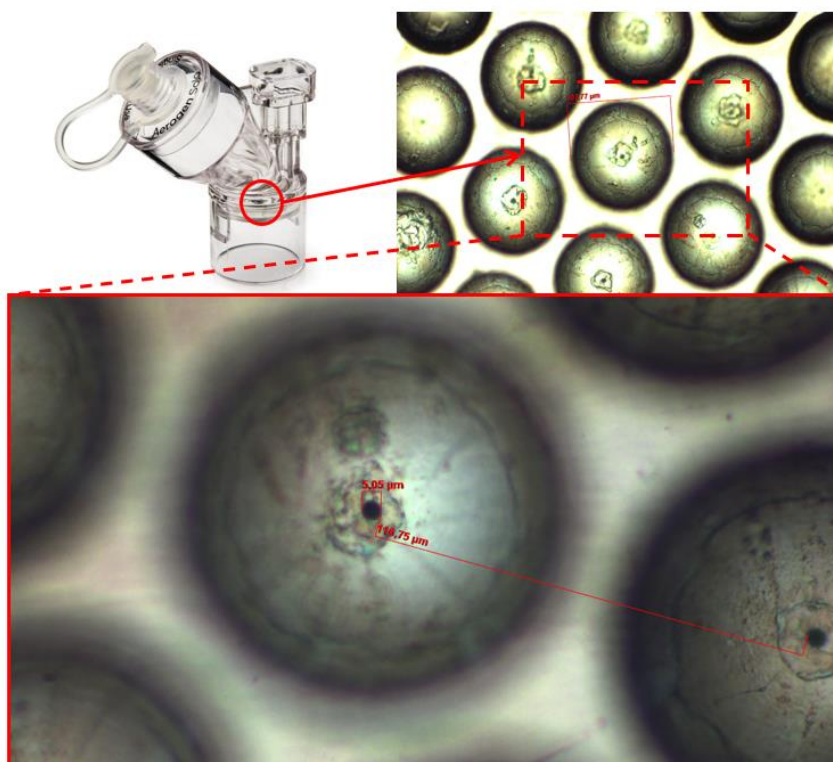

Figure 1:

Product photo of a "Pre-mounted" Aerogen-Mesh (left above); Model "Solo", surface (Topside = Inlet) with 100fold (right above) and 500fold (below) magnification.

The Aerogen Mesh exhibit a pore size of ~5,1 µm for the droplet generation while the complete "Inlet-Funnel" show a diameter of ~ 108 µm. The distance of the pores was determined to be ~ 117 µm; this result represents quite common values for Meshes on the market for numerous applications. Besides the Aerogen-Mesh we implemented 2 different Meshes from Optnics. Figure 2a shows the second kind of Mesh(es), used in this study.
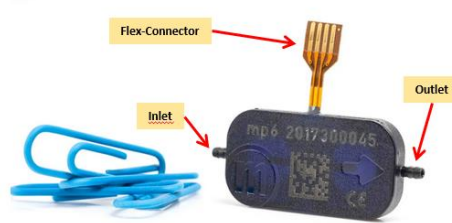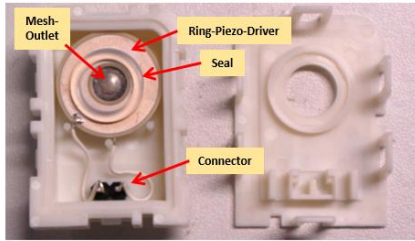
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Figure 2:

left (a), interieur of an Optnics Mesh; right (b), mp6 micropump of Bartels Mikrotechnik (Photo taken in 2017).

Figure 2b introduces our mp6 micropump which acts as an excellent Mesh-Driver. For this study we have designed four different experiments in sum to demonstrate the possibilities of applications as well as the flexibility which can be achieved in combination with the mp6 micropump. The following Figure 3 illustrates Experiments #1 - #3.
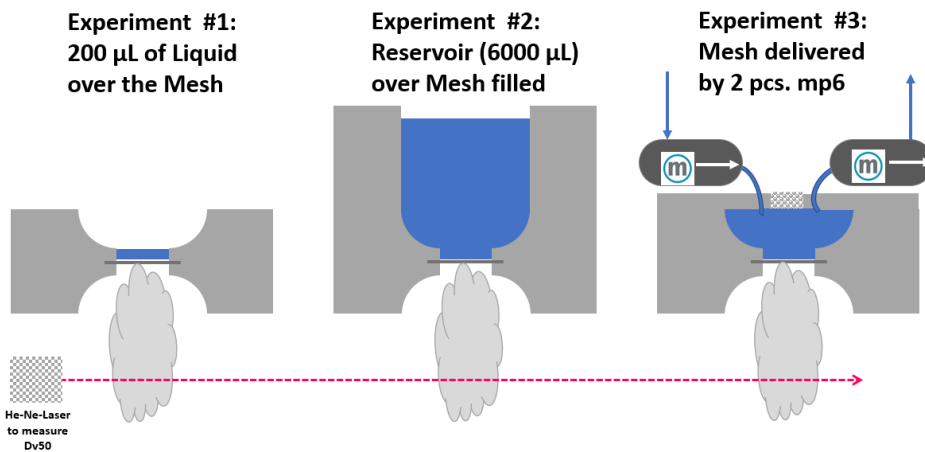

Figure 3:

Experiments #1 - #3 (with gas permeable hydrophobic seal) for nebulization of liquids, performed in Bartels` laboratories.

In all experiments, our Malvern-Spraytec-Analyzer has been used for the determination of the generated particle sizes. This method of particle characterization is based on light scattering; monochromatic light source: He-Ne-Laser (633 nm wavelength). Experiment #1. A small amount of 200 μL Liquid is placed on the Mesh-Inlet. Experiment #2. Much more applicable, the Mesh is equipped with a reservoir of ~6000 μL for liquid which enables a much longer operating time. Experiment #3, advantages in summary. If 2 pcs. of mp6 micropumps are even combined, an extremely extended duration of nebulization can be achieved, because the reservoir can contain a much higher amount of liquid and rather be placed elsewhere in a thinkable "Device"; i.e., right next, above or below – the mp6 pump can deliver "upwards" to the mesh – the place of nebulization; the porous seal prevents a loss of liquid. Furthermore, due to the design of the set-up, the mesh can be orientated in any direction for continuous runs.

Table 1 summarizes the results of these experiments. For that, we have chosen 2 different meshes from Optnics – one size below and one size above the Aerogen-Mesh with respect to its pore diameter (small: ~4,4 μm = Optnics-Mesh #A vs. medium ~5,1 μm Aerogen-Mesh vs. huge: ~7,5 μm Optnics-Mesh #B).

Table 1: Full Data-Set of two different Optnics-Vibrating-Meshes, driven by the original Electronic @ 108 kHz / 35 Vpp (Sine) / 2,5 W.

| | | | Nebulized liquid particles Dv50 [μm]* | | Volume-Flow of nebulized pure Water [μL/min] | | |
| | Pore diameter | Inter Pore | | | 200 μL of Liquid | Reservoir (6000 μl) over | Mesh delivered |
Sample ID	[μm]	distance [μm]	Water	Ethanol	over the Mesh	Mesh filled	by 2 pcs. **mp6****
Mesh #A	4,4 ± 0,3	91 ± 1	5,5 ± 0,6	4,4 ± 0,1	113 ± 13	116 ± 11	206 ± 27
Mesh #B	7,5 ± 0,1	90 ± < 0,5	19,4 ± 0,4	17,2 ± 0,2	1686 ± 142	1766 ± 271	2066 ± 70

* = Experiments performed using the 6000 μL Reservoir.

** = Reservoir equipped with a gas permeable seal; one mp6-Pump for each line, forward and reverse, respectively.

Several aspects of the results have to be highlighted. Nebulization of ethanol, often used as a solvent for medical drugs, led to a bit smaller particle size as compared to water. This effect could be compensated by an increased pore diameter if ~5 µm particles are desired (~4,4 µm → ~6 µm pore diameter). The most interesting point is the measured volume flowrate if the delivery by a reservoir (Experiment #2) is compared with those of a mp6-driven set-up in experiment #3. In the experiments with mesh #A & #B, the mp6 micropumps were adjusted to ~50% of their capacity (~125 Vpp = ~4 mL/min @ 60 Hz). It can be seen that meshes with "common" pore sizes such as Optnics Mesh #A as well as the Aerogen-Mesh can be emphasized to the 2fold nebulization-effectivity. In conclusion, a mp6-driven mesh is delivered by "convection" and not by a simple steady bulk of liquid in a reservoir.

Figure 4 below shows a typical test set-up using the Aerogen-Mesh in combination with 2 pcs. of mp6 during the characterization of the particle size.
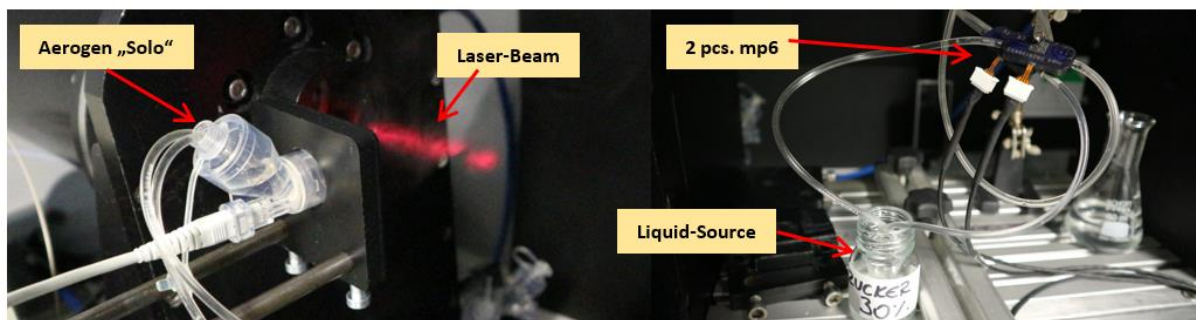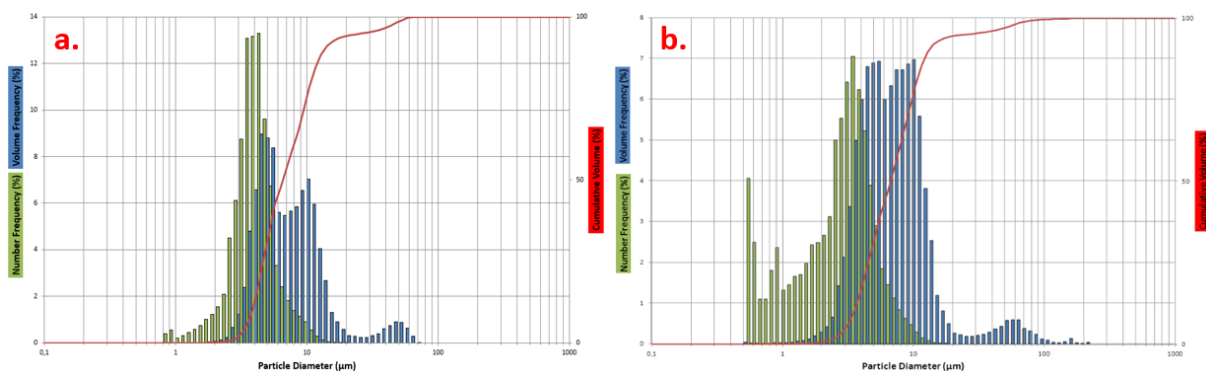

Figure 4:
Experiment #3, Aerogen-Mesh (Reservoir open; equal to flexible), forward & backward-pipes, driver-cable, mp6 micropumps and pressure less liquid source, respectively; components mounted in the actually active Malvern-Spraytec-Analyzer.

Figure 5a-f below presents six randomly selected plots of "Particle-Frequency" & cum. Volume vs. Particle Diameter. The most relevant information is that in any case the change from the "Reservoir-Driven Mesh" to the "mp6-Driven Mesh" (i.e., a → b, c → d and e → f) led **not to a significant** change with respect to the calculated Dv50-Particle-Size. Relevant data in Figure 7 (incl. standard deviation) below clearly supports that finding. A negligible, not relevant change in case of the Size-Distribution can be detected for Mesh #A of Optnics (4,4 µm Pore Diameter) and Aerogen (5,1µm). In order to compensate / modulate this minor effect, we are working on optimization of the mp6-Frequency beyond 60Hz, even downwards or upwards as well as its waveform. In contrast, Mesh #B of Optnics (~7,5 µm Pore-Size) shows nearly no change which clearly indicates that the smaller meshes were not driven in the 100% optimal "Window".
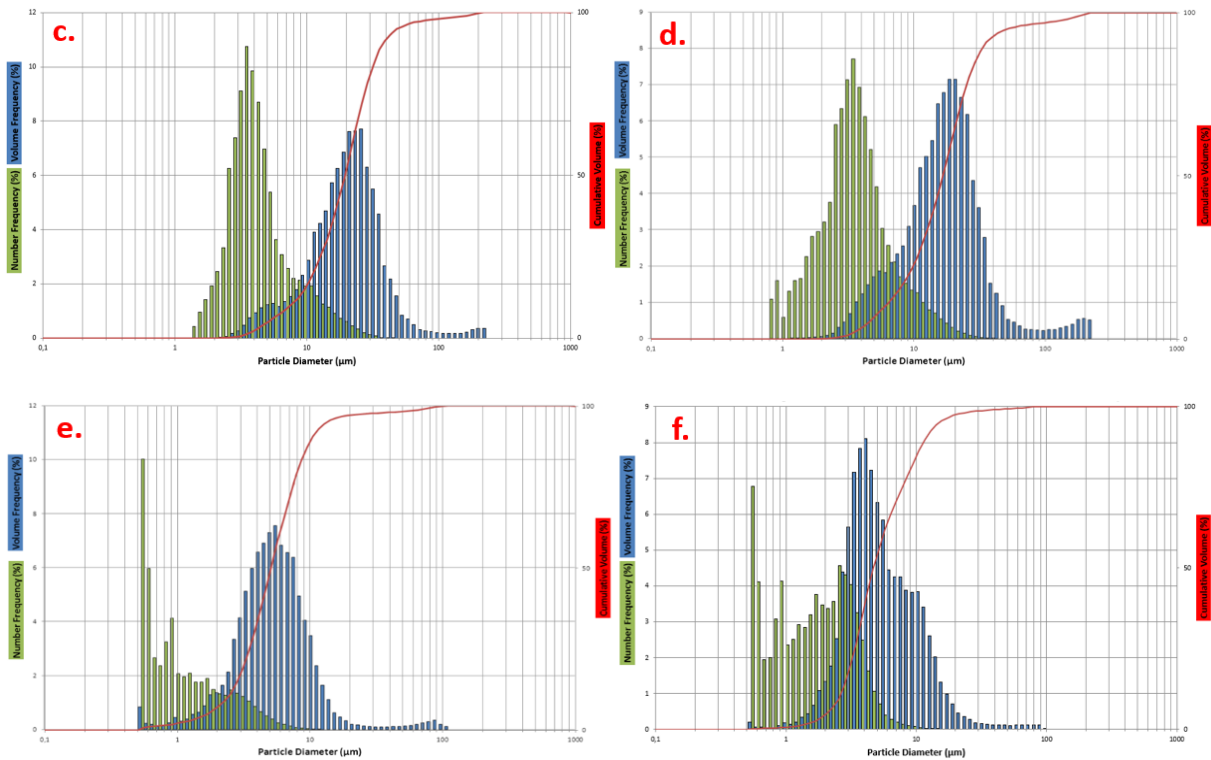
Figure 5a-f:
(in general, from left to right, Reservoir-driven → mp6-driven): a&b above, Mesh #A from Optnics; c&d in the center, Mesh #B from Optnics; e&f below, Mesh from Aerogen.

Finally, in order to vary the manner of spraying, Figure 6 shows Experiment #4. Here, we orientated two reservoir-driven meshes from Aerogen in an angle of 90° to each other. Also in this experiment, the "Sweet-Spot" to interfere with the laser beam of the Malvern-Spraytec-Analyzer was adjusted to be ~5 cm behind the operating mesh, inhere, the chosen collision point of both meshes was the same.

Experiment #4: 2 Mesh dual-nebulization

Figure 6:
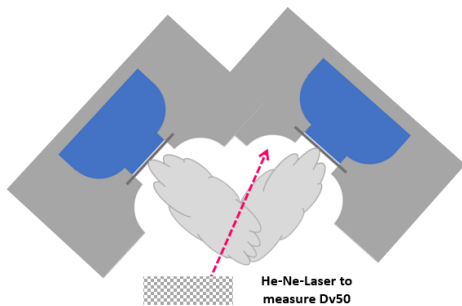
Reservoir-driven "Dual-Mesh-Setup" Experiment #4 using two meshes from Aerogen. "Sweet-Spot" = point of measurement = 5cm.

In all performed experiments, we have detected no significant differences of the measured Dv50-Value for the generated particle size, no matter if ethanol or water was sprayed, single or dual. The desired, inhalable particle size of ~5 µm is maintained, even, as long as the pore size is approx. 5 µm or smaller. Figure 7 summarizes the core results of our study.
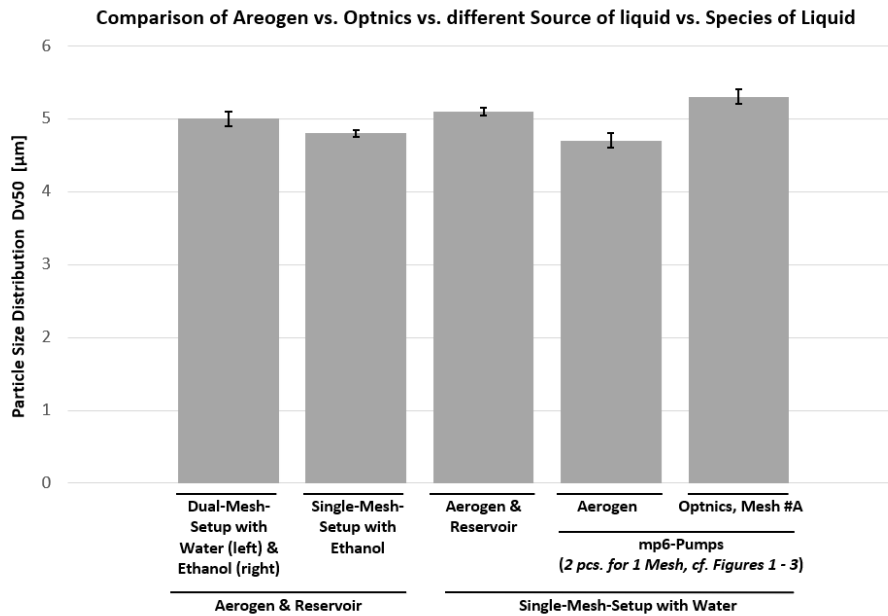
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Comparison of Areogen vs. Optnics vs. different Source of liquid vs. Species of Liquid

By evaluating the data presented in Figure 7, we can conclude that both, critical medical formulations can be sprayed by dual-driven meshes as well as mp6-driven runs will perform equal in order to guarantee the desired Dv50-Value with respect to the particle size. In many cases, medical drugs are not soluble in water, hence, ethanol is the solvent of choice (or mixtures of both).

In the next step of this study, we enlarged the range of application in order to clarify another relevant issue: not every medical formulation deals with the viscosity of water or ethanol (1,0 . . . ν . . . 1,2 cP @ 20°C). For that purpose, we selected two "Model-Compounds", namely, saccharose (table sugar) and glycerin (99%, pure) for increase of the viscosity of aqueous test-solutions. Figure 8 below summarizes the results of the Particle-Size distribution (Dv50-Value) vs. viscosity of the model-Solution of both System-Species; Mesh vs. Collision-Nozzle.

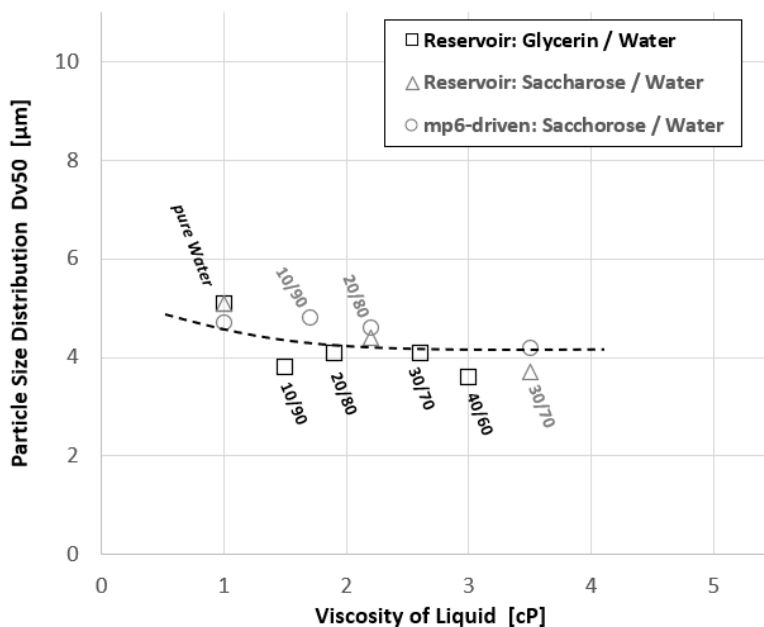**Nebulization of Liquids by Aerogen-Mesh @ varied viscosity**

Figure 9: Particle size distribution (Dv50) vs. viscosity of the nebulized Model-Liquids.

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Surprisingly, if the solutions` viscosity is suggestively increased, the Aerogen-Mesh maintains the Dv50 value. We assume that this result is caused by the mechanism of the particle generation. The Mesh forms the droplets by shaking off the liquid "piece-by-piece" from the ends of the filled outlet-funnels. Another correlating point is that the mesh does not operate any more, if the viscosity is more than ~3,5 cP. In that case, Mesh`s Driving-Force for shaking off the liquid tents to be smaller as compared to the needed force for "pore-dewetting" (5,1 µm Outlets of the Mesh).

Outlook: Ongoing experiments (in progress) have shown that Mesh #B from Optnics (~7,5 µm Pore diameter) shifts the data points of Mesh #A simply upwards, parallel the x-Axis, independently from the viscosity. This indicated a brilliant tool for the controlled particle generation with every desired droplet-diameter.

Components and systems used:

- mp6 micropump by Bartels Mikrotechnik
- mp-Labtronix by Bartels Mikrotechnik
- vibrating mesh "Solo" by Aerogen
- two vibrating meshes by Optnics
- Saint-Gobain Tygon LMT-55
- Malvern Spraytec Analyzer

Acknowledgement:

Our Partner, Aerogen from Galway, Ireland, was instrumental in defining our research path, whereby we were able to develop a great solution for active and accurate atomization of liquids generating a well-defined aerosol. For that, we are extremely grateful and we are looking forward to our close collaboration. In case you are interested in the above-described microfluidic solution for mist generation or if you are interested in getting in touch with either one of us, Aerogen or Bartels Mikrotechnik, please feel free to contact us. You can find the contact details below.

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Bartels Mikrotechnik with passion for microfluidics!

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