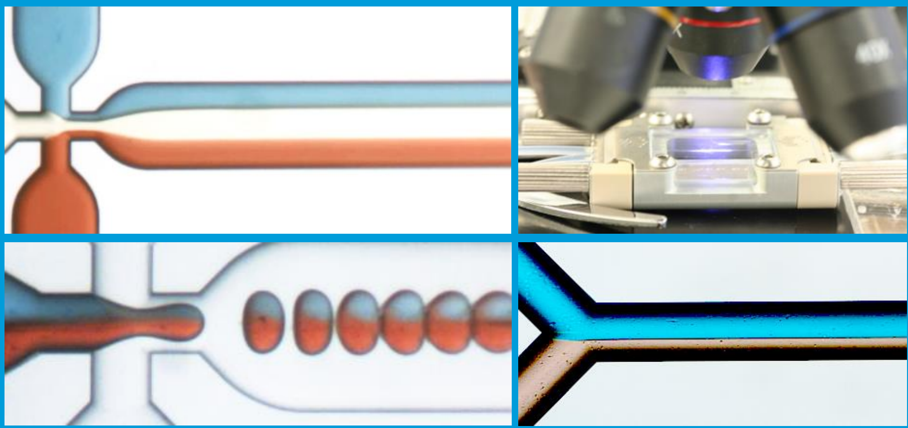
Introduction to Mixing and Droplet Production in Microfluidics

Dolomite's Educational Microfluidic System



dolomite

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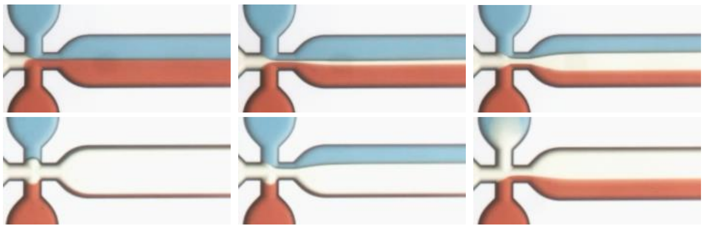
Summary

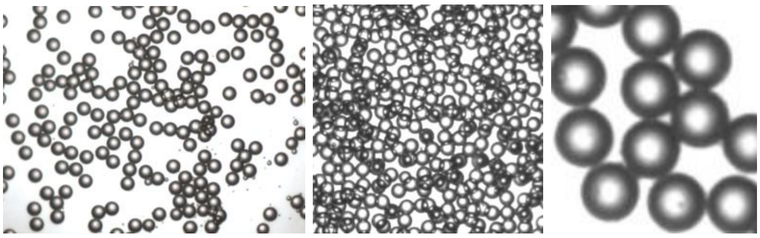
This application note introduces researchers to fundamental fluid operations in microfluidics. It also helps users decide how to design their systems. Most often systems are comprised of a microfabricated device (glass, PDMS, polymer), connectors, interfaces, pumps, sensors, control software and fluid accessories.

The application note is written in a simple, direct way that emphasizes concepts and understanding, rather than technical detail. It aims at providing the reader with the concepts, methods and data they need to grasp situations which typically arise in microfluidic systems.



An example of stoichiometry control using multiple fluids in simple microfluidic geometries.

Mixing is perhaps the most fundamental fluid operation in microfluidics. Given the unique properties of microfluidics, mixing is therfore demonstrated using different chips to show various options that are available. The educational system uses 3 different chips to show mixing in at least 3 different modes. These chips are: 1) a Y-junction chip (100 µm etch depth), 2) a droplet junction chip (100 µm), and 3) a micromixer chip (50 µm characteristic size). Dyed aqueous liquids are used in all tests.



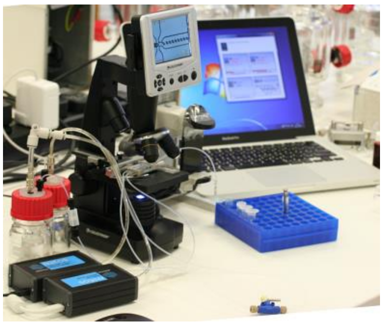
Emulsion production (highly monodisperse, 1% cv) at various volume fractions.

Droplet production is important when using immiscible fluids (most commonly water based with additives or salts and mineral oil, paraffins, fluorocarbons, etc.). A flow focussing method is used to make monodisperse (<5% CV) droplets. A Droplet Junction Chip (100 µm etch depth) and the 2R Droplet Junction Chip (100 µm etch depth) are used in separate tests to show how a variety of droplets can be produced. These droplets are then collected off-chip and analysed to measure their sizes.

All of the tests demonstrated here work on the principle of pressure based pumping. At least two, and at times three fluid reservoirs are pressurized. The flow resistance setup by cutting tubing of various lengths (explained in the appendix), coupled with the pump pressure dictates the fluid flow rates. The tests demonstrate the flexibility of the educational system to be used in a variety of ways, inspiring new users of microfluidics, and the adoption of the technology in innovative situations.

Educational Microfluidic Systems

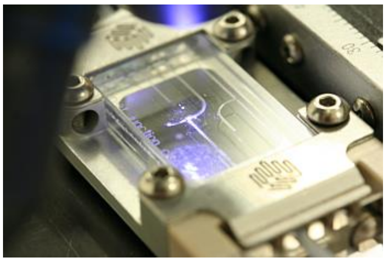
Microfluidics deals with the study of fluids moving in micrometer sized channels. The fluids may be single phase or multiphase, miscible or immiscible, and liquids or gases. It is a relatively new discipline, yet highly multidisciplinary and exponentially growing. Stimulated by the considerable development of applications in the pharmaceutical, biomedical and chemical engineering domains, the complexities built onto microfluidic systems are increasing rapidly.



The Educational microfluidic systems showing the Fluika Pressure pumps, digital microscope, and a laptop to control the system.

This application note demonstrates Dolomite's Educational System for users looking at moving to microfluidic systems. It gives a first-hand taster of some basic principles of microfluidics in a convenient low cost flexible and easily reconfigurable system.

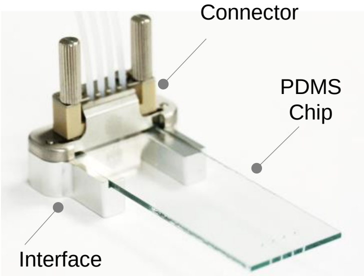
The application note is written in a simple, direct way that emphasizes concepts and understanding, rather than technical detail. It aims at providing the reader with the concepts, methods and data they need to grasp situations which typically arise in microfluidic systems.

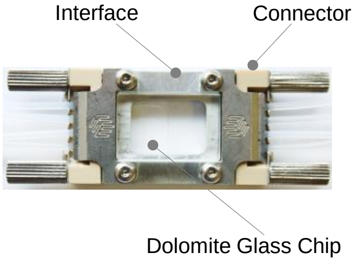


Both PDMS as well as glass based microfluidic substrates can be incorporated into the system, and are compatible with the digital microscope. Shown here is droplet production.

Most starting users are interested in one of two options:

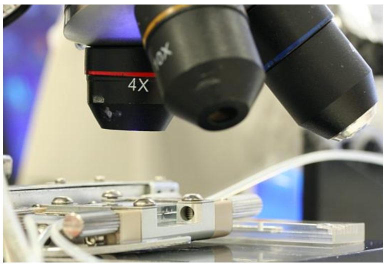
- The ability to continue to use PDMS chips with a collection of Dolomite components such as connectors, interfaces, pumps, sensor and control software.
- The ability to have their chips designed and manufactured in glass. These users additionally add on Dolomite components such as connectors, interfaces, pumps, sensor and control software.





Two different substrates (left: PDMS+glass, right: Glass) used with Dolomite's interface and connectors. Both options are compatible with the Educational Microfluidic System.

The educational system uses USB based PC control to change the pressure (and flow rates) in the fluidic system.

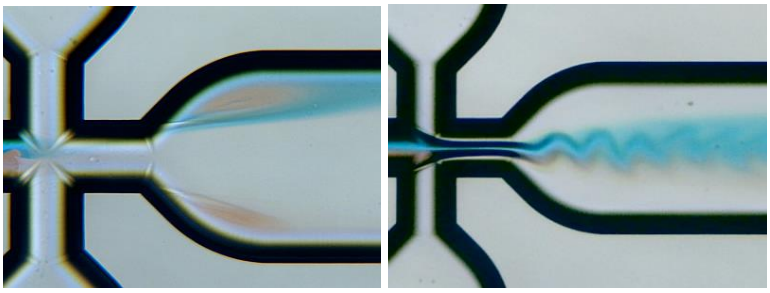


The digital microscope has 3 objectives, and with a stage that moves in x, y and z axes. Live images are seen on the screen and images and videos can be captured on the SD card.

Both of the above options are possible for users interested in using the Educational System. The small experimental footprint is advantageous in busy laboratories, and it offers the ability to use small fluid volumes. This means that hazardous fluids can be used in a controlled way. The Educational Microfluidic System will help promote the utilisation of microfluidics at an earlier stage of research.

Micro Scale Mixing Demonstrated Using a Few Standard Chips

Mixing is perhaps the most fundamental fluid operation when considering miscible fluids. Given the small length scales in microfluidics, the dimensionless numbers (Peclet number, Reynolds number, capillary number, and Weber number) are relatively low compared with larger benchtop fluid processing apparatus. As a result some fluidic phenomena do not directly scale down with size, but change in characteristic. This change in behaviour warrants a feasibility check for mixing.



Examples of complex shear induced flow patterns observed. These cause chaotic interaction between miscible aqueous coflowing streams.

Microscale mixing has special significance in bio- and chemical analyses using µTAS (micro total analysis systems) or lab-on-chips. Often the dominant mechanism for mass transport becomes diffusion based, which is when it becomes necessary to artificially add additional advection in the form of chaotic flow.

There have been various mixing methods proposed, starting from as simple as coflowing laminar diffusion, to using field effects (electric, magnetic) to add energy to mixing systems. In this application note we demonstrate passive mixing strategies showing the following:

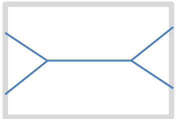
- Mixing of 2 Fluids Using Y Junction Chip (100 µm etch depth) – laminar flow diffusion based mixing
- Mixing of 2 Fluids Using 2R Droplet Chip (100 µm etch depth) – mixing of red and blue colored aqueous fluids passing through a constriction.
- Mixing of 2 Fluids Using Micromixer Chip (50 µm etch depth) – split and recombine type mixing using stratified flows.

The fluids to be mixed are surrogate fluids and chosen from some commonly available fluid tracking dyes.

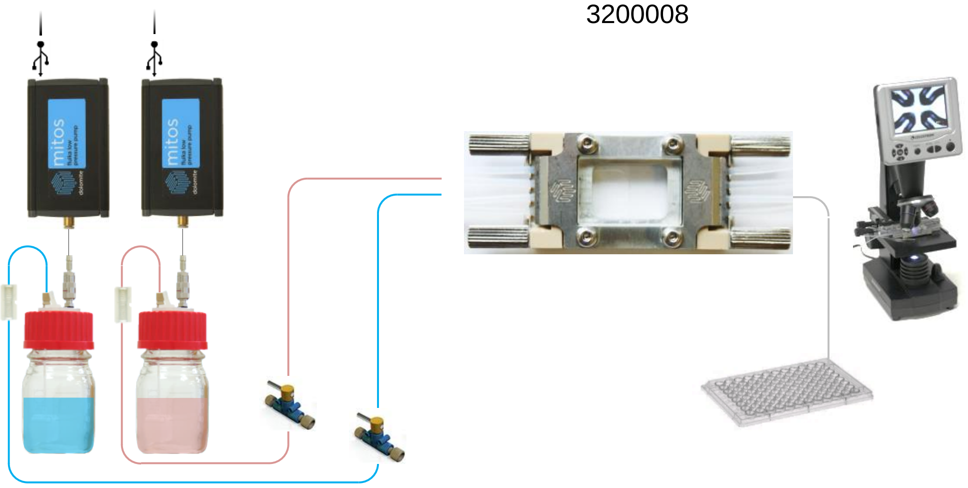
Aqueous red reagent	Aqueous blue reagent
10 ml Deionized Water with Tesco red food coloring	10 ml Deionized Water with 861146 SIGMA-ALDRICH Erioglaucine disodium salt *

* *Synonym: Acid Blue 9, Alphazurine FG, FD&C;BLUE No. 1*

Mixing of 2 Fluids Using Y Junction Chip



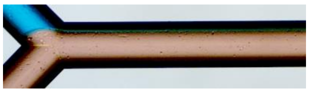
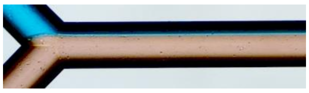
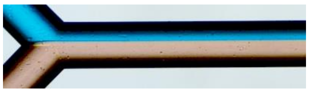
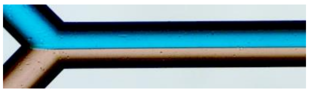
2-in, 2-out configuration.



One of the chip outlets is blocked so as to force the mixed fluids to use the one remaining outlet.

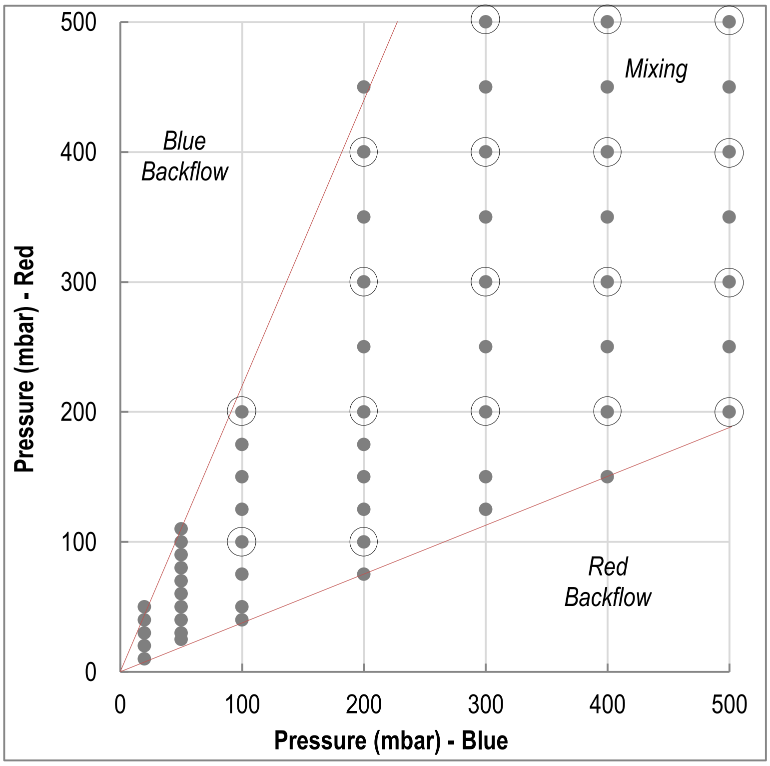
	Aqueous (red) OD(mm), ID(mm); L(mm)	Aqueous (blue) OD(mm), ID(mm); L(mm)
Pump to Pressure vessel	Pneumatic	Pneumatic
Pressure Vessel to Coupling	1.60, 0.25, 200	1.60, 0.25, 200
Coupling to Valve	1.60, 0.25, 300	1.60, 0.25, 300
Valve to Chip	1.60, 0.25, 200	1.60, 0.25, 200
Chip to Collection	1.60, 0.25, 500	

Details of tubing lengths cut and used to connect between various components.

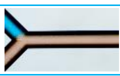
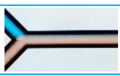
Pressure Red (mbar)	Pressure Blue (mbar)	Junction Images	Interfacial Position (measured) ~ (Q_b/Q_r)
100	40		0.22
100	50		0.30
100	75		0.41
100	100		0.50
100	125		0.59
100	150		0.65
100	175		0.70
100	200		0.72

Typical images showing the effect of relative changes in flow rates between the two fluids streams.

Image of well plate where samples from the above tests are collected.

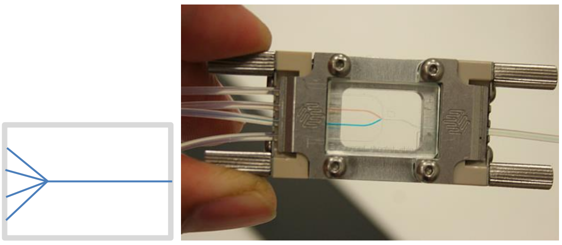


Phase Diagram showing operating space. Junction images for circled data points are presented in the table below. Flow rate estimation methods are presented in Appendix B.

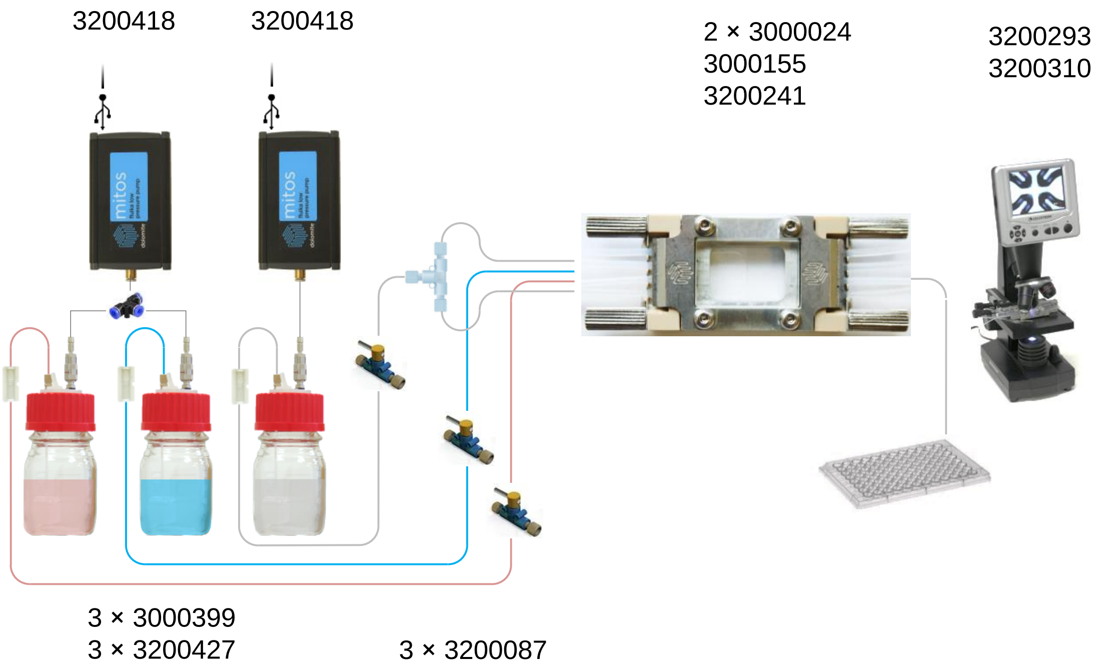
Pressure of red dyed aqueous fluid	500	-						
	400	-						
	300	-						
	200							
	100			-	-	-	-	
		100	200	250	300	350	400	500
		Pressure of blue dyed aqueous fluid						

Stoichiometry control by use of relative pressures (mbar).

Mixing of 2 Fluids Using 2R Droplet Chip

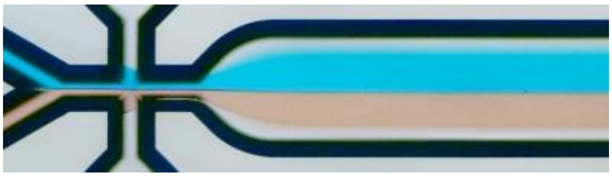
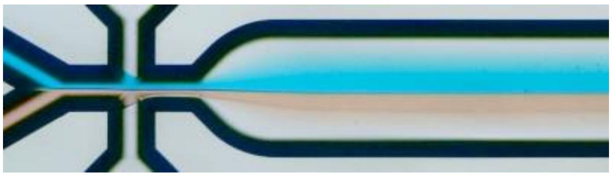
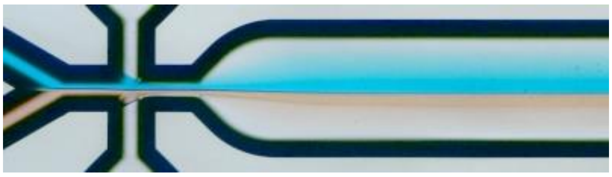
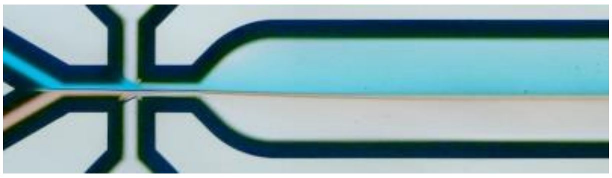
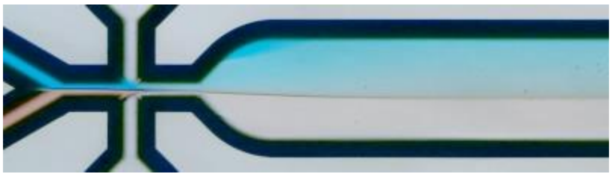


Left: 4-in, 1-out configuration. Right: Image of mixing in chip + connector + tubing assembly.

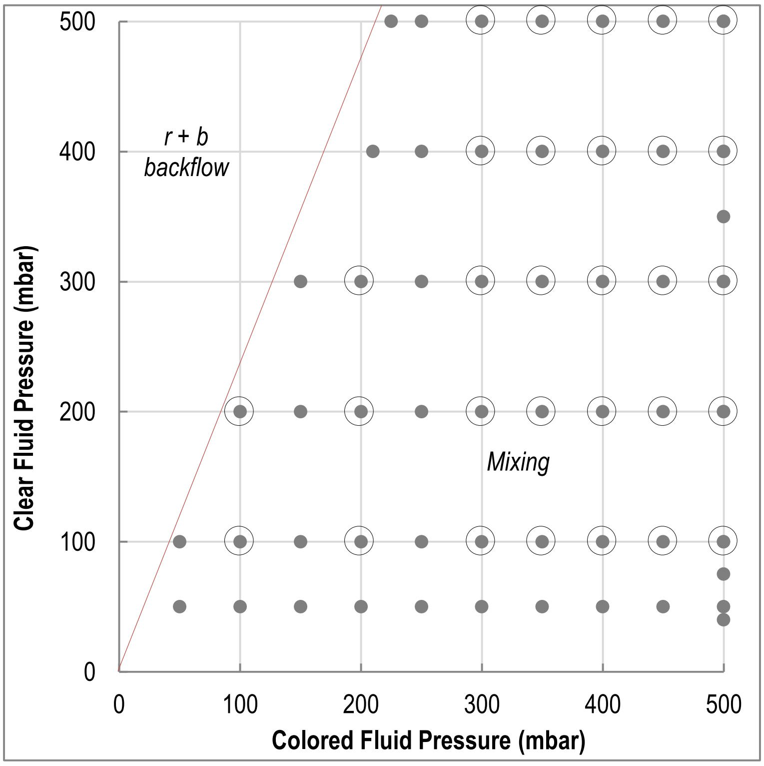


	Aqueous (red) OD(mm), ID(mm); L(mm)	Aqueous (blue) OD(mm), ID(mm); L(mm)	Aqueous (clear) OD(mm), ID(mm); L(mm)
Pump to Pressure vessel	Pneumatic		Pneumatic
Pressure Vessel to Coupling	1.60, 0.25, 200	1.60, 0.25, 200	1.60, 0.25, 200
Coupling to Valve	1.60, 0.25, 300	1.60, 0.25, 300	1.60, 0.25, 300
Valve to Chip	1.60, 0.25, 200	1.60, 0.25, 200	1.60, 0.25, 200
Chip to Collection	1.60, 0.25, 500		

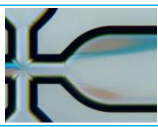
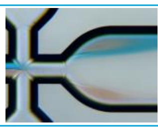
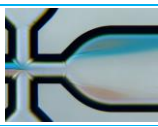
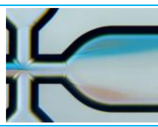
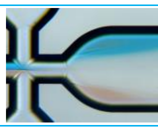
Details of tubing lengths cut and used to connect between various components.

Pressure R+B (mbar)	Pressure Clear (mbar)	Junction Images
500	40	
500	75	
500	100	
500	200	
500	300	
500	350	
500	400	
500	500	

Typical images showing the effect of relative changes in flow rates between the two fluids streams.

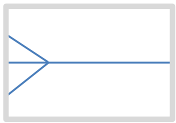


Phase Diagram showing operating space. Junction images for circled data points are presented in the table below. Flow rate estimation methods are presented in Appendix B.

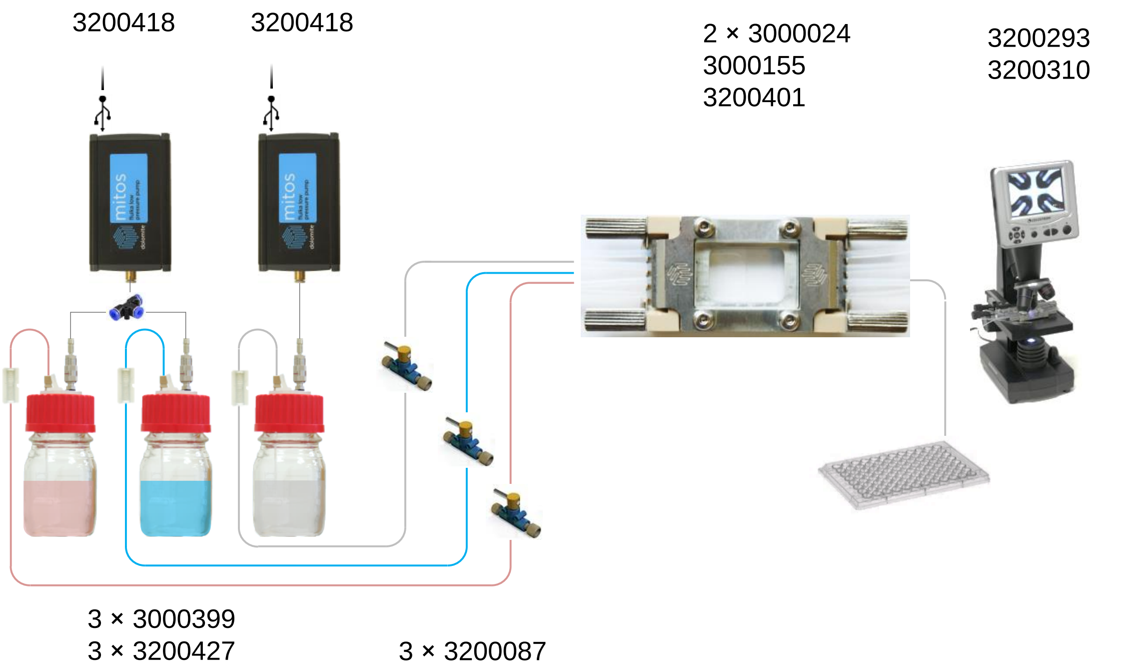
Pressure of clear aqueous fluid	500	-	-					
	400	-	-					
	300	-						
	200							
	100							
		100	200	300	350	400	450	500
		Pressure of dyed aqueous fluid (mix of red and blue)						

Stoichiometry control by use of relative pressures (mbar). Red and blue mixed aqueous phase pressure varies across columns, and the clear aqueous phase pressure varies across rows.

Mixing of 2 Fluids Using Micromixer Chip

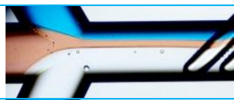
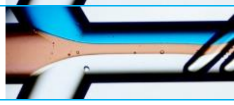
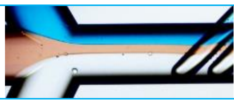
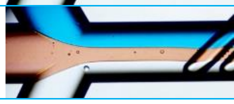
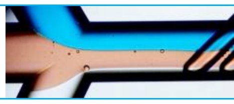
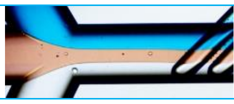
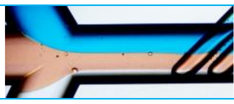


Left: Simplifed schematic of 3-in, 1-out configuration. Right: The split and recombine feature of the chip is visible in the chip + connector + tubing assembly.

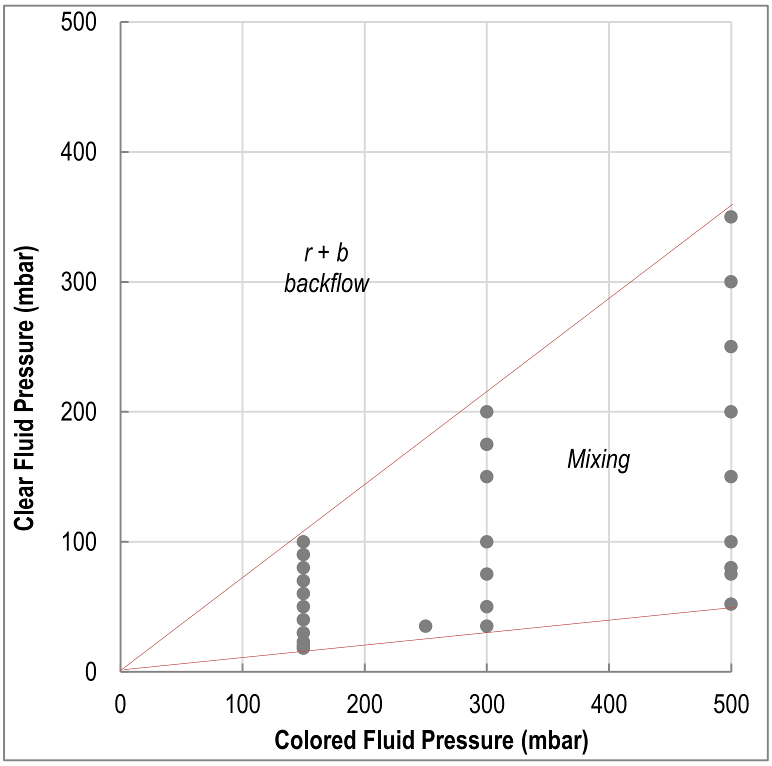


	Aqueous (red) OD(mm), ID(mm); L(mm)	Aqueous (blue) OD(mm), ID(mm); L(mm)	Aqueous (clear) OD(mm), ID(mm); L(mm)
Pump to Pressure vessel	Pneumatic		Pneumatic
Pressure Vessel to Coupling	1.60, 0.25, 200	1.60, 0.25, 200	1.60, 0.25, 200
Coupling to Valve	1.60, 0.25, 300	1.60, 0.25, 300	1.60, 0.25, 300
Valve to Chip	1.60, 0.25, 200	1.60, 0.25, 200	1.60, 0.25, 200
Chip to Collection	1.60, 0.25, 500		

Details of tubing lengths cut and used to connect between various components.

Pressure of dyed aqueous fluid (mix of red and blue)	300	-	-	
	250	-	-	
	200	-		
	175	-		-
	150	-		
	100	-		
	90		-	-
	80		-	
	75			
	70		-	-
	60		-	-
	52		-	
	50			-
	40		-	-
	35	-		-
	30		-	-
	23		-	-
	20		-	-
	18		-	-
		150	300	500
		Pressure of clear aqueous fluid		

Stoichiometry control by use of relative pressures (mbar).



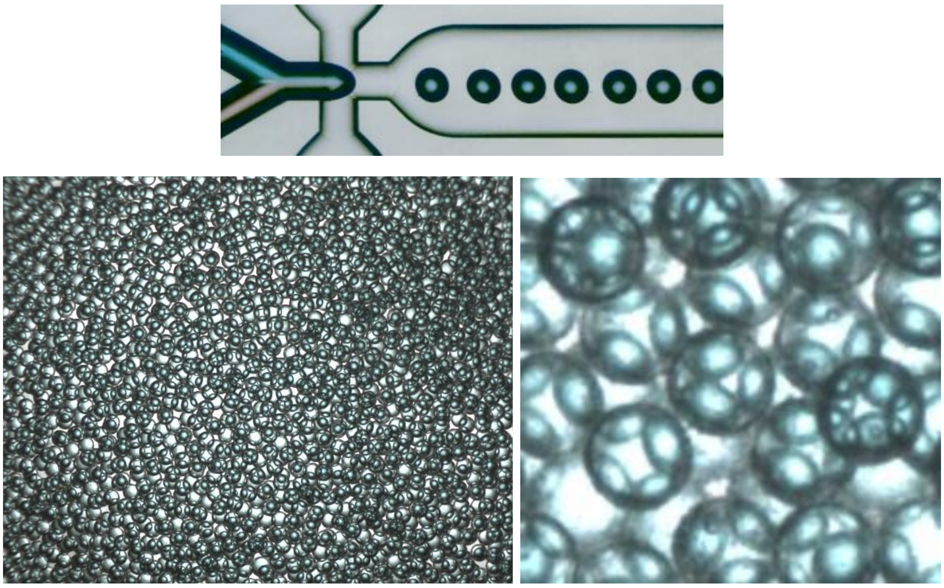
Phase Diagram showing operating space. Flow rate estimation methods are presented in Appendix B.

Droplet Production Demonstrated with a Few Standard Chips

There is an exponentially growing branch of microfluidics utilizing fluids which are immiscible and develop a fluid interface when in contact. These two fluids most commonly are aqueous (water based with additives or salts) and organic (mineral oil, paraffins, fluorocarbons, etc.). The objective is to create a controlled emulsion, one droplet at a time. Depending upon the application, either fluid may form the dispersed phase (droplets) or the continuous phase (carrier). Owing to high surface area to volume ratios, the chip surface coating has a dominant effect, and these coatings can be advantageously used to control the droplet formation.

Compartmentalization of fluids has many advantages, some of which are isolation of test volumes, reduction in contamination possibility, and increased experimental throughput for the same given volume.

Microtechnology based droplet generation also offers unparalleled control in the size of the droplets produced. These can be as monodisperse as having 1 % standard deviation over a size of 100 µm.



Top: Fluid pinchoff at a flow focussing junction resulting in 100 µm droplets. Lower left and lower right: Surfactant stabilized droplets (100 µm large) collected in a well plate at various magnifications.

Dolomite's droplet systems are typically used to manufacture monodisperse droplets between 5 µm diameter and 250 µm diameters. Often these droplets are then processed downstream thermochemically, catalytically, or simply irradiated to convert from liquid phase to solid phase, thereby producing solid particles. In this application note we demonstrate the ability to generate water in mineral oil droplets using the educational microfluidic system, and using two difference droplet generating chips. These are:

- Droplet Production Using Droplet Junction Chip (100 µm etch depth) – one stream of water is pinched off into droplets at a flow focussing junction. The mineral oil forms the continuous phase.
- Droplet Production Using 2R Droplet Junction Chip (100 µm etch depth) – a red colored aqueous stream mixes with a blue colored aqueous stream, and the mixed

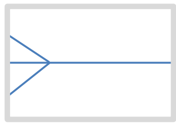
product is instantaneously pinched off and encapsulated inside a droplet. The surrounding continuous phase is mineral oil.

Red aqueous fluid	Blue aqueous fluid	Carrier Fluid
10ml Deionized Water with Tesco red food coloring	10ml Deionized Water with 861146 SIGMA-ALDRICH Erioglaucine disodium salt †	20ml Mineral Oil (Sigma Aldrich, M5904) mixed with 1% (v/v) SPAN-80 (Fluka, 85548).

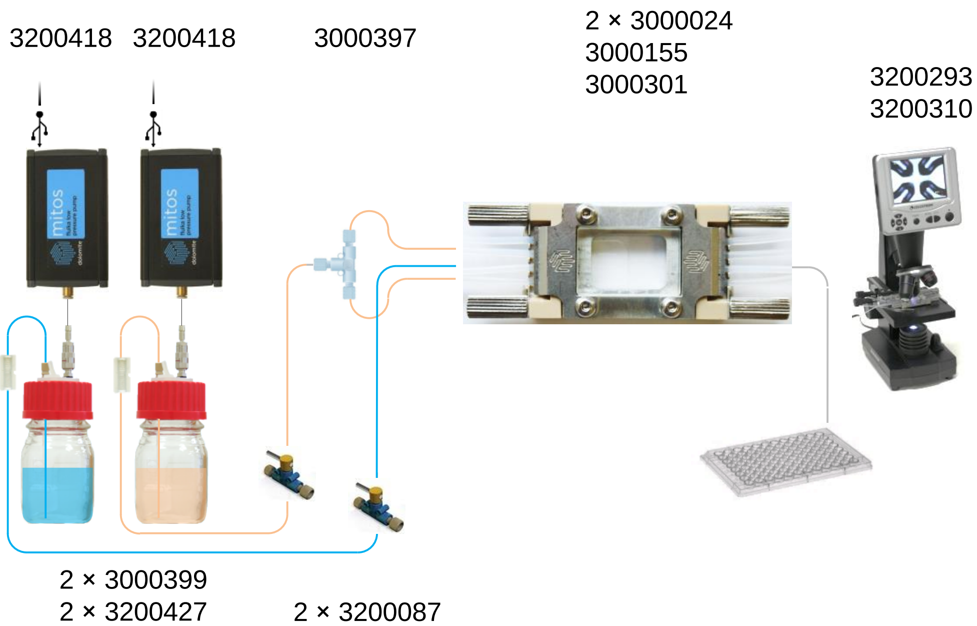
In addition to being used as microreactors ranging from the nano- to femtoliter range; droplet-based systems have also been used to directly synthesize particles and encapsulate many biological entities for biomedicine and biotechnology applications. These particles can be used in a diverse range of applications, including the synthesis of biomolecules, drug delivery, and diagnostic testing.

† *Synonym: Acid Blue 9, Alphazurine FG, FD&C;BLUE No. 1*

Droplet Production Using Droplet Junction Chip

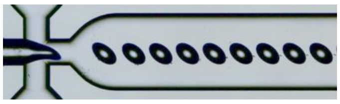
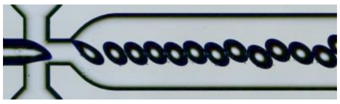
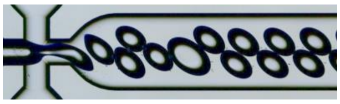
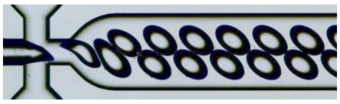
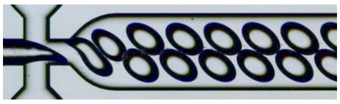
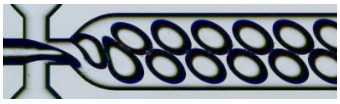
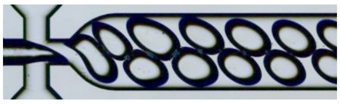
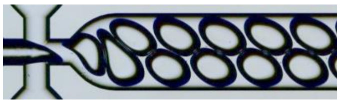
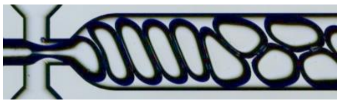


3-in, 1-out configuration.



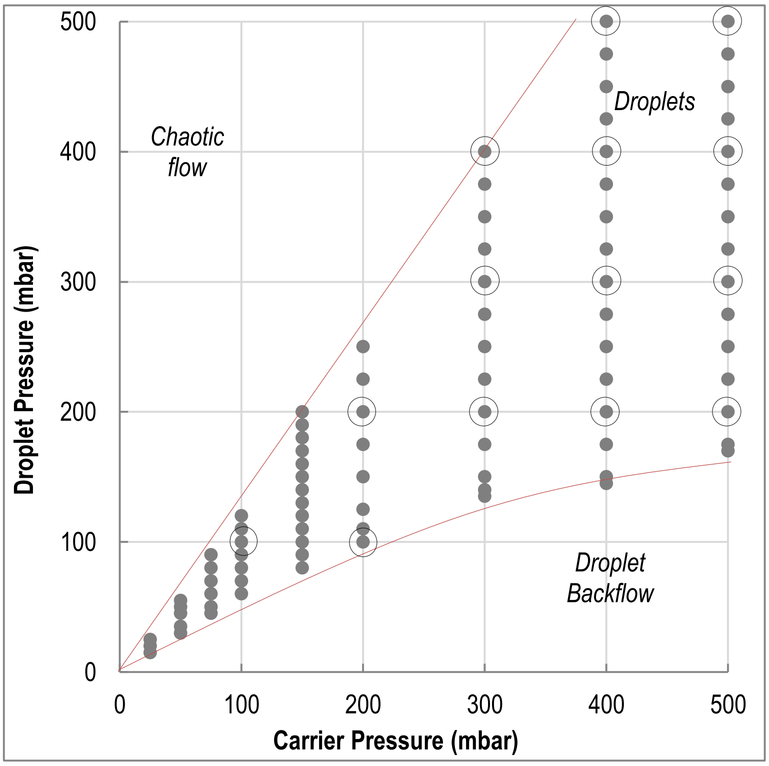
<table>
<tr><th></th><th>Organic Carrier
OD(mm), ID(mm); L(mm)</th><th>Aqueous Droplet
OD(mm), ID(mm); L(mm)</th></tr>
<tr><td>Pump to Pressure vessel</td><td>Pneumatic tubing</td><td>Pneumatic tubing</td></tr>
<tr><td>Pressure Vessel to Coupling</td><td>0.25; 200</td><td>0.25; 200</td></tr>
<tr><td>Coupling to Valve</td><td>0.25; 300</td><td>0.25; 300</td></tr>
<tr><td>Valve to T-piece</td><td>0.25; 200</td><td rowspan="2">0.10; 450</td></tr>
<tr><td>T-piece to Chip</td><td>0.25; 500 mm (×2)</td></tr>
<tr><td>Chip to Collection</td><td colspan="2">0.25; 300</td></tr>
</table>

Details of tubing lengths cut and used to connect between various components.

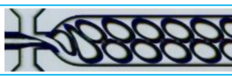
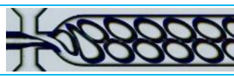
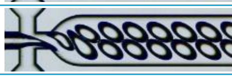
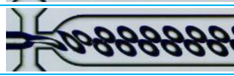
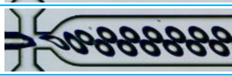
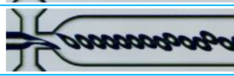
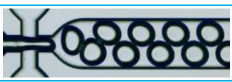
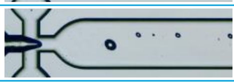
Pressure Carrier	Pressure Droplet	Junction Images	Droplet Diameter
(mbar)	(mbar)		µm
300	135		-
300	140		45.7
300	150		81.1
300	175		84.8
300	200		94.6
300	225		101.1[‡]
300	250		115.8
300	275		120.7
300	300		130.4
300	325		140.2
300	350		150.0
300	375		156.5
300	400		182.6

Typical images showing the effect of relative changes in flow rates between the two fluids streams. The digital microscope has a line scan (top to bottom) of about 30 Hz. Droplets produced at rates higher than the scan rate appear skewed.

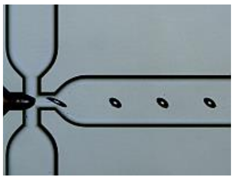
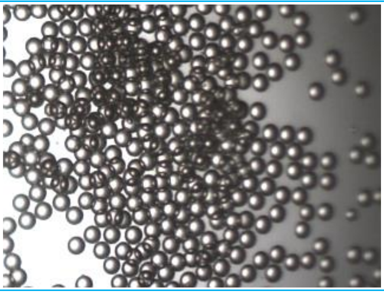
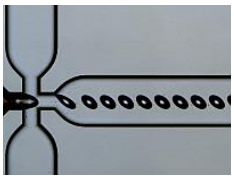
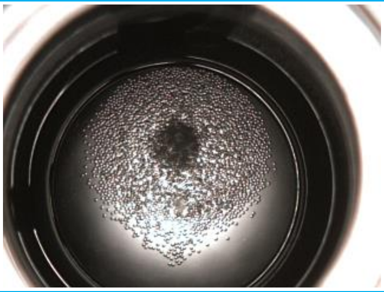
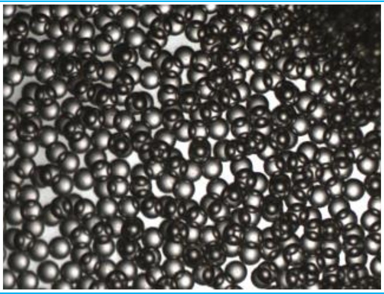
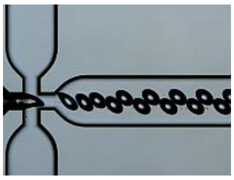
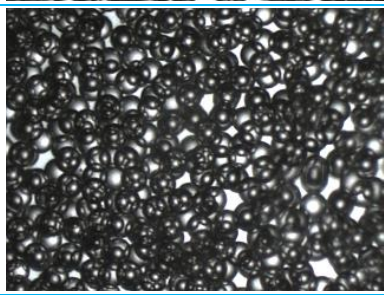
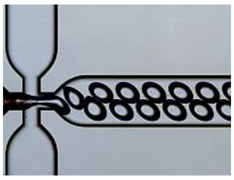
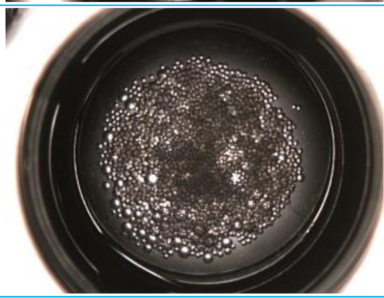
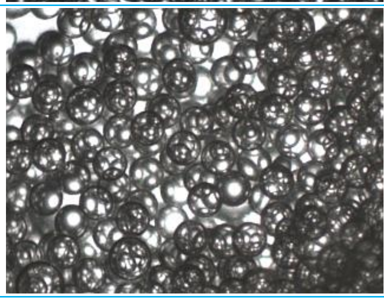
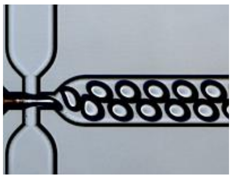
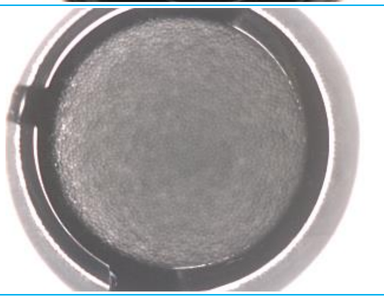
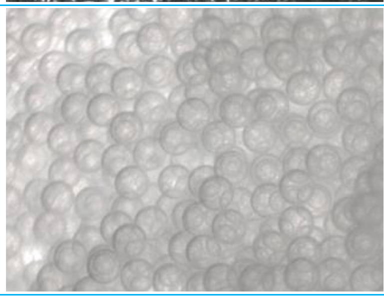
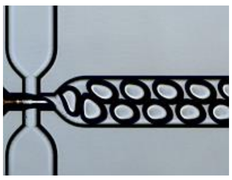
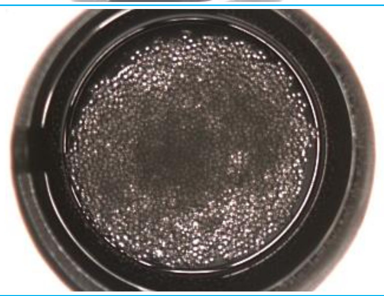
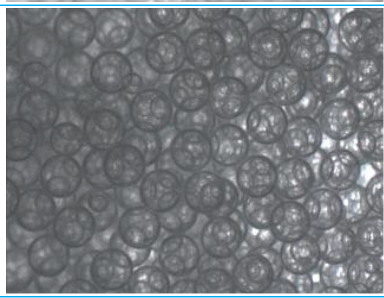
[‡] *Droplet sizes larger than the channel depth will be squashed. The apparent size will then be larger than the actual size. A correction method is suggested on Page 6 of http://www.dolomite-microfluidics.com/images/stories/PDFs/application_notes/Droplet_Junction_Chip_characterisation_-_application_note.pdf*

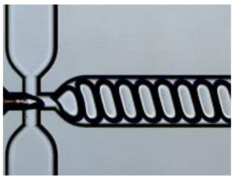
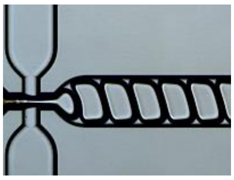
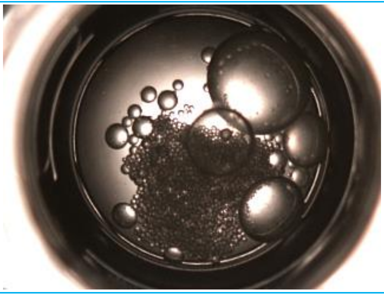
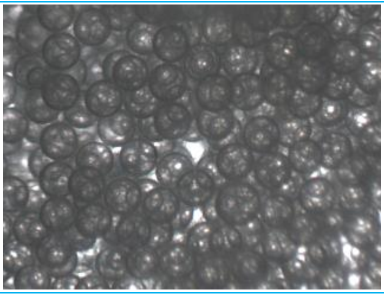


Phase Diagram showing operating space. Junction images for circled data points are presented in the table below. Flow rate estimation methods are presented in Appendix B.

Pressure of aqueous droplet phase	500	-	-	-		
	400	-	-			
	300	-	-			
	200	-				
	100			-	-	-
		100	200	300	400	500
		Pressure of carrier phase (mineral oil) with 1% SPAN-80				

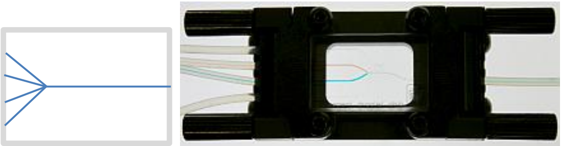
Stoichiometry control by use of relative pressures (mbar).

Pressure Carrier	Pressure Droplet	On-chip Junction Image	In-well collected emulsion	High magnification emulsion sample in well-plate.
(mbar)	(mbar)			
300	140			
300	150			
300	200			
300	300			
300	325			
300	350			

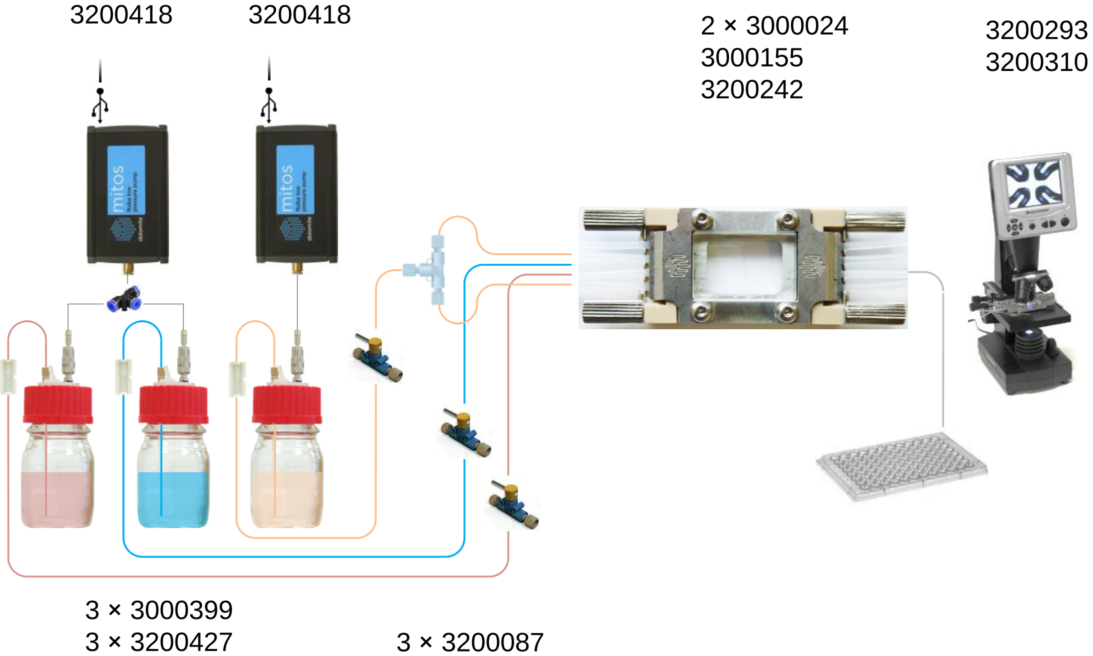
300	375			
300	400			

The last test results shows some very large droplets. This indicates that the droplet stability has significant dependence on the droplet size.

Droplet Production Using 2R Droplet Junction Chip

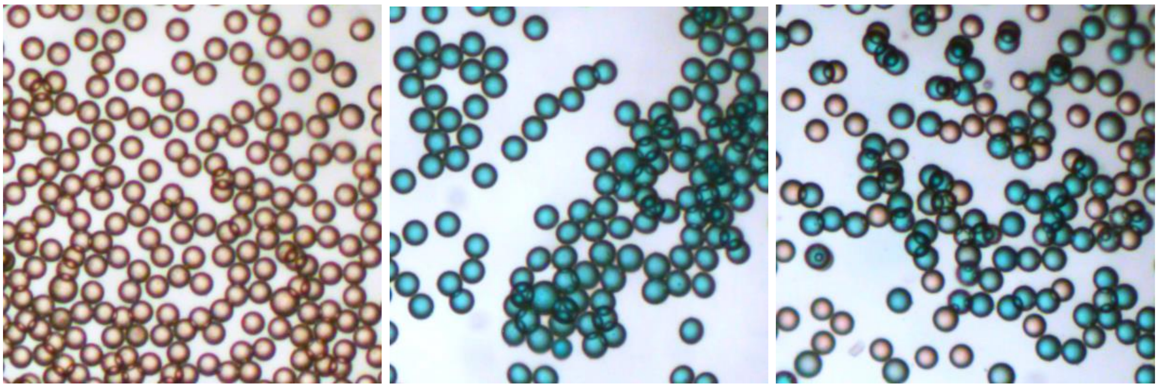


Left: Schematic of 4-in, 1-out configuration. Right: Backlit image of chip, connector and tubing showing droplet production.

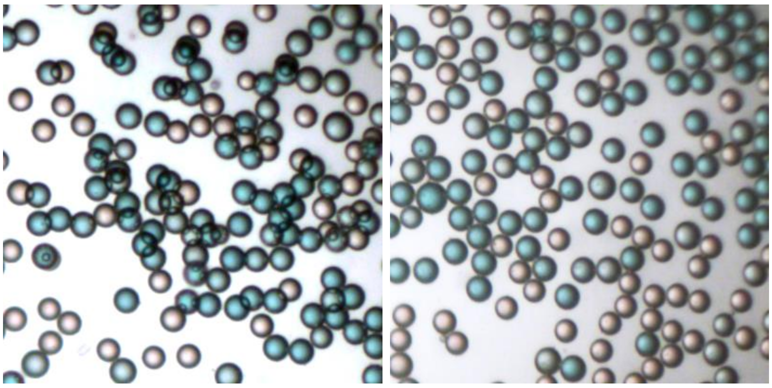


	Aqueous (red) OD(mm), ID(mm); L(mm)	Aqueous (blue) OD(mm), ID(mm); L(mm)	Organic OD(mm), ID(mm); L(mm)
Pump to Pressure vessel	Pneumatic		Pneumatic
Pressure Vessel to Coupling	1.60, 0.25, 200	1.60, 0.25, 200	1.60, 0.25, 200
Coupling to Valve	1.60, 0.25, 300	1.60, 0.25, 300	1.60, 0.25, 300
Valve to T-Piece	1.60, 0.10, 1000	1.60, 0.10, 1000	1.60, 0.25, 200
T-Piece to Chip			1.60, 0.25, 300
Chip to Collection	1.60, 0.25, 500		

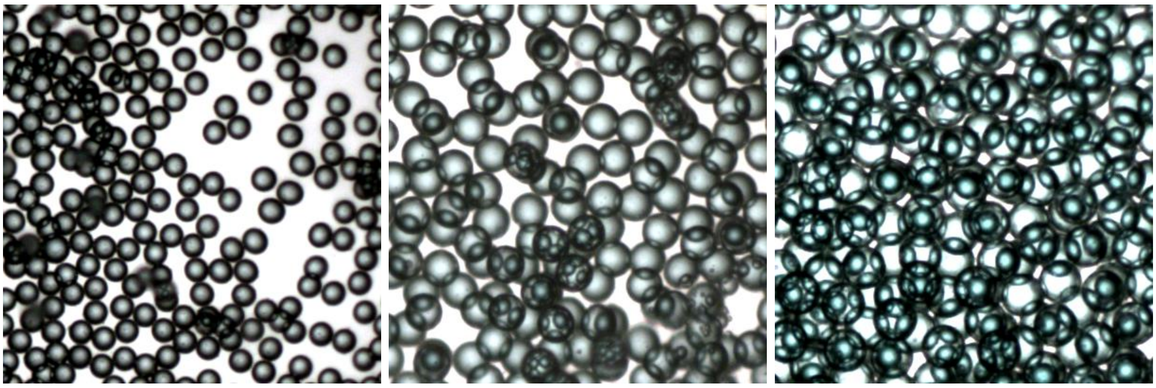
Details of tubing lengths cut and used to connect between various components.



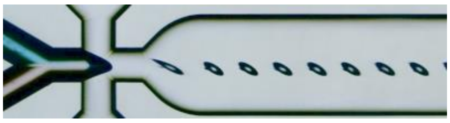
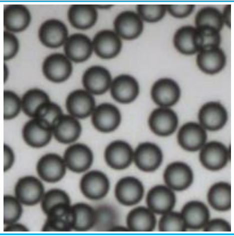
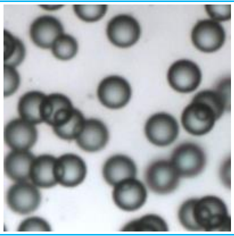
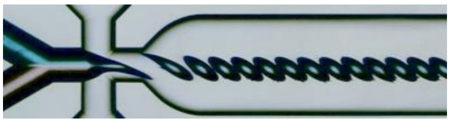
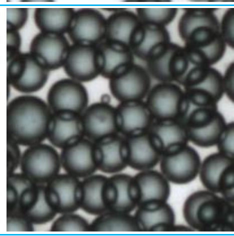
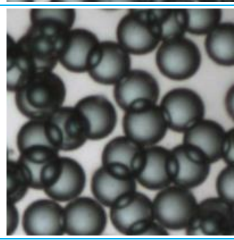
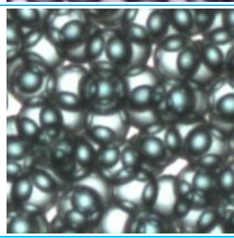
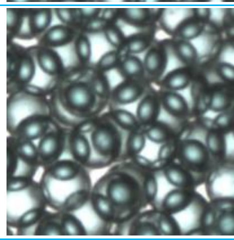
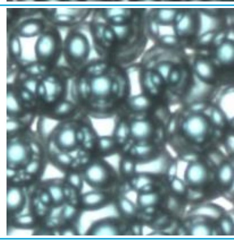
Droplets made with only the red component (left), only the blue component (middle), by alternating red and blue components (right).

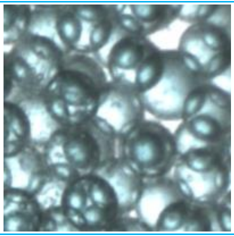
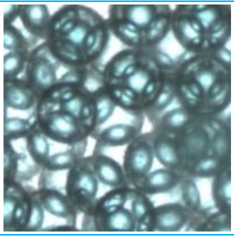
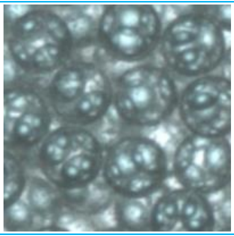
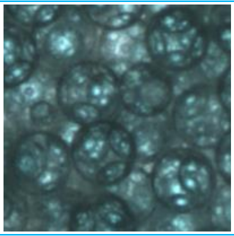
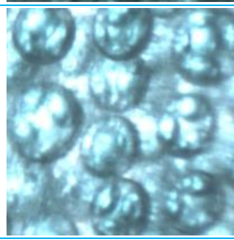


Droplets made by alternating red and blue components.



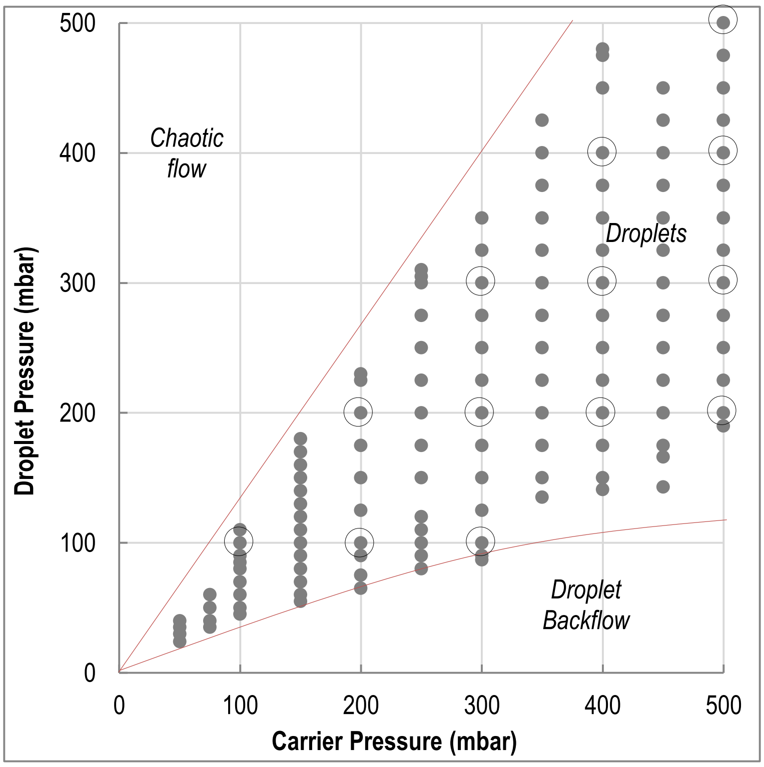
Droplets made by mixing red and blue components. These appear darker as a result of the blue mixing with the red.

Pressure Carrier (mbar)	Pressure Droplet (mbar)	Junction Images	Droplet Diameter	Collection
500	190		41.0	
500	200		57.4	
500	225		75.4	
500	250		78.7	
500	275		88.5	
500	300		96.7	
500	325		91.8	

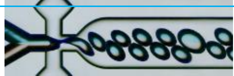
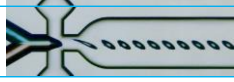
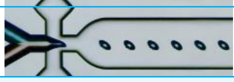
500	350		103.3[§]	
500	375		111.5	
500	400		123.0	
500	425		118.0	
500	450		139.3	

Typical images showing the effect of relative changes in flow rates between the two fluids streams.

[§] *Droplet sizes larger than the channel depth will be squashed. The apparent size will then be larger than the actual size. A correction method is suggested on Page 4 of http://www.dolomite-microfluidics.com/images/stories/PDFs/application_notes/Droplet_Junction_Chip_characterisation_-_application_note.pdf#page=6*



Phase Diagram showing operating space. Junction images for circled data points are presented in the table below. Flow rate estimation methods are presented in Appendix B.

Pressure of dyed aqueous fluid (mix of red and blue)	500	-	-	-	-	
	400	-	-	-		
	300	-	-			
	200	-				
	100				-	-
		100	200	300	400	500
		Pressure of carrier phase (mineral oil) with 1% SPAN-80				

Stoichiometry control by use of relative pressures (mbar).

Conclusion

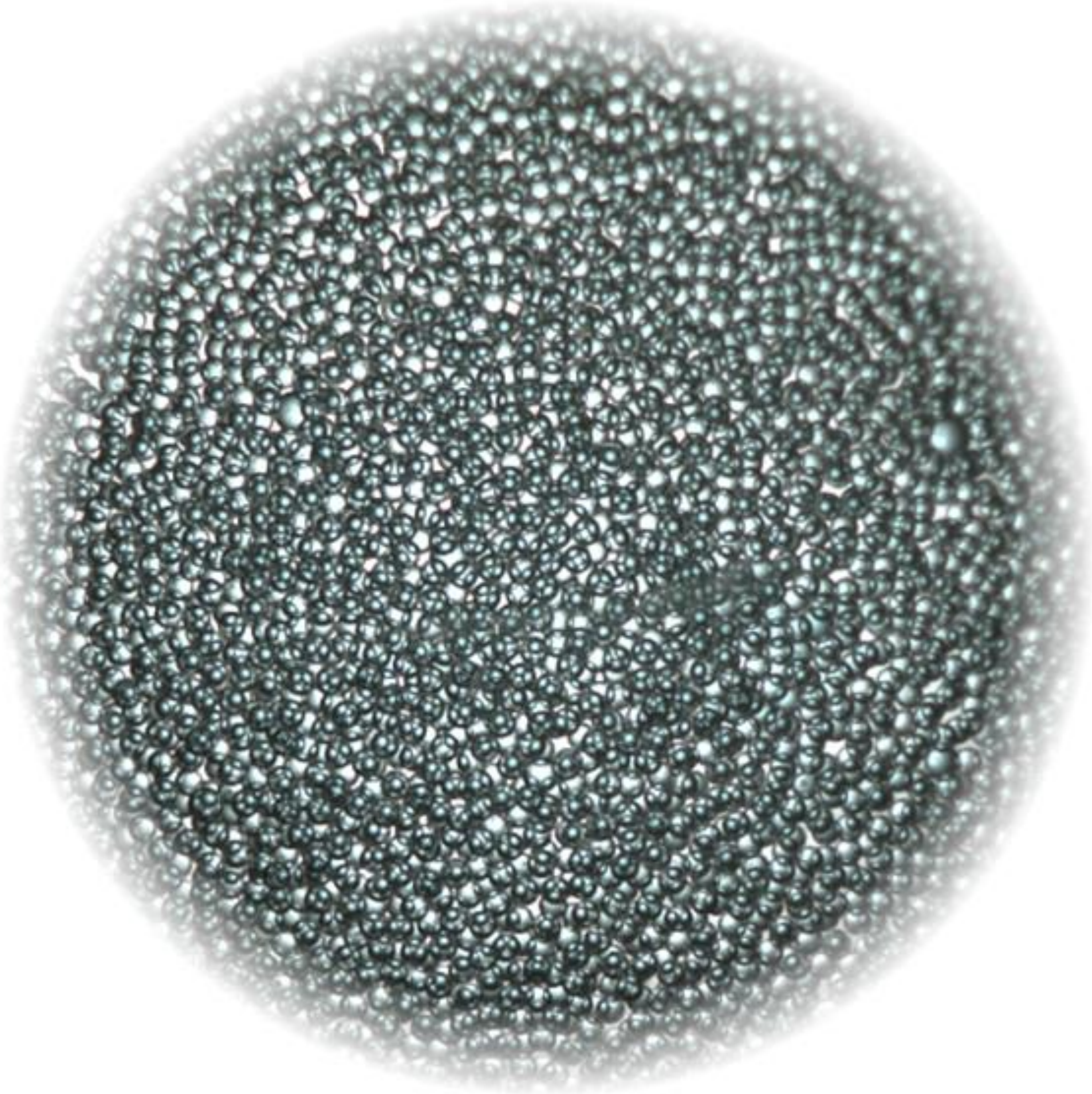
The educational microfluidic system is demonstrated in various different configurations to achieve fluid handling, specifically for mixing and droplet production. It is shown that the Dolomite Fluika pumps, chips and connectors and fluid accessories can be very quickly reconfigured to change the functionality of the system.

At least three different configurations have been demonstrated for mixing. These differ in the use of the microfluidic chip – Y-Junction chip, Droplet Junction chip, 2R Droplet Junction Chip, and the Micromixer Chip. Each configuration has its own merits and demerits, and the most suitable means of mixing should be selected depending on the specific application in mind.

Droplet production has been demonstrated using Dolomite's droplet junction chips. These are used along with the Dolomite interfaces and connectors providing a seamless leak proof connection that quickly enables users to get started with producing monodisperse emulsion. We have also demonstrated the mixing of two aqueous liquids just prior to droplet production.

Microfluidics being a multidisciplinary field has attracted researchers from many fields. The novelty often comes from coupling their areas of specialization with miniaturized fluid handling devices provided by Dolomite. Dolomite's products and specifically the educational microfluidic system enable a diverse group of researchers to study the fundamentals of microfluidics. The rapid development of this field in just a few years versus the vast amount of literature generated is often confusing. This approach eliminates the complexities of advanced systems in the learning phase, while at the same time giving users a sense of adaptability of their processes to the microscale world.

Chemists, biologists, physicists, and biomedical engineers are eager to explore the microfluidic world for which the educational system is a powerful starting system. There are features available in terms of control, operating space, thermochemical additive complexities that can be added on to user processes by Dolomite, and these constitute advanced systems. The educational system simplifies things greatly and presents a robust and dependable microfluidic system for entry level researchers.



Appendix A: System Component List

Part No.	Part Description	#
3200418	Mitos Fluika Low Pressure Pump	2
3200427	Mitos Fluika Pressure Vessel, 100ml	2
3200241	2 Reagent Droplet Chip (100µm etch depth)	1
3200401	Micromixer Chip	1
3200008	Y-junction Chip	1
3000301	Droplet Junction Chip (100µm etch depth), hydrophobic	1
3200242	2 Reagent Droplet Chip (100µm etch depth), hydrophobic	1
3000024	Linear Connector 4-way	2
3000155	H Interface	1
3200232	PDMS Chip Interface	1
3200300	FEP Tubing, 1/16" x 0.1mm, 10 metres	1
3200063	FEP Tubing, 1/16" x 0.25mm, 10 metres	1
3200064	FEP Tubing, 1/16" x 0.5mm, 10 metres	1
3000056	Plug FEP (pack of 10) 1.6 mm	1
3200087	2-way In-line Valve	3
3000477	End Fittings and Ferrules for 1.6mm Tubing (pack of 10)	1
3000398	PTFE Tube Cutter	1
3000399	1/4 - 28 Straight Female Coupling, ECTFE	2
3200245	Ferrule with Integrated Filter (pack of 10)	1

3000397	T-connector ETFE	1
3800193	Pneumatic Connector	1
3200293	Digital Microscope	1
3200310	Microscope Stage Adaptor Kit for Edge Interfaces	1
3200095	Mitos Sensor Display (Optional)	3
3200244	Mitos Flow Rate Sensor, mixed pack of 3 (Optional)	1

Appendix B: Pressure Based Fluid Pumping

The educational microfluidic system by default does not contain flow rate sensors. Considering the near laminar flow in microenvironments, it relies upon the Stokes approximation. In this flow regime, the pressure is directly proportional to the flow rate, and is dependent on material properties such as density, viscosity, and the dimensional information such as flow cross sectional area and flow path length.

A useful approximation is given by the Hagen–Poiseuille equation, also known as the Hagen–Poiseuille law, Poiseuille law or Poiseuille equation. This is a physical law that gives the pressure drop in a fluid flowing through a long cylindrical pipe $\Delta P = \left(\frac{8\mu L}{\pi r^4}\right) Q$ where the pressure drop across a pipe of fixed geometry is directly proportional to the flow rate. The quantity in the parenthesis is the effective flow resistance and can be compared analogously to the Ohm's law for circuits ($V=R \cdot I$).

A similar algorithm is implemented in an online flow calculator on the Dolomite website** and users are recommended to refer to this when setting up flow resistances. This calculator uses a more general representation that can also handle rectangular cross sectioned flow paths such as those found in Dolomite's chips. The isotropic wet etch lithography results in near rectangular cross sections. The calculator presents the following options:

- Displacement Pumping – Input flow rate (Q) and obtain the back gradient (ΔP).
- Pressure Driven Flow – Input the pressure gradient (ΔP) and obtain the effective flow rate (Q)

A step-wise example is presented on the following page for the following parameters.

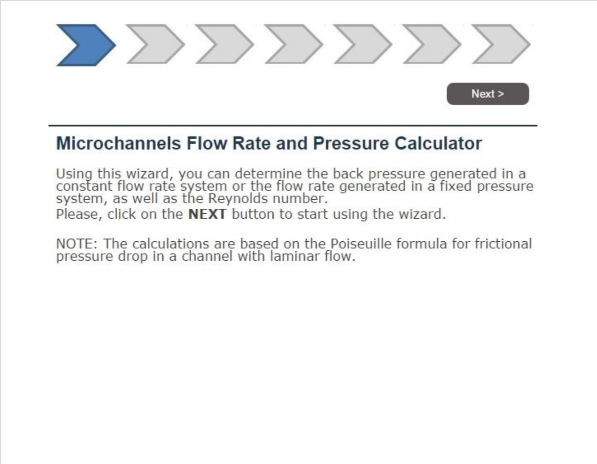
Tube Diameter	100 µm
Tube Length	1500 mm
Pumping Method	Pressure Driven Flow
Viscosity	1 cP – Water at room temperature
Density	1 g/cm^3 – Water at room temperature
Pressure	100 mbar
Calculated Flow Rate	**0.98 µL/min**

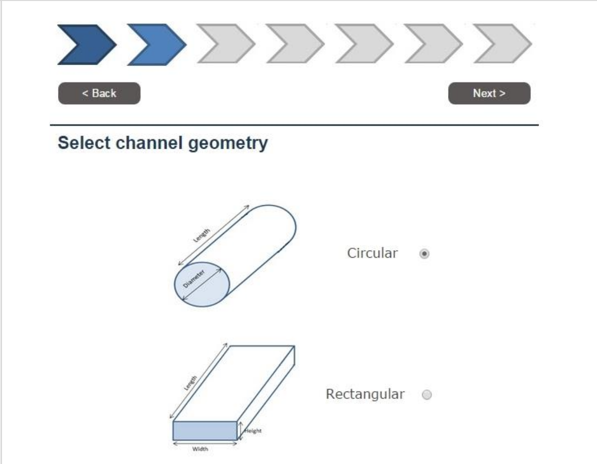
The pressure gradient assumes atmospheric pressure at the outlet of the tube. Also, the calculator assumes single channel uncouple flow. In case of dual channel couple flow, users are advised to refer to the calculation in another application note††.

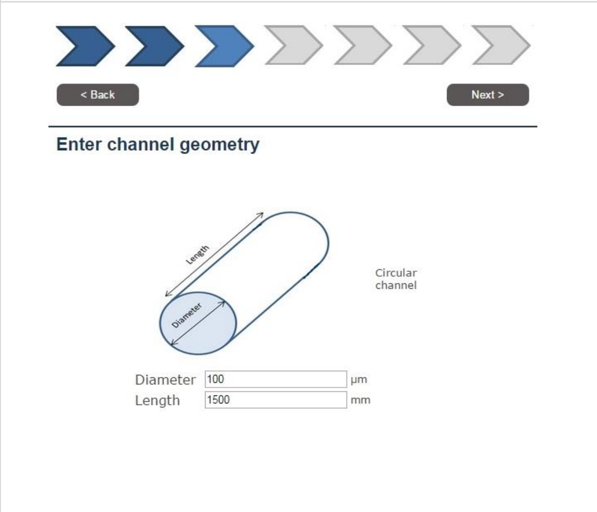
If actual flow rate information is required, independent free standing flow sensors can be purchased from Dolomite. These are in-line sensors precalibrated for a number of fluids. User calibration can be done for custom fluids. USB connectivity ensures that in addition to reading the data off the display, data can also be logged on a PC.

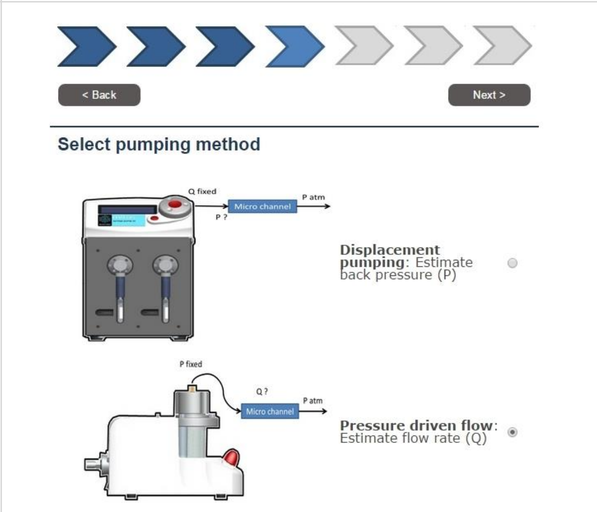
** http://www.dolomite-microfluidics.com/en/applications/application-notes/172

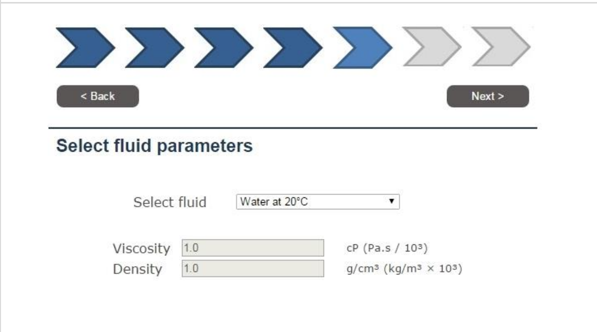
†† http://www.dolomite-microfluidics.com/images/stories/PDFs/application_notes/Droplet_Junction_Chip_characterisation_-_application_note.pdf

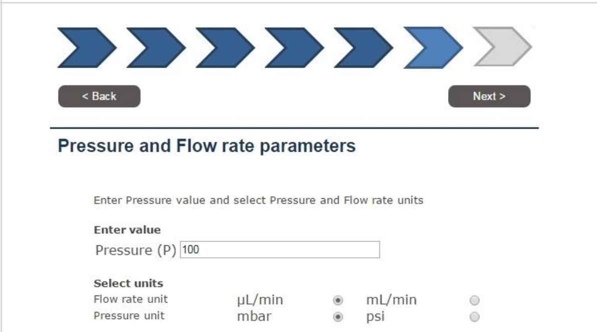

Next >
Microchannels Flow Rate and Pressure Calculator
Using this wizard, you can determine the back pressure generated in a constant flow rate system or the flow rate generated in a fixed pressure system, as well as the Reynolds number.
Please, click on the NEXT button to start using the wizard.
NOTE: The calculations are based on the Poiseuille formula for frictional pressure drop in a channel with laminar flow.

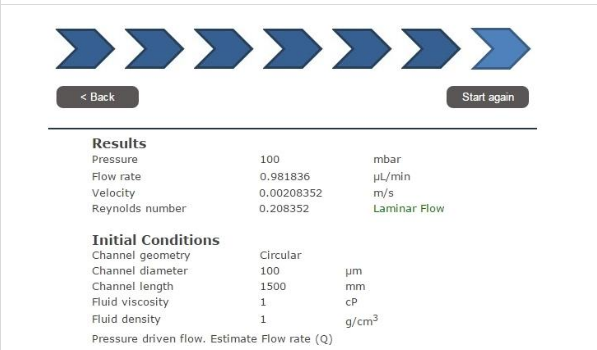

< Back
Next >
Select channel geometry
Length
Diameter
Circular
Length
Height
Width
Rectangular


< Back
Next >
Enter channel geometry
Length
Diameter
Circular channel
Diameter 100 µm
Length 1500 mm


< Back
Next >
Select pumping method
Q fixed
Micro channel
P atm
P ?
Displacement pumping: Estimate back pressure (P)
P fixed
Q ?
Micro channel
P atm
Pressure driven flow: Estimate flow rate (Q)


< Back
Next >
Select fluid parameters
Select fluid Water at 20°C
Viscosity 1.0 cP (Pa.s / 10³)
Density 1.0 g/cm³ (kg/m³ × 10³)


< Back
Next >
Pressure and Flow rate parameters
Enter Pressure value and select Pressure and Flow rate units
Enter value
Pressure (P) 100
Select units
Flow rate unit µL/min mL/min
Pressure unit mbar psi


< Back
Start again
Results
Pressure 100 mbar
Flow rate 0.981836 µL/min
Velocity 0.00208352 m/s
Reynolds number 0.208352 Laminar Flow
Initial Conditions
Channel geometry Circular
Channel diameter 100 µm
Channel length 1500 mm
Fluid viscosity 1 cP
Fluid density 1 g/cm³
Pressure driven flow. Estimate Flow rate (Q)

dolomite

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