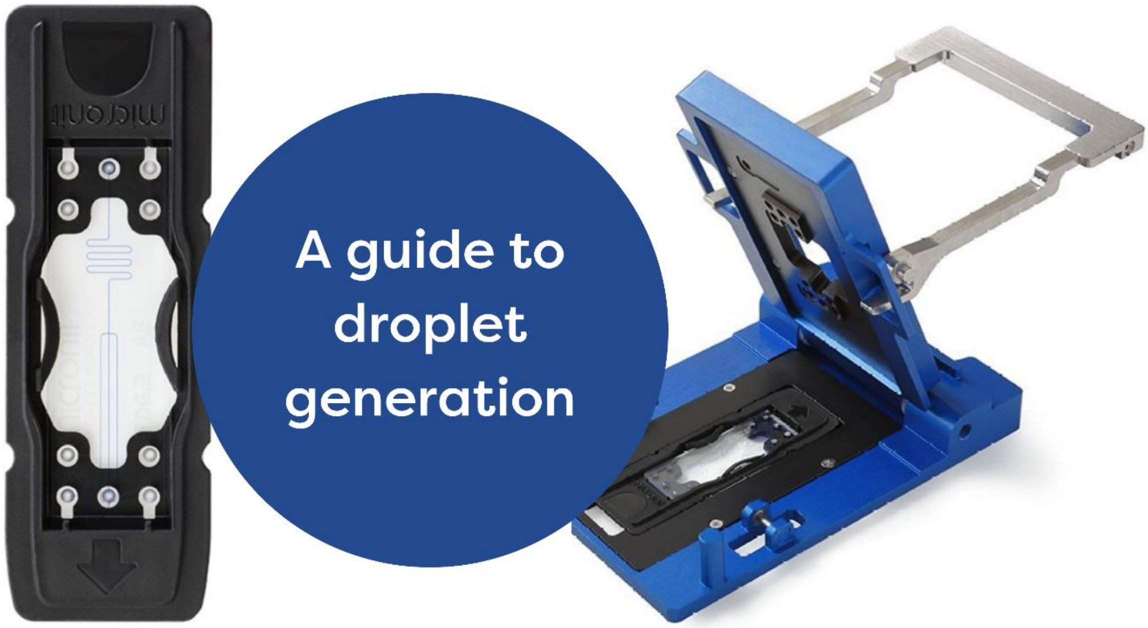
A guide to droplet generation



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Introduction

The use of droplet generators as research tools ensure you have both an easy to set-up system and a versatile platform for your investigations. Droplet generator chips offer a way to create highly monodispersed bubbles and droplets at user defined production rates.

Key features of droplet generator chips:

- Selection of devices for a range of droplet sizes up to 140µm in diameter
- Chemically inert materials
- Large viewing area of the channels
- A building block in a modular system

Droplet generators

The droplet generator chips are available as topconnect and sideconnect versions. The chips are manufactured from borosilicate glass and are supplied in the standard polypropylene (PP) Fluidic slide. The glass chips are naturally hydrophilic and can be delivered with a hydrophobic coating on the channel surface, allowing either oil or water based droplets.

Different interfacing concepts

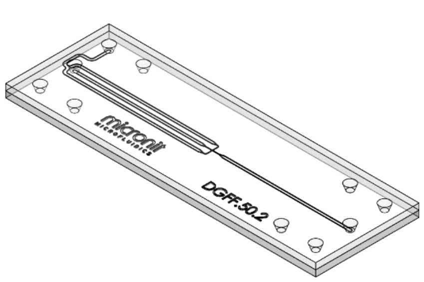
The topconnect version in combination with our Fluidic Connect Pro holder offers the ideal user experience. Under certain circumstances, however, our sideconnect platform is a better choice. This platform is more suitable for applications that need:

- A straight flow path (without 90 degree bend)
- A small footprint
- A cost effective design for potential volume production (small chip size)

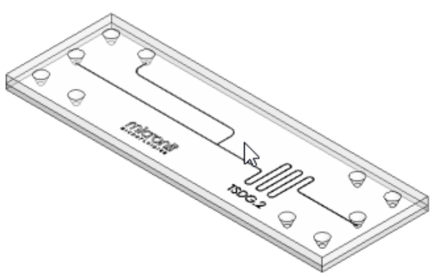
A choice of designs

The focused flow droplet generators come in four versions. All have the same chip size but the channels and nozzles have different sizes. Chips are offered with nozzle sizes of 10µm, 20µm, 50µm and 75µm. The droplets that are generated with these chips are in the range of the size of the nozzle.

In addition we offer a T-junction droplet generator, the channel height is 20µm in this design.



Focused flow droplet generator design.



T-shaped droplet generator design.

Custom designs

What if you need other features for your droplet generators? You might need more inlets or outlets, different channel dimension or parameters, integrated electrodes, other material choices like for instance fused silica, etc. Contact us to discuss the possibilities of manufacturing custom made droplet generators.

Droplet generation

The choice of the correct droplet generator for your application is not always an easy one. There are many variables which can affect the size, frequency and consistency of the droplets produced, including:

- Channel dimensions and geometry
- Flow actuation stability
- Flow rates of each fluid, both relative and total
- Channel wetting properties: hydrophobic (coated), hydrophilic (uncoated), etc.
- Miscibility of the continuous (outer) and dispersive (inner) fluids
- Viscosity and surface tension of the continuous (outer) and dispersed (inner) fluids
- Surfactant type and concentration

Focused flow geometry

The focused flow design consists of a cross junction where the inner fluid or dispersed phase enters through a single channel and the outer fluid referred to as the continuous phase impinges on the dispersed phase from two channels diametrically opposite each other. This combination of dispersed phase surrounded by continuous phase flows through the output channel, via the orifice. The orifice is a constriction in the channel used to create a controlled break-up of the dispersed phase into droplets.

T-junction geometry

The T-junction design consists of a main channel and perpendicular channel. The main channel contains the continuous phase (outer fluid) and the perpendicular channel the dispersed phase (inner fluid). This is a very basic and easy-to-use shape, although the possibilities to tweak the droplet size are limited.

Flow rate control

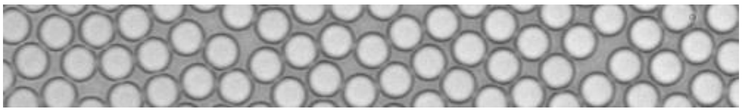
A key factor to the production of uniform droplets is stability of the flow rate. In order to have a system running with constant throughput, a settling time is needed between changing flow rate parameters and obtaining droplets with low polydispersity. This time varies, depending on the actuation system used, with the worst case being 20 minutes wait time for a system using a coarse controlled syringe pump and large plastic syringes, with long sections of Teflon tubing for interconnection to the system.
Once the system flow parameters have been set and the stabilization period is finished, the production mechanism of the droplets shows only small variations. The time to reach stable production can be reduced by using shorter interconnection tubing, as well as pressure driven flows or syringe pumps with reduced pulsations to the flow rate pumping. If the flow rate is not stable, it can help to add some back pressure after your droplet generator. At elevated pressures, small variations are of less influence on the droplet system.

Droplet sizes and production frequencies

Effect of flow rate ratios

The use of flow rate ratio variation as a control parameter for selecting droplet size is a well-established technique due to both its simplicity and robust repeatability. What can be seen is that the increase in the continuous phase flow rate compared to the dispersed phase flow rate enables the creation of smaller droplets, and vice versa: a decrease will lead to an increase in size. The system will reach a natural limit in terms of the variations, as too slow a rate of flow for the inner fluid will cause droplet production to stop and two fast a rate will mean the dispersive phase will run parallel to the continuous phase with no droplets formed. A further effect of varying the flow rate ratio is to alter the production frequency. This however is not purely dependent on the flow rate ratio, but is also affected by the individual flow rates as well as the fluid parameters themselves. Figures 1 and 2 show guides to the range of frequencies possible for our DGFF.50.2 and DGFF.75.2 droplet generator chips when the flow rates of the fluids are varied. For these results FC40 oil, de-ionized water and Tween 20 was used.

Focused flow droplet generator 10.2.



Droplet result focused flow droplet generator 10.2.

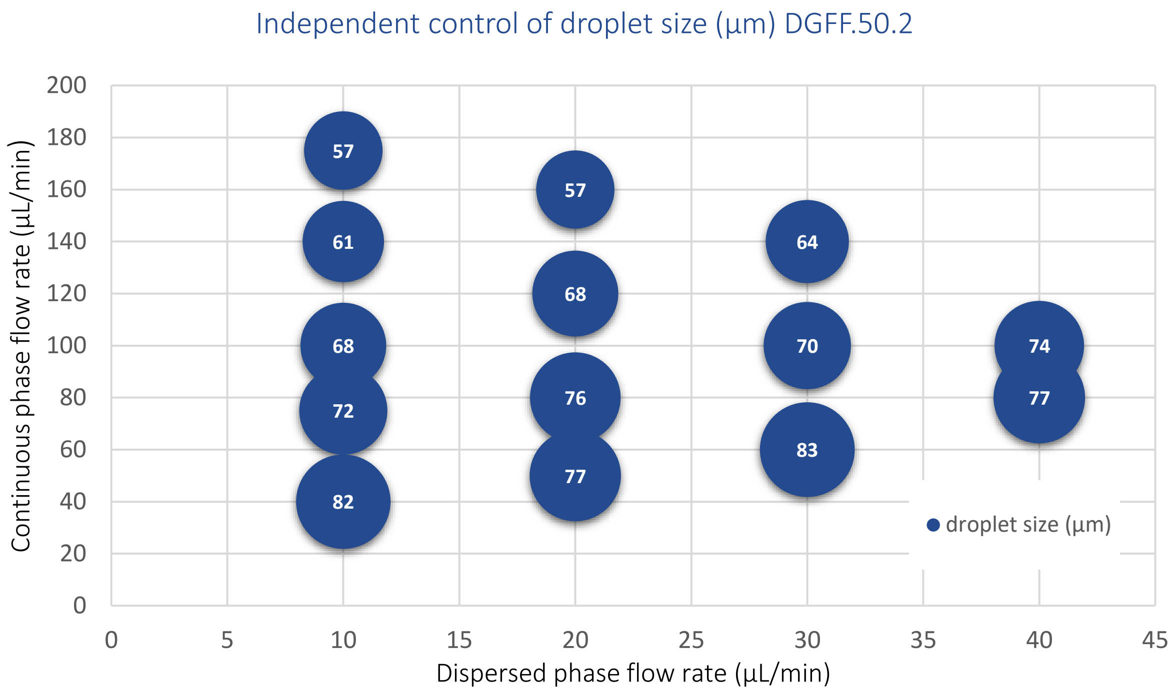


Figure 1 Production frequency as a function of flow rates for the FFDG.50.2 chip for a specific set of circumstances.

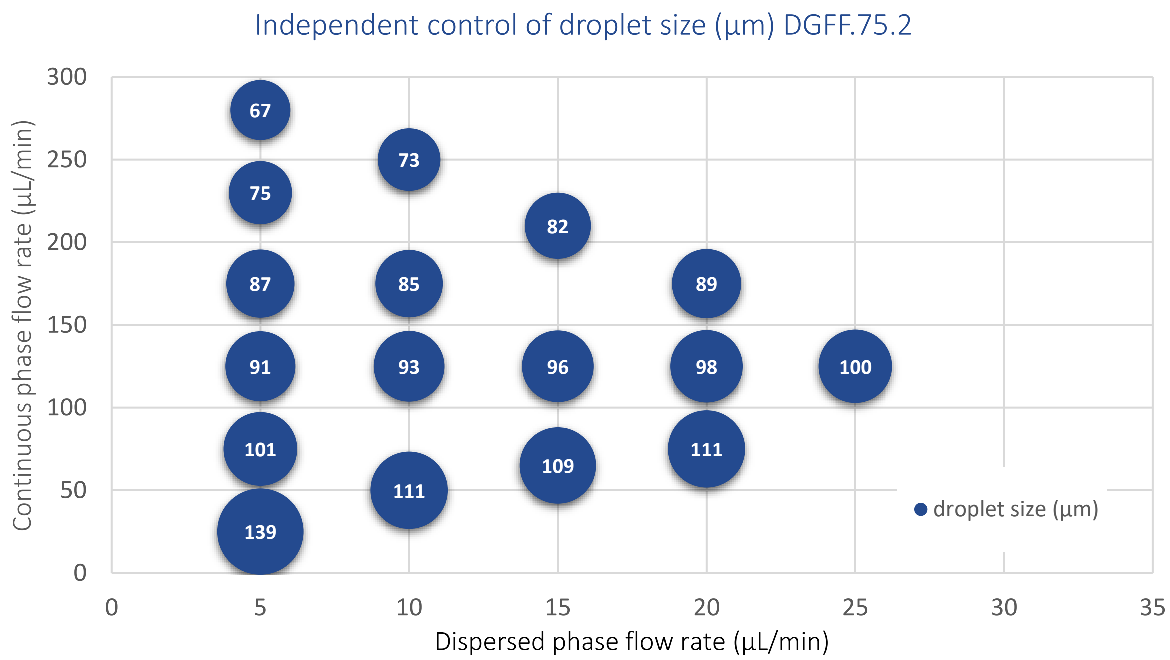


Figure 2 Production frequency as a function of flow rates for the FFDG.75.2 chip for a specific set of circumstances.

Figures 3 and 4 show the droplet sizes as a function of flow rates. What can be seen is that the droplet size depends a lot on flow rates. Depending on required production rates not all droplet sizes are achievable.

A general rule of thumb for microfluidic droplet generation is that the smaller the droplets created, the faster the frequency at which this can be achieved. Naturally, droplet sizes are always depending on the physical size and individual geometry of the particular device that is used.

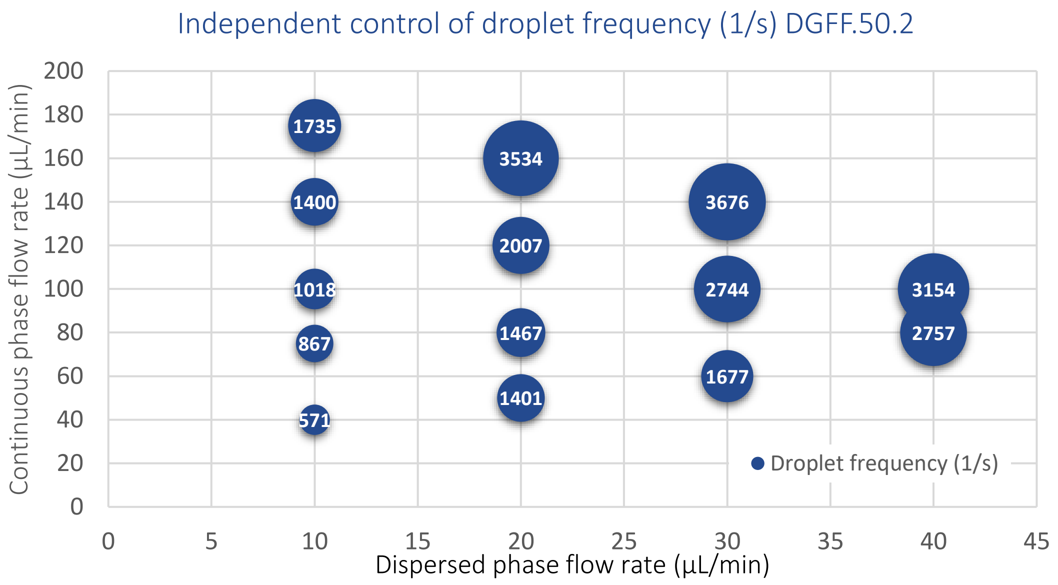


Figure 3 Droplet size as a function of flow rate for the DGFF.50.2 chip with a specific set of circumstances.

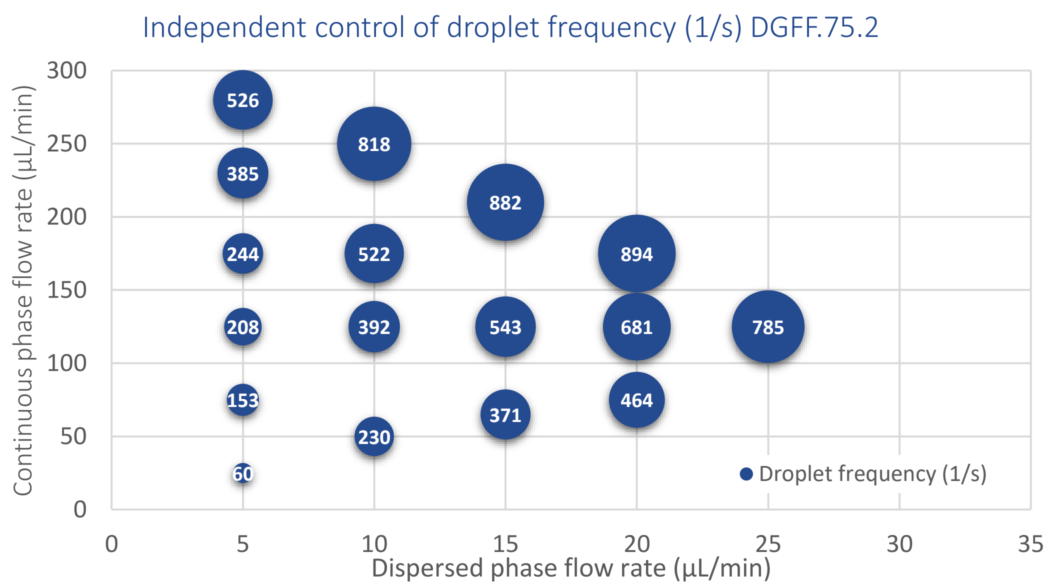


Figure 4 Droplet size as a function of flow rate for the DGFF.75.2 chip with a specific set of circumstances.

Effect of total flow rates

As a general rule, increased total flow rates lead to increased production frequencies for the droplets. However, there is a natural limit to this trend as at sufficiently high flow rates the fluids will flow parallel to each other with no real interaction or droplet formation occurring.

Surface properties

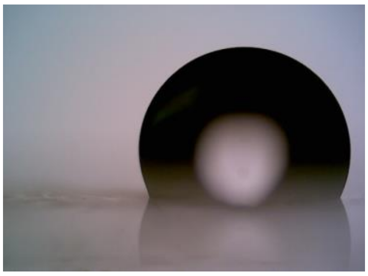
Fluid selections

A key factor in droplet size and production is the interfacial surface tension between the continuous and dispersive phases. The interaction between the two fluids can influence the production rates and sizes of droplets produced, with rates increasing and sizes decreasing as the value for interfacial tension decreases.

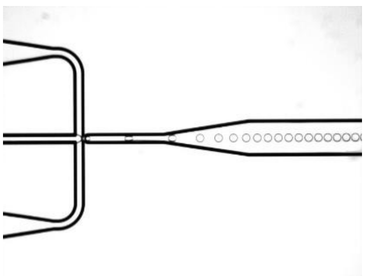
The choice of fluids used in droplet generation is generally based on what is under investigation. However, in order to ensure good droplet formation, two fluids that are immiscible are necessary. It is also recommended that the use of highly viscous fluids is avoided for small channel geometries, as this has an adverse effect on flow rates and pressures, because high viscosity fluids tend to break-up into larger droplets than fluids of lower viscosity.

Surface wetting properties

The contact angle between the fluids and the droplet generator surface is key for the stability of the wetting of the continuous phase. If the wetting is more preferential for the dispersive phase, then pinning of the droplets to the channel can occur. The standard uncoated droplet generators of Micronit are glass based, thus hydrophilic and are suitable for making organic droplets in an aqueous phase (oil-in-water droplets). It is possible for Micronit to provide a coating which renders the surface of the droplet generators hydrophobic, thus suitable for making aqueous droplets in an organic phase (water-in-oil droplets). This coating is based on a fluorinated polymer and ensures the coated surface has a contact angle of more than 90° with water.



Hydrophobic surface coating.



Droplets can be oil-in-water or water-in-oil.

Surfactant additions

The use of surfactant fluids, in very low concentrations of around 1-5% v/v, aids the stability of the droplets produced and reduces the instances of droplet coalescence. The surfactant population concentrates at the interface between the two fluids as the molecules naturally orient to have the hydrophilic head and hydrophobic tail in contact with the appropriate fluid. Choices of surfactant are dependent on the fluids used for the production of the droplets:

- Addition to organic fluids: Span 80 and Triton X-100
- Addition to aqueous solutions: Tween 20, Tween 80 and SDS (sodium dodecyl sulphate)

Cleaning & maintenance

Recommended cleaning technique

In general, it is advisable to use pre-filtered fluids in the droplet generators, as channel sizes are small and blockages can easily occur. This should help to reduce blocked channels and prolong the lifetime of the chip. However, it is still necessary to maintain your droplet production system, including occasionally cleaning the droplet generator chip. We recommend to flush it with de-ionized water, a solvent or another compatible fluid. To remove larger blockages from the channels, we recommend placing the chip in an ultrasound bath for 10-15 minutes before flushing fluids through the system at high pressures (7bar) or flow rates (100-200µl/min). The use of chemicals for more abrasive cleaning is possible if necessary, such as the use of sequential flushing with acetone, distilled water and finally isopropanol or another alcohol solution.

Finally, for uncoated pure glass devices it is possible to use a solution of sodium hydroxide (NaOH). A solution of 1M sodium hydroxide in water is effective, however lower concentrations might also be sufficient. If traces of the cleaning solution remain inside the chip after cleaning and rinsing with water is not possible, then ammonia can be used instead. Please note that this should not be attempted with coated devices, as coatings will be removed when using solutions like NaOH.

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