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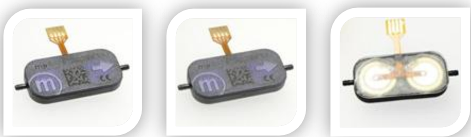
Application Note

Operating Micropumps at Low Flow Rates – Guideline

This document describes the actual steps to select and use a restrictor for any possible fluidic system with one of our micropumps. It is based on the previous application note "Operating Micropumps at Low Flow Rates". For detailed information please refer to that document.

Micropump flow rates and pressure range

Our micropumps are able to deliver the flow rates and pressure levels as shown below. The data is achieved using the controller mp-x at amplitude of 250 Vpp and a frequency of 100 Hz (for water) and 300 Hz (for air).



	mp6	mp6-AIR	mp6-pp
water			
maximum pressure	600 mbar 8.7022 psi		650 mbar 9.4274 psi
maximum flow	7 ml/min		5 ml/min
air			
maximum pressure		100 mbar 1.4503 psi	150 mbar 2.1755 psi
maximum flow		18 ml/min	14 ml/min

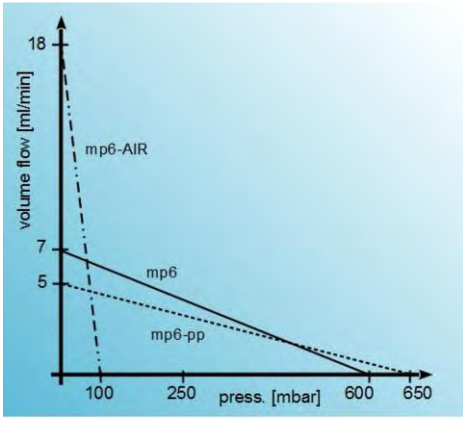


Figure 1 Standard micropump flow rate and pressure range and typically pump curves.

Low flow rates without restrictor

The simplest method to achieve low flow rates is to lower the amplitude. The typical pump curve of volume flow over pressure will then be parallel translated so that the overall performance of the pump is decreased. This effect is shown in Figure 2.

The consequence is that the generated pressure levels are also lowered, which may be unsuitable for the application. Additionally some minor pressure raise along the fluidic line –

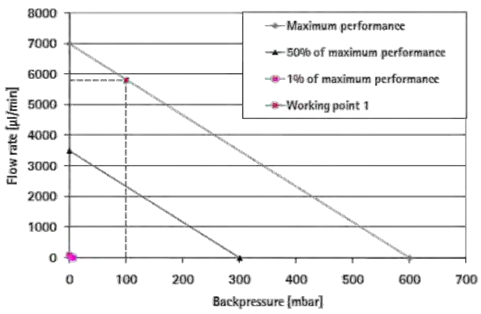


Figure 2 Pump curve of mp6 with different amplitude settings.

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for instance some clogging – can stop the flow completely as the pressure is too low to overcome that. Therefore, this method is a bit instable for low flow rates.

Another possibility is to change the frequency with unchanged amplitude. This will make the pump "inefficient" and flow rate and pressure goes down with it. See Figure 3 for the general performance change with frequency. Note that the peak frequency is also dependent on the viscosity of the liquid.

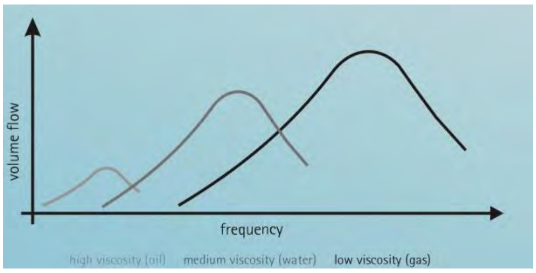


Figure 3 Volume flow of mp6 dependent on frequency.

However, tuning the frequency will result in the same effect as mentioned above:

Without restrictor: Low flow rate = low pressure generation

Low flow rates with restrictor

When a restrictor is applied – preferably connected to the pump exit – the flow rate is reduced by the fluidic resistance. That means with max amplitude and optimal frequency the flow rate is only as high as the restrictor allows. With max amplitude the pressure generation of the pump is the same as without the restrictor. If you change the amplitude in such a system the pump curve will be parallel translated again. Hence, with the right choice of restrictor the desired max flow rate can be achieved and the full pressure generation range is available, see the change of the pump curve in Figure 4.

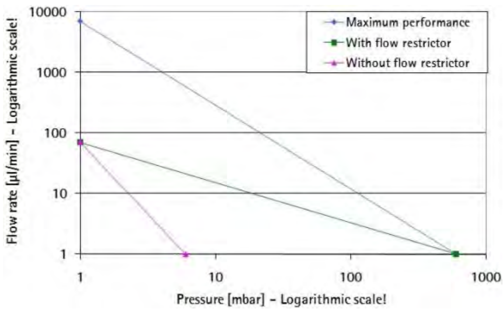


Figure 4 Pump curve changed by restrictor use.

With restrictor: Low flow rate = full pressure generation available

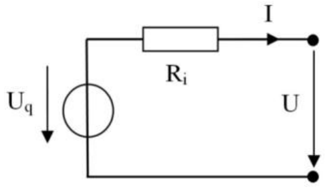
Selecting the right restrictor

There are two possible ways to restrict the flow rate, either with a small diameter tubing (a capillary) or with an orifice. This document concentrates on capillaries as they allow adjusting to desired flow rates by changing the length. Orifices come in preset dimensions – diameter and length - and it may not be possible to find the correct orifice for the specific flow rate.

Calculating the correct restrictor can be done with treating the pump as an electrical circuit, calculating the internal fluidic resistance of the pump, adding the restrictor as a resistor and applying the law of

Hagen-Poiseuille to determine this resistance. The max flow rate is then dependent on the total resistance of this system. All steps of this calculation are shown in Figure 5.

Background: Pump will be treated as a real voltage source (analogue to electrical)

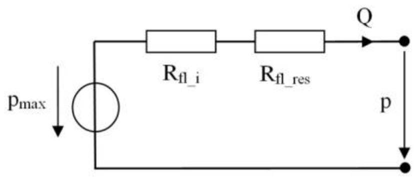


electrical	fluidical	
U = Uq - I * Ri	p = pmax - Q * Rfli	Rfli = internal fluidic resistance of the pump
		pmax = max pressure generation of the pump
Ik = Uq / Ri	Q = pmax / Rfli	Qmax = max flow rate of the pump
=> Ri = Uq / Ik	=> Rfli = pmax / Qmax	

Step 1: Calculate the internal resistance of the pump

Rfli = pmax / Qmax
Rfli = 600 [mbar] / 7 [ml/min] = 5,1429E+11 [Pas/m³] mp6 pump only. Resistance is always the same !!!

Background: Additional restrictor in this system



Qmax = pmax / Rges Rges = total resistance
Rfl_res = resistance of restrictor
Rges = Rfli + Rfl_res

Step 2: Calculate the resistance of the restrictor

calculated via law of Hagen-Poiseuille (Q = π * r^4 * p / 8 * η * L)
R = Q / p
Rfl_res = (8 * η * L) / (π * R^4) with R = D/2
Rfl_res = (128 * η * L) / (π * D^4)

R = radius of opening diameter of restrictor
p = pressure difference
η = dynamic viscosity of liquid
L = length of restrictor opening

Step 3: Calculate the max flow rate based on restrictor values

example: restrictor with D = 100 [µm] and L = 10 [mm]
water, η = 0.001 [Pas]
==> Rfl_res = 4.0744E+12 [Pas /m³]

Qmax = pmax / Rges = pmax / (Rfli + Rfl_res)
Qmax = 600 [mbar] / (5.1429E+11 [Pas / m³] + 4.0744E+12 [Pas / m³])
==> Qmax = 1.3076E-8 [m³/s] = 784.54 [µl/min]

Figure 5 Calculation steps to find the correct restrictor dimensions.

As the fluidic resistance of the restrictor is dependent to the power of 4 (!) of its diameter but only linearly to the length, the diameter is the most significant parameter to choose.
Thus with the internal resistance of the pump, the viscosity of the liquid and the dimensions of the restrictor it is possible to find the resulting max flow rate.

Nevertheless, it has to be noted that this calculation delivers only theoretical values. In reality, the actual restricted flow rate differs a bit from this calculation. The cause is that the law of Hagen-Poiseuille should

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be used for constant laminar flow inside a tube. With the pump and its pulsating behavior the flow is not perfectly constant and it may not be completely laminar due to the diameter changes at the beginning and end of the capillary.
It is recommended to regard the found restrictor dimensions as a rough estimation that requires some experiments for fine-tuning of the length.

Once the restrictor is finally set it is then possible to vary the flow rate (by changing the amplitude) from the new restricted max flow to zero. The full range of the amplitude allows smaller flow rate steps with voltage changes than with the un-restricted pump. The flow tolerance is also reduced accordingly.

target max flow rate [µl/min]	capillary diameter in [µm] 25	50	100	
500		1,025	16,41	capillary length [mm]
250		2,13	34,08	
200		2,68	42,91	
150		3,6	57,64	
100		5,44	87,09	
50		10,96	175,45	
25	1,375	22	352,16	
10	3,446	55,145	882,31	

Figure 6 Calculation results for capillary diameter and length for different target flow rates (based on water and micropump mp6).

Additional information

- With a restrictor the diameter of the fluidic line changes from wide to small and back to wide again. This can create some difficulties when priming the system, because air bubbles may block the small opening of the restrictor. It is possible to force them through with enough pressure, but this may be far more than the pump can deliver or the fluidic system can endure without leaking.
  If air bubbles can't be avoided otherwise they can either be pushed aside into an extra air bubble pocket where they can't block or they have to go through the restrictor. If pushed aside they may interfere with pumping as they act as a pressure buffer. If they have to go through the restrictor some special funnel structure may be required. See Figure 7 below for some clarification.

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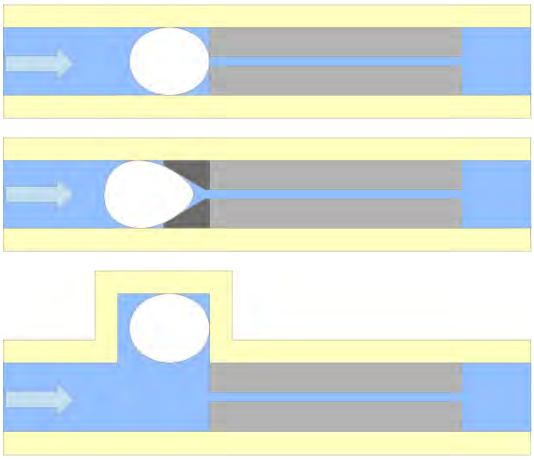

Figure 7 Air bubble and restrictor

Top: Large air bubble can block the restrictor opening.

Middle: A funnel element allows deformation of the air bubble so that it can go through.

Bottom: Air bubble pocket to keep the restrictor opening free

- Regardless of the amplitude a certain pressure will be built up in front of the restrictor. When the pump is switched off this pressure is not relieved instantly, hence the flow will not stop instantly. It will push some liquid further through the restrictor and some backwards through the pump (as the mp6-style pumps are not completely tight for small backflows).
  This effect has to be considered. It can be compensated with a valve somewhere downstream the restrictor to close the fluidic line, or with a pressure relieve valve between pump and restrictor.
- Possible capillary material:
  PEEK tubing and polyimide (PI) tubing comes in a wide variety of diameters and can be found at these suppliers: Professional Plastics, IDEX, Sigma Aldrich, Putnam Plastics, Biomerics, Vention Medical, MicroLumen and many others.
  Other materials are also possible for capillaries; however the compatibility with the used liquid has to be checked. PEEK and PI material are known to be very resistant.
- Possible orifice restrictor parts:
  Orifice restrictors (sometimes also named flow orifices or flow restrictors or flow regulators) consist typically of an single hole in a metal screen or a sapphire disc, although there are some products available that have funnel elements too. As mentioned above they come in preset dimensions and can be found at these suppliers: Lee Company, Global Spec, O'Keefe Controls Co., AirCom Pneumatic GmbH and others.

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