Shear stress and shear rates for all channel µ-Slides

- based on numerical calculations

Table of content:

Formulas for shear stress and shear rates – for all ibidi channel slides

The shear stress is based on the dynamical viscosity of water at 22 °C, η = 0.01 dyn·s/cm² (=1 mPa·s = 1cP). Please refer to page 5 for calculation with different viscosity. For simplicity the calculations include conversions of units (not shown).

Φ flow rate τ shear stress γ shear rate η dynamical viscosity (η = 0.01 dyn·s/cm²)

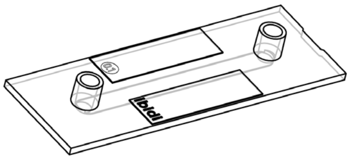
μ-Slide I [0.1] Luer:

Shear stress

$$\tau[\frac{dyn}{cm^2}] = 20.255\ \Phi[\frac{ml}{min}]$$

Shear rate

$$\gamma[s^{-1}] = 2025.5\ \Phi[\frac{ml}{min}]$$



Tables on page 8

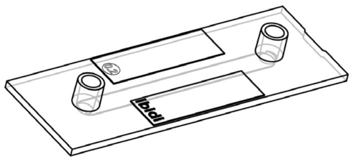
μ-Slide I [0.2] Luer:

Shear stress

$$\tau[\frac{dyn}{cm^2}] = 5.129\ \Phi[\frac{ml}{min}]$$

Shear rate

$$\gamma[s^{-1}] = 512.9\ \Phi[\frac{ml}{min}]$$



Tables on page 9

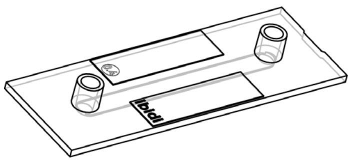
μ-Slide I [0.4] Luer:

Shear stress

$$\tau[\frac{dyn}{cm^2}] = 1.316\ \Phi[\frac{ml}{min}]$$

Shear rate

$$\gamma[s^{-1}] = 131.6\ \Phi[\frac{ml}{min}]$$



Tables on page 10

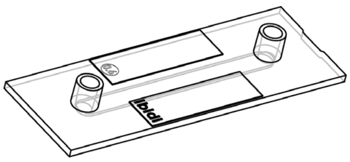
μ-Slide I [0.6] Luer:

Shear stress

$$\tau[\frac{dyn}{cm^2}] = 0.601\ \Phi[\frac{ml}{min}]$$

Shear rate

$$\gamma[s^{-1}] = 60.1\ \Phi[\frac{ml}{min}]$$



Tables on page 11

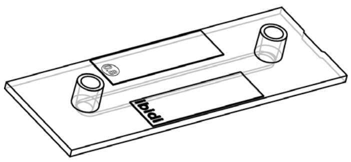
μ-Slide I [0.8] Luer:

Shear stress

$$\tau[\frac{dyn}{cm^2}] = 0.347\ \Phi[\frac{ml}{min}]$$

Shear rate

$$\gamma[s^{-1}] = 34.7\ \Phi[\frac{ml}{min}]$$

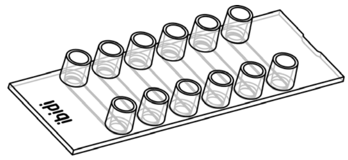


Tables on page 12

µ-Slide VI $^{0.4}$:

Shear stress $$\tau[\frac{dyn}{cm^2}] = 1.761\,\Phi[\frac{ml}{min}]$$

Shear rate $$\gamma[s^{-1}] = 176.1\,\Phi[\frac{ml}{min}]$$

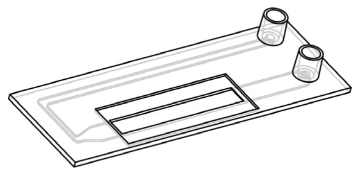


Tables on page 13

µ-Slide upright $^{0.8}$:

Shear stress $$\tau[\frac{dyn}{cm^2}] = 0.347\,\Phi[\frac{ml}{min}]$$

Shear rate $$\gamma[s^{-1}] = 34.7\,\Phi[\frac{ml}{min}]$$



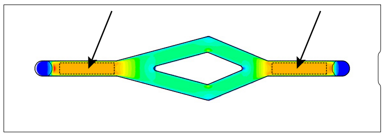
Tables on page 14

µ-Slide y-shaped:

(single channel area)

Shear stress $$\tau[\frac{dyn}{cm^2}] = 2.274\,\Phi[\frac{ml}{min}]$$

Shear rate $$\gamma[s^{-1}] = 227.4\,\Phi[\frac{ml}{min}]$$



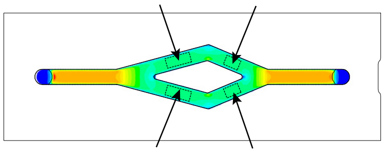
Numerical simulations in Application Note 18 on www.ibidi.com.

µ-Slide y-shaped:

(branched area)

Shear stress $$\tau[\frac{dyn}{cm^2}] = 1.137\,\Phi[\frac{ml}{min}]$$

Shear rate $$\gamma[s^{-1}] = 113.7\,\Phi[\frac{ml}{min}]$$

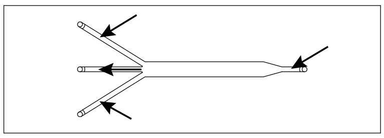


µ-Slide III ^{3in1}:

(1 mm channels)

Shear stress $$\tau[\frac{dyn}{cm^2}] = 7.741\,\Phi[\frac{ml}{min}]$$

Shear rate $$\gamma[s^{-1}] = 774.1\,\Phi[\frac{ml}{min}]$$

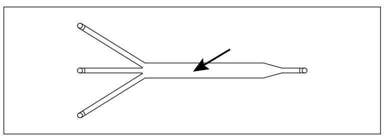


µ-Slide III ^{3in1}:

(3 mm channel)

Shear stress $$\tau[\frac{dyn}{cm^2}] = 2.274\,\Phi[\frac{ml}{min}]$$

Shear rate $$\gamma[s^{-1}] = 227.4\,\Phi[\frac{ml}{min}]$$



IMPORTANT NOTE:
The flow rate Φ is given in [µl/min] for µ-Slide VI $^{0.1}$ and µ-Slide III $^{0.1}$: For all other slides it is given in [ml/min]

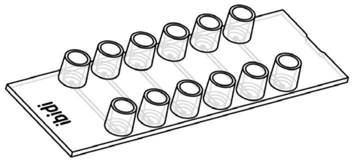
µ-Slide VI $^{0.1}$:

Shear stress

$$\tau[\frac{dyn}{cm^2}] = 0.107\ \Phi[\frac{\mu l}{min}]$$

Shear rate

$$\gamma[s^{-1}] = 10.7\ \Phi[\frac{\mu l}{min}]$$



Tables on page 14

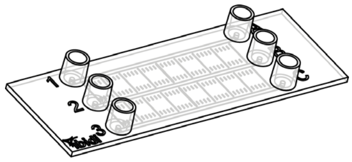
µ-Slide III $^{0.1}$:

Shear stress

$$\tau[\frac{dyn}{cm^2}] = 0.107\ \Phi[\frac{\mu l}{min}]$$

Shear rate

$$\gamma[s^{-1}] = 10.7\ \Phi[\frac{\mu l}{min}]$$



Tables on page 15

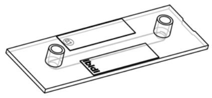
Φ flow rate
τ shear stress
γ shear rate
η dynamical viscosity

Shear stress calculation with different dynamical viscosity η

For simplicity the calculations include conversions of units (not shown).

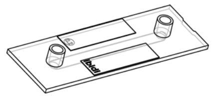
μ-Slide I $^{0.1}$ Luer

$$\tau[\frac{dyn}{cm^2}] = \eta\,[\frac{dyn \cdot s}{cm^2}] \cdot 2025.5\ \Phi[\frac{ml}{min}]$$



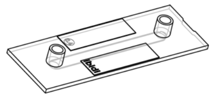
μ-Slide I $^{0.2}$ Luer

$$\tau[\frac{dyn}{cm^2}] = \eta\,[\frac{dyn \cdot s}{cm^2}] \cdot 512.9\ \Phi[\frac{ml}{min}]$$



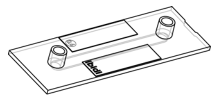
μ-Slide I $^{0.4}$ Luer

$$\tau[\frac{dyn}{cm^2}] = \eta\,[\frac{dyn \cdot s}{cm^2}] \cdot 131.6\ \Phi[\frac{ml}{min}]$$



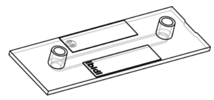
μ-Slide I $^{0.6}$ Luer

$$\tau[\frac{dyn}{cm^2}] = \eta\,[\frac{dyn \cdot s}{cm^2}] \cdot 60.1\,\Phi[\frac{ml}{min}]$$



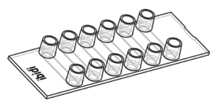
μ-Slide I $^{0.8}$ Luer

$$\tau[\frac{dyn}{cm^2}] = \eta\,[\frac{dyn \cdot s}{cm^2}] \cdot 34.7\ \Phi[\frac{ml}{min}]$$



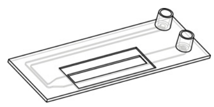
μ-Slide VI $^{0.4}$

$$\tau[\frac{dyn}{cm^2}] = \eta\,[\frac{dyn \cdot s}{cm^2}] \cdot 176.1\,\Phi[\frac{ml}{min}]$$



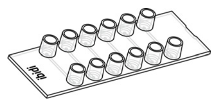
μ-Slide upright $^{0.8}$

$$\tau[\frac{dyn}{cm^2}] = \eta\,[\frac{dyn \cdot s}{cm^2}] \cdot 34.7\ \Phi[\frac{ml}{min}]$$



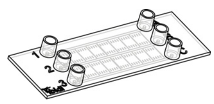
μ-Slide VI $^{0.1}$

$$\tau[\frac{dyn}{cm^2}] = \eta\,[\frac{dyn \cdot s}{cm^2}] \cdot 10.7\ \Phi[\frac{\mu l}{min}]$$



μ-Slide III $^{0.1}$

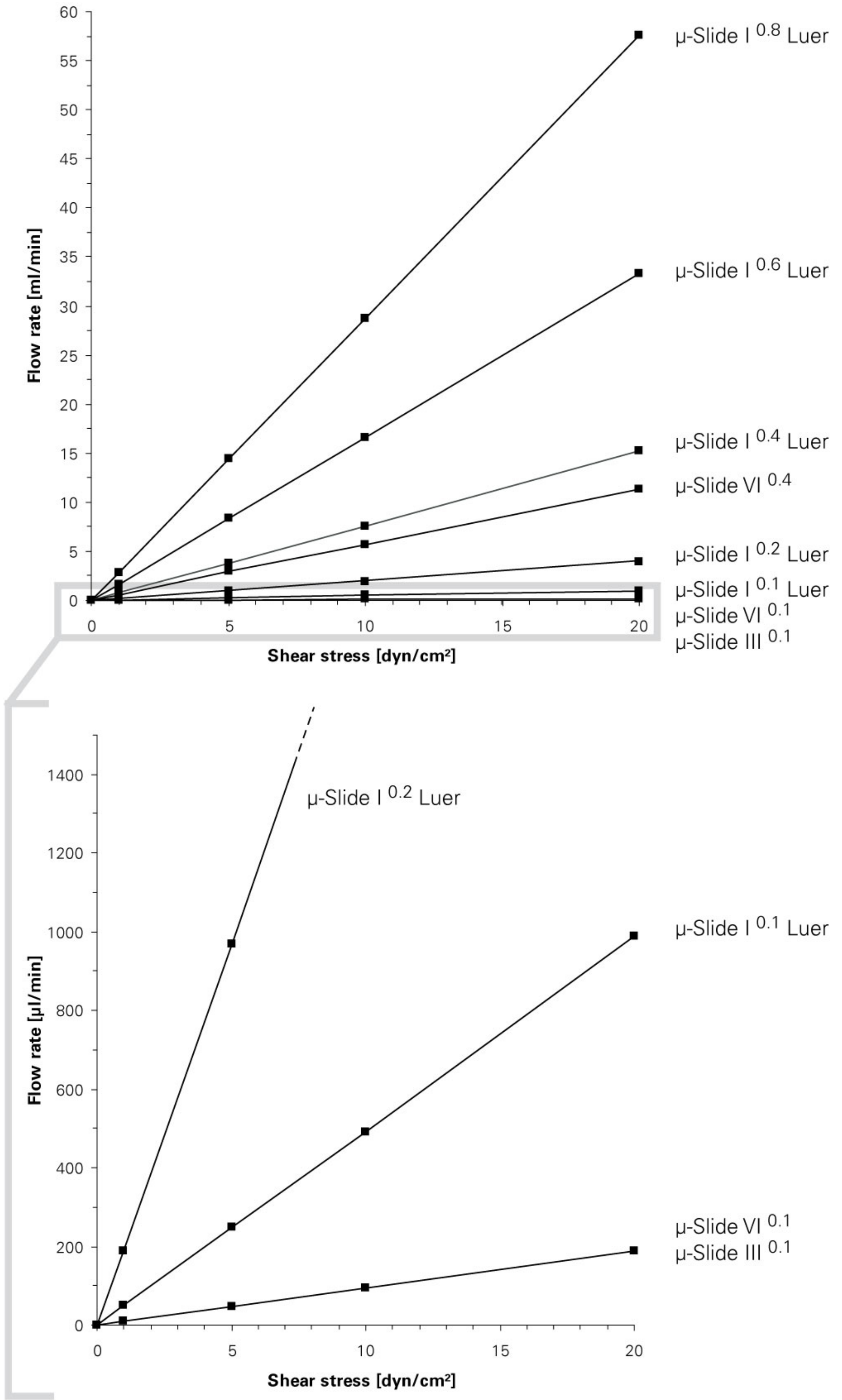
$$\tau[\frac{dyn}{cm^2}] = \eta\,[\frac{dyn \cdot s}{cm^2}] \cdot 10.7\ \Phi[\frac{\mu l}{min}]$$



IMPORTANT NOTE:
The flow rate Φ is given in [μl/min] for μ-Slide VI $^{0.1}$ and μ-Slide III $^{0.1}$: For all other slides it is given in [ml/min]

Application Note 11

Ranges of shear stress and flow rates



Experimental Aspects

In order to set up the right experiment you first should define the following parameters of your experiment:

- Cell type (vessel specific)
- **Shear stress** (vessel specific)
- Medium and viscosity of the needed medium
- Available volume
- Available amount of cells
- Duration
- Flow characteristics (continuous, one way, oscillating…)
- Needed number of cells, i.e. growth area required
- Coating of the surface (cell type dependent)
- More experimental details, e.g. addition of substances
- Experimental endpoint

Choosing the right slide

The selection of the slide determines the range of shear stress that can be applied (see page 6). Generally the following correlations can be applied:

- A small channel generates high shear stress values.
- A large channel generates low shear stress values.

Choosing the right flow rate

Once you have chosen a slide you can determine the required flow rate to achieve the desired shear stress as given by the formulas in this Application Note.

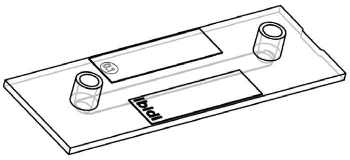
Choosing the right perfusion system (pump)

Depending on setup specifications (duration, volume, flow characteristics…) different pumps are optimal.
For long term cultivation (e.g. endothelial cell conditioning under flow) we recommend the ibidi Pump System.

Shear Stress table for µ-Slide I $^{0.1}$ Luer for viscosity η=0.01 dyn·s/cm²:

t[dyn/cm^2]	Φ[ml/min]	t[dyn/cm^2]	Φ[ml/min]	t[dyn/cm^2]	Φ[ml/min]
0,1	0,00	4	0,20	25	1,23
0,2	0,01	5	0,25	30	1,48
0,3	0,01	6	0,30	35	1,73
0,4	0,02	7	0,35	40	1,97
0,5	0,02	8	0,39	45	2,22
0,6	0,03	9	0,44	50	2,47
0,7	0,03	10	0,49	55	2,72
0,8	0,04	11	0,54	60	2,96
0,9	0,04	12	0,59	65	3,21
1	0,05	13	0,64	70	3,46
1,2	0,06	14	0,69	75	3,70
1,4	0,07	15	0,74	80	3,95
1,6	0,08	16	0,79	85	4,20
1,8	0,09	17	0,84	90	4,44
2	0,10	18	0,89	95	4,69
2,2	0,11	19	0,94	100	4,94
2,4	0,12	20	0,99	105	5,18
2,6	0,13	21	1,04	110	5,43
2,8	0,14	22	1,09	115	5,68
3	0,15	23	1,14	120	5,92

$$\tau[\frac{dyn}{cm^2}] = 20.255\ \Phi[\frac{ml}{min}]$$



Shear Rate table for µ-Slide I $^{0.1}$ Luer:

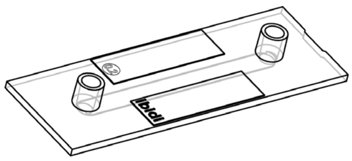
γ[1/s]	Φ[ml/min]	γ[1/s]	Φ[ml/min]	γ[1/s]	Φ[ml/min]
5	0,00	600	0,30	7000	3,46
10	0,00	700	0,35	7500	3,70
20	0,01	800	0,39	8000	3,95
30	0,01	900	0,44	8500	4,20
40	0,02	1000	0,49	9000	4,44
50	0,02	1250	0,62	9500	4,69
125	0,06	1500	0,74	10000	4,94
150	0,07	1750	0,86	10500	5,18
175	0,09	1800	0,89	11000	5,43
200	0,10	1850	0,91	11500	5,68
225	0,11	1900	0,94	12000	5,92
250	0,12	2000	0,99	12500	6,17
275	0,14	2500	1,23	13000	6,42
300	0,15	3000	1,48	13500	6,67
325	0,16	3500	1,73	14000	6,91
350	0,17	4000	1,97	14500	7,16
375	0,19	4500	2,22	15000	7,41
400	0,20	5000	2,47	15500	7,65
450	0,22	5500	2,72	16000	7,90
500	0,25	6000	2,96	16500	8,15

$$\gamma[s^{-1}] = 2025.5\ \Phi[\frac{ml}{min}]$$

Shear Stress table for μ-Slide I $^{0.2}$ Luer for viscosity η=0.01 dyn·s/cm^2:

τ[dyn/cm^2]	Φ[ml/min]	τ[dyn/cm^2]	Φ[ml/min]	τ[dyn/cm^2]	Φ[ml/min]
0,1	0,02	4	0,78	25	4,87
0,2	0,04	5	0,97	30	5,85
0,3	0,06	6	1,17	35	6,82
0,4	0,08	7	1,36	40	7,80
0,5	0,10	8	1,56	45	8,77
0,6	0,12	9	1,75	50	9,75
0,7	0,14	10	1,95	55	10,72
0,8	0,16	11	2,14	60	11,70
0,9	0,18	12	2,34	65	12,67
1	0,19	13	2,53	70	13,65
1,2	0,23	14	2,73	75	14,62
1,4	0,27	15	2,92	80	15,60
1,6	0,31	16	3,12	85	16,57
1,8	0,35	17	3,31	90	17,55
2	0,39	18	3,51	95	18,52
2,2	0,43	19	3,70	100	19,50
2,4	0,47	20	3,90	105	20,47
2,6	0,51	21	4,09	110	21,45
2,8	0,55	22	4,29	115	22,42
3	0,58	23	4,48	120	23,39

$$\tau[\frac{dyn}{cm^2}] = 5.129\ \Phi[\frac{ml}{min}]$$



Shear Rate table for μ-Slide I $^{0.2}$ Luer:

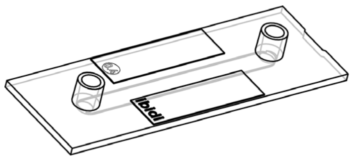
γ[1/s]	Φ[ml/min]	γ[1/s]	Φ[ml/min]	γ[1/s]	Φ[ml/min]
5	0,01	600	1,17	7000	13,65
10	0,02	700	1,36	7500	14,62
20	0,04	800	1,56	8000	15,60
30	0,06	900	1,75	8500	16,57
40	0,08	1000	1,95	9000	17,55
50	0,10	1250	2,44	9500	18,52
125	0,24	1500	2,92	10000	19,50
150	0,29	1750	3,41	10500	20,47
175	0,34	1800	3,51	11000	21,45
200	0,39	1850	3,61	11500	22,42
225	0,44	1900	3,70	12000	23,39
250	0,49	2000	3,90	12500	24,37
275	0,54	2500	4,87	13000	25,34
300	0,58	3000	5,85	13500	26,32
325	0,63	3500	6,82	14000	27,29
350	0,68	4000	7,80	14500	28,27
375	0,73	4500	8,77	15000	29,24
400	0,78	5000	9,75	15500	30,22
450	0,88	5500	10,72	16000	31,19
500	0,97	6000	11,70	16500	32,17

$$\gamma[s^{-1}] = 512.9\ \Phi[\frac{ml}{min}]$$

Shear Stress table for µ-Slide I $^{0.4}$ Luer for viscosity η=0.01 dyn·s/cm²:

τ[dyn/cm²]	Φ[ml/min]	τ[dyn/cm²]	Φ[ml/min]	τ[dyn/cm²]	Φ[ml/min]
0,1	0,08	4	3,04	25	18,99
0,2	0,15	5	3,80	30	22,79
0,3	0,23	6	4,56	35	26,59
0,4	0,30	7	5,32	40	30,39
0,5	0,38	8	6,08	45	34,18
0,6	0,46	9	6,84	50	37,98
0,7	0,53	10	7,60	55	41,78
0,8	0,61	11	8,36	60	45,58
0,9	0,68	12	9,12	65	49,38
1	0,76	13	9,88	70	53,18
1,2	0,91	14	10,64	75	56,97
1,4	1,06	15	11,39	80	60,77
1,6	1,22	16	12,15	85	64,57
1,8	1,37	17	12,91	90	68,37
2	1,52	18	13,67	95	72,17
2,2	1,67	19	14,43	100	75,97
2,4	1,82	20	15,19	105	79,76
2,6	1,98	21	15,95	110	83,56
2,8	2,13	22	16,71	115	87,36
3	2,28	23	17,47	120	91,16

$$\tau[\frac{dyn}{cm^2}] = 1.316\ \Phi[\frac{ml}{min}]$$



Shear Rate table for µ-Slide I $^{0.4}$ Luer:

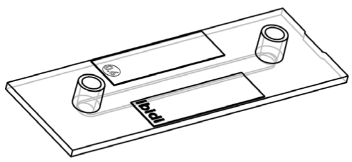
γ[1/s]	Φ[ml/min]	γ[1/s]	Φ[ml/min]	γ[1/s]	Φ[ml/min]
5	0,04	600	4,56	7000	53,18
10	0,08	700	5,32	7500	56,97
20	0,15	800	6,08	8000	60,77
30	0,23	900	6,84	8500	64,57
40	0,30	1000	7,60	9000	68,37
50	0,38	1250	9,50	9500	72,17
125	0,95	1500	11,39	10000	75,97
150	1,14	1750	13,29	10500	79,76
175	1,33	1800	13,67	11000	83,56
200	1,52	1850	14,05	11500	87,36
225	1,71	1900	14,43	12000	91,16
250	1,90	2000	15,19	12500	94,96
275	2,09	2500	18,99	13000	98,76
300	2,28	3000	22,79	13500	102,55
325	2,47	3500	26,59	14000	106,35
350	2,66	4000	30,39	14500	110,15
375	2,85	4500	34,18	15000	113,95
400	3,04	5000	37,98	15500	117,75
450	3,42	5500	41,78	16000	121,55
500	3,80	6000	45,58	16500	125,34

$$\gamma[s^{-1}] = 131.6\ \Phi[\frac{ml}{min}]$$

Shear Stress table for µ-Slide I $^{0.6}$ Luer for viscosity η=0.01 dyn·s/cm²:

τ[dyn/cm²]	Φ[ml/min]	τ[dyn/cm²]	Φ[ml/min]	τ[dyn/cm²]	Φ[ml/min]
0,1	0,17	4	6,66	25	41,60
0,2	0,33	5	8,32	30	49,92
0,3	0,50	6	9,98	35	58,24
0,4	0,67	7	11,65	40	66,55
0,5	0,83	8	13,31	45	74,87
0,6	1,00	9	14,97	50	83,19
0,7	1,16	10	16,64	55	91,51
0,8	1,33	11	18,30	60	99,83
0,9	1,50	12	19,97	65	108,15
1	1,66	13	21,63	70	116,47
1,2	2,00	14	23,29	75	124,79
1,4	2,33	15	24,96	80	133,11
1,6	2,66	16	26,62	85	141,43
1,8	2,99	17	28,29	90	149,75
2	3,33	18	29,95	95	158,07
2,2	3,66	19	31,61	100	166,39
2,4	3,99	20	33,28	105	174,71
2,6	4,33	21	34,94	110	183,03
2,8	4,66	22	36,61	115	191,34
3	4,99	23	38,27	120	199,66

$$\tau[\frac{dyn}{cm^2}] = 0.601\,\Phi[\frac{ml}{min}]$$



Shear Rate table for µ-Slide I $^{0.6}$ Luer:

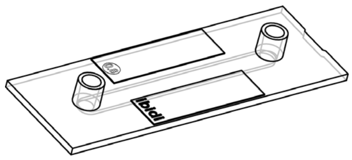
γ[1/s]	Φ[ml/min]	γ[1/s]	Φ[ml/min]	γ[1/s]	Φ[ml/min]
5	0,08	600	9,98	7000	116,47
10	0,17	700	11,65	7500	124,79
20	0,33	800	13,31	8000	133,11
30	0,50	900	14,97	8500	141,43
40	0,67	1000	16,64	9000	149,75
50	0,83	1250	20,80	9500	158,07
125	2,08	1500	24,96	10000	166,39
150	2,50	1750	29,12	10500	174,71
175	2,91	1800	29,95	11000	183,03
200	3,33	1850	30,78	11500	191,34
225	3,74	1900	31,61	12000	199,66
250	4,16	2000	33,28	12500	207,98
275	4,58	2500	41,60	13000	216,30
300	4,99	3000	49,92	13500	224,62
325	5,41	3500	58,24	14000	232,94
350	5,82	4000	66,55	14500	241,26
375	6,24	4500	74,87	15000	249,58
400	6,66	5000	83,19	15500	257,90
450	7,49	5500	91,51	16000	266,22
500	8,32	6000	99,83	16500	274,54

$$\gamma[s^{-1}] = 60.1\,\Phi[\frac{ml}{min}]$$

Shear Stress table for µ-Slide I $^{0.8}$ Luer for viscosity η=0.01 dyn·s/cm²:

τ[dyn/cm²]	Φ[ml/min]	τ[dyn/cm²]	Φ[ml/min]	τ[dyn/cm²]	Φ[ml/min]
0,1	0,29	4	11,51	25	71,95
0,2	0,58	5	14,39	30	86,34
0,3	0,86	6	17,27	35	100,73
0,4	1,15	7	20,15	40	115,11
0,5	1,44	8	23,02	45	129,50
0,6	1,73	9	25,90	50	143,89
0,7	2,01	10	28,78	55	158,28
0,8	2,30	11	31,66	60	172,67
0,9	2,59	12	34,53	65	187,06
1,0	2,88	13	37,41	70	201,45
1,2	3,45	14	40,29	75	215,84
1,4	4,03	15	43,17	80	230,23
1,6	4,60	16	46,05	85	244,62
1,8	5,18	17	48,92	90	259,01
2,0	5,76	18	51,80	95	273,40
2,2	6,33	19	54,68	100	287,79
2,4	6,91	20	57,56	105	302,18
2,6	7,48	21	60,44	110	316,56
2,8	8,06	22	63,31	115	330,95
3,0	8,63	23	66,19	120	345,34

$$\tau[\frac{dyn}{cm^2}] = 0.347\ \Phi[\frac{ml}{min}]$$



Shear Rate table for µ-Slide I $^{0.8}$ Luer:

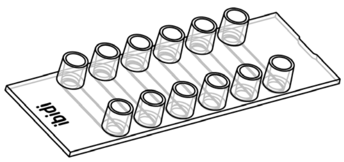
γ[1/s]	Φ[ml/min]	γ[1/s]	Φ[ml/min]	γ[1/s]	Φ[ml/min]
5	0,14	600	17,27	7000	201,45
10	0,29	700	20,15	7500	215,84
20	0,58	800	23,02	8000	230,23
30	0,86	900	25,90	8500	244,62
40	1,15	1000	28,78	9000	259,01
50	1,44	1250	35,97	9500	273,40
125	3,60	1500	43,17	10000	287,79
150	4,32	1750	50,36	10500	302,18
175	5,04	1800	51,80	11000	316,56
200	5,76	1850	53,24	11500	330,95
225	6,48	1900	54,68	12000	345,34
250	7,19	2000	57,56	12500	359,73
275	7,91	2500	71,95	13000	374,12
300	8,63	3000	86,34	13500	388,51
325	9,35	3500	100,73	14000	402,90
350	10,07	4000	115,11	14500	417,29
375	10,79	4500	129,50	15000	431,68
400	11,51	5000	143,89	15500	446,07
450	12,95	5500	158,28	16000	460,46
500	14,39	6000	172,67	16500	474,85

$$\gamma[s^{-1}] = 34.7\ \Phi[\frac{ml}{min}]$$

Shear Stress table for µ-Slide VI $^{0.4}$ for viscosity η=0.01 dyn·s/cm²:

τ[dyn/cm²]	Φ[ml/min]	τ[dyn/cm²]	Φ[ml/min]	τ[dyn/cm²]	Φ[ml/min]
0,1	0,06	4	2,27	25	14,19
0,2	0,11	5	2,84	30	17,03
0,3	0,17	6	3,41	35	19,87
0,4	0,23	7	3,97	40	22,71
0,5	0,28	8	4,54	45	25,54
0,6	0,34	9	5,11	50	28,38
0,7	0,40	10	5,68	55	31,22
0,8	0,45	11	6,24	60	34,06
0,9	0,51	12	6,81	65	36,90
1,0	0,57	13	7,38	70	39,74
1,2	0,68	14	7,95	75	42,57
1,4	0,79	15	8,51	80	45,41
1,6	0,91	16	9,08	85	48,25
1,8	1,02	17	9,65	90	51,09
2,0	1,14	18	10,22	95	53,93
2,2	1,25	19	10,79	100	56,77
2,4	1,36	20	11,35	105	59,60
2,6	1,48	21	11,92	110	62,44
2,8	1,59	22	12,49	115	65,28
3,0	1,70	23	13,06	120	68,12

$$\tau[\frac{dyn}{cm^2}] = 1.761\,\Phi[\frac{ml}{min}]$$



Shear Rate table for µ-Slide VI $^{0.4}$:

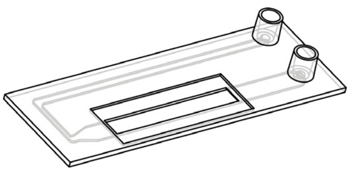
γ[1/s]	Φ[ml/min]	γ[1/s]	Φ[ml/min]	γ[1/s]	Φ[ml/min]
5	0,03	600	3,41	7000	39,74
10	0,06	700	3,97	7500	42,57
20	0,11	800	4,54	8000	45,41
30	0,17	900	5,11	8500	48,25
40	0,23	1000	5,68	9000	51,09
50	0,28	1250	7,10	9500	53,93
125	0,71	1500	8,51	10000	56,77
150	0,85	1750	9,93	10500	59,60
175	0,99	1800	10,22	11000	62,44
200	1,14	1850	10,50	11500	65,28
225	1,28	1900	10,79	12000	68,12
250	1,42	2000	11,35	12500	70,96
275	1,56	2500	14,19	13000	73,80
300	1,70	3000	17,03	13500	76,63
325	1,84	3500	19,87	14000	79,47
350	1,99	4000	22,71	14500	82,31
375	2,13	4500	25,54	15000	85,15
400	2,27	5000	28,38	15500	87,99
450	2,55	5500	31,22	16000	90,83
500	2,84	6000	34,06	16500	93,66

$$\gamma[s^{-1}] = 176.1\,\Phi[\frac{ml}{min}]$$

Shear Stress table for µ-Slide upright $^{0.8}$ for viscosity η=0.01 dyn·s/cm²:

τ[dyn/cm²]	Φ[ml/min]	τ[dyn/cm²]	Φ[ml/min]	τ[dyn/cm²]	Φ[ml/min]
0,1	0,29	4	11,51	25	71,95
0,2	0,58	5	14,39	30	86,34
0,3	0,86	6	17,27	35	100,73
0,4	1,15	7	20,15	40	115,11
0,5	1,44	8	23,02	45	129,50
0,6	1,73	9	25,90	50	143,89
0,7	2,01	10	28,78	55	158,28
0,8	2,30	11	31,66	60	172,67
0,9	2,59	12	34,53	65	187,06
1,0	2,88	13	37,41	70	201,45
1,2	3,45	14	40,29	75	215,84
1,4	4,03	15	43,17	80	230,23
1,6	4,60	16	46,05	85	244,62
1,8	5,18	17	48,92	90	259,01
2,0	5,76	18	51,80	95	273,40
2,2	6,33	19	54,68	100	287,79
2,4	6,91	20	57,56	105	302,18
2,6	7,48	21	60,44	110	316,56
2,8	8,06	22	63,31	115	330,95
3,0	8,63	23	66,19	120	345,34

$$\tau[\frac{dyn}{cm^2}] = 0.347\ \Phi[\frac{ml}{min}]$$



Shear Rate table for µ-Slide upright $^{0.8}$:

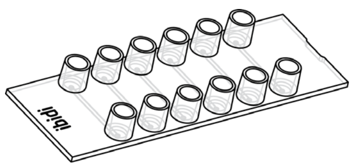
γ[1/s]	Φ[ml/min]	γ[1/s]	Φ[ml/min]	γ[1/s]	Φ[ml/min]
5	0,14	600	17,27	7000	201,45
10	0,29	700	20,15	7500	215,84
20	0,58	800	23,02	8000	230,23
30	0,86	900	25,90	8500	244,62
40	1,15	1000	28,78	9000	259,01
50	1,44	1250	35,97	9500	273,40
125	3,60	1500	43,17	10000	287,79
150	4,32	1750	50,36	10500	302,18
175	5,04	1800	51,80	11000	316,56
200	5,76	1850	53,24	11500	330,95
225	6,48	1900	54,68	12000	345,34
250	7,19	2000	57,56	12500	359,73
275	7,91	2500	71,95	13000	374,12
300	8,63	3000	86,34	13500	388,51
325	9,35	3500	100,73	14000	402,90
350	10,07	4000	115,11	14500	417,29
375	10,79	4500	129,50	15000	431,68
400	11,51	5000	143,89	15500	446,07
450	12,95	5500	158,28	16000	460,46
500	14,39	6000	172,67	16500	474,85

$$\gamma[s^{-1}] = 34.7\ \Phi[\frac{ml}{min}]$$

Shear Stress table for µ-Slide VI $^{0.1}$ for viscosity η=0.01 dyn·s/cm^2:

τ[dyn/cm^2]	Φ[µl/min]	τ[dyn/cm^2]	Φ[µl/min]	τ[dyn/cm^2]	Φ[µl/min]
0,1	0,94	4	37,48	25	234,24
0,2	1,87	5	46,85	30	281,08
0,3	2,81	6	56,22	35	327,93
0,4	3,75	7	65,59	40	374,78
0,5	4,68	8	74,96	45	421,62
0,6	5,62	9	84,32	50	468,47
0,7	6,56	10	93,69	55	515,32
0,8	7,50	11	103,06	60	562,17
0,9	8,43	12	112,43	65	609,01
1	9,37	13	121,80	70	655,86
1,2	11,24	14	131,17	75	702,71
1,4	13,12	15	140,54	80	749,55
1,6	14,99	16	149,91	85	796,40
1,8	16,86	17	159,28	90	843,25
2	18,74	18	168,65	95	890,10
2,2	20,61	19	178,02	100	936,94
2,4	22,49	20	187,39	105	983,79
2,6	24,36	21	196,76	110	1030,64
2,8	26,23	22	206,13	115	1077,49
3	28,11	23	215,50	120	1124,33

$$\tau[\frac{dyn}{cm^2}] = 0.10673\ \Phi[\frac{\mu l}{min}]$$



Shear Rate table for µ-Slide VI $^{0.1}$:

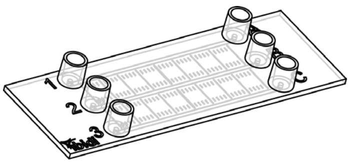
γ[1/s]	Φ[µl/min]	γ[1/s]	Φ[µl/min]	γ[1/s]	Φ[µl/min]
5	0,47	600	56,22	7000	655,86
10	0,94	700	65,59	7500	702,71
20	1,87	800	74,96	8000	749,55
30	2,81	900	84,32	8500	796,40
40	3,75	1000	93,69	9000	843,25
50	4,68	1250	117,12	9500	890,10
125	11,71	1500	140,54	10000	936,94
150	14,05	1750	163,97	10500	983,79
175	16,40	1800	168,65	11000	1030,64
200	18,74	1850	173,33	11500	1077,49
225	21,08	1900	178,02	12000	1124,33
250	23,42	2000	187,39	12500	1171,18
275	25,77	2500	234,24	13000	1218,03
300	28,11	3000	281,08	13500	1264,87
325	30,45	3500	327,93	14000	1311,72
350	32,79	4000	374,78	14500	1358,57
375	35,14	4500	421,62	15000	1405,42
400	37,48	5000	468,47	15500	1452,26
450	42,16	5500	515,32	16000	1499,11
500	46,85	6000	562,17	16500	1545,96

$$\gamma[s^{-1}] = 10.673\ \Phi[\frac{\mu l}{min}]$$

Shear Stress table for µ-Slide III $^{0.1}$ for viscosity η=0.01 dyn·s/cm²:

τ[dyn/cm²]	Φ[µl/min]	τ[dyn/cm²]	Φ[µl/min]	τ[dyn/cm²]	Φ[µl/min]
0,1	0,94	4	37,48	25	234,24
0,2	1,87	5	46,85	30	281,08
0,3	2,81	6	56,22	35	327,93
0,4	3,75	7	65,59	40	374,78
0,5	4,68	8	74,96	45	421,62
0,6	5,62	9	84,32	50	468,47
0,7	6,56	10	93,69	55	515,32
0,8	7,50	11	103,06	60	562,17
0,9	8,43	12	112,43	65	609,01
1	9,37	13	121,80	70	655,86
1,2	11,24	14	131,17	75	702,71
1,4	13,12	15	140,54	80	749,55
1,6	14,99	16	149,91	85	796,40
1,8	16,86	17	159,28	90	843,25
2	18,74	18	168,65	95	890,10
2,2	20,61	19	178,02	100	936,94
2,4	22,49	20	187,39	105	983,79
2,6	24,36	21	196,76	110	1030,64
2,8	26,23	22	206,13	115	1077,49
3	28,11	23	215,50	120	1124,33

$$\tau[\frac{dyn}{cm^2}] = 0.10673\ \Phi[\frac{\mu l}{min}]$$



Shear Rate table for µ-Slide III $^{0.1}$:

γ[1/s]	Φ[µl/min]	γ[1/s]	Φ[µl/min]	γ[1/s]	Φ[µl/min]
5	0,47	600	56,22	7000	655,86
10	0,94	700	65,59	7500	702,71
20	1,87	800	74,96	8000	749,55
30	2,81	900	84,32	8500	796,40
40	3,75	1000	93,69	9000	843,25
50	4,68	1250	117,12	9500	890,10
125	11,71	1500	140,54	10000	936,94
150	14,05	1750	163,97	10500	983,79
175	16,40	1800	168,65	11000	1030,64
200	18,74	1850	173,33	11500	1077,49
225	21,08	1900	178,02	12000	1124,33
250	23,42	2000	187,39	12500	1171,18
275	25,77	2500	234,24	13000	1218,03
300	28,11	3000	281,08	13500	1264,87
325	30,45	3500	327,93	14000	1311,72
350	32,79	4000	374,78	14500	1358,57
375	35,14	4500	421,62	15000	1405,42
400	37,48	5000	468,47	15500	1452,26
450	42,16	5500	515,32	16000	1499,11
500	46,85	6000	562,17	16500	1545,96

$$\gamma[s^{-1}] = 10.673\ \Phi[\frac{\mu l}{min}]$$

Background information

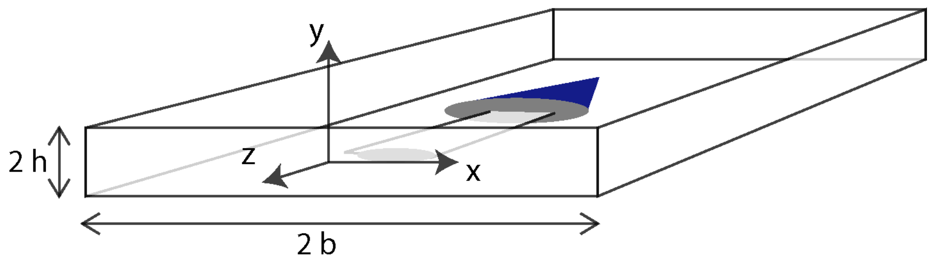
The local flow velocity v(x,y) is calculated by (Cornish 1928)[1)]:

$$v(x,y) = -\frac{1}{\eta}\frac{dp}{dz}\left\{\frac{b^2}{2} - \frac{x^2}{2} - \sum_{n=0}^{\infty}\frac{(-1)^n(2b^2)}{(2n+1)^3}\left(\frac{2}{\pi}\right)^3 \frac{\cosh\left[(2n+1)\left(\frac{\pi y}{2b}\right)\right]}{\cosh\left[(2n+1)\left(\frac{\pi h}{2b}\right)\right]}\cos\left[\frac{(2n+1)\pi x}{2b}\right]\right\}$$

The total flow Φ through the channel is calculated by[1)]:

$$\Phi = -\frac{1}{\eta}\frac{dp}{dz}\left\{\frac{4}{3}hb^3 - 8b^4\left(\frac{2}{\pi}\right)^5\sum_{n=0}^{\infty}\frac{1}{(2n+1)^5}\tanh\left[\frac{(2n+1)\pi h}{2b}\right]\right\}$$

2h is the height of the channel in direction of the y-axis, 2 b is the width of the channel in direction of the x-axis, the z-axis is in direction of the flow. $\frac{dp}{dz}$ is the change of pressure along the channel.



Used parameters: The coordinate cross is in the center of the channel. The y-axis is in vertical direction, the x-axis in horizontal direction and perpendicular to the flow direction. The z-axis is parallel to the flow direction.

$\frac{dp}{dz}$ is eliminated by using:

$$\Phi = -\frac{1}{\eta}\frac{dp}{dz}\underbrace{\left\{\frac{4}{3}hb^3 - 8b^4\left(\frac{2}{\pi}\right)^5\sum_{n=0}^{\infty}\frac{1}{(2n+1)^5}\tanh\left[\frac{(2n+1)\pi h}{2b}\right]\right\}}_{q}$$

$$\frac{dp}{dz} = -\eta\frac{\Phi}{q}$$

[1)] Cornish, R. J. (1928). "Flow in a Pipe of Rectangular Cross-Section." Proc. R. Soc. A **12o**(786): 691-700.

Shear stress is calculated using the relation

$$\tau(x,y)=\eta\frac{\partial v(x,y)}{\partial y}\bigg|_{y=-h}=\eta\left(-\frac{1}{\eta}\frac{dp}{dz}\sum_{n=0}^{\infty}\frac{(-1)^n b\pi}{(2n+1)^2}\left(\frac{2}{\pi}\right)^3\frac{\sinh\left[(2n+1)\frac{\pi y}{2b}\right]}{\cosh\left[(2n+1)\frac{\pi h}{2b}\right]}\cos\left[\frac{(2n+1)\pi x}{2b}\right]\right)\Bigg|_{y=-h}$$

Elimination of $\frac{dp}{dz}$ gives:

$$\tau(x,y)=\eta\left(-\frac{1}{\eta}\left(-\eta\frac{\Phi}{q}\right)\sum_{n=0}^{\infty}\frac{(-1)^n b\pi}{(2n+1)^2}\left(\frac{2}{\pi}\right)^3\frac{\sinh\left[(2n+1)\frac{\pi y}{2b}\right]}{\cosh\left[(2n+1)\frac{\pi h}{2b}\right]}\cos\left[\frac{(2n+1)\pi x}{2b}\right]\right)\Bigg|_{y=-h}=$$

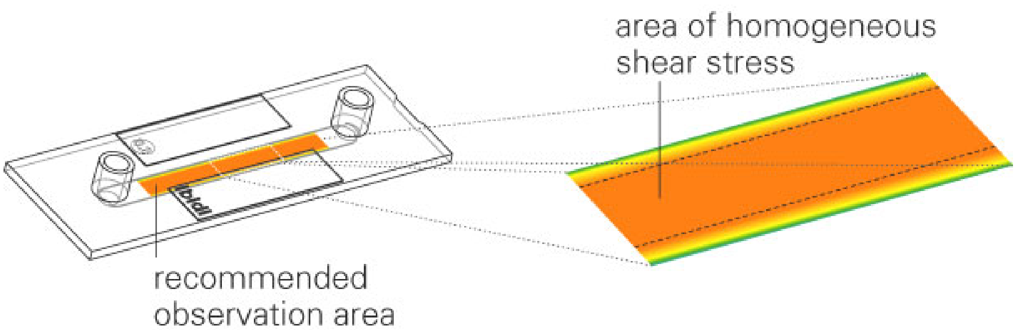
$$=\eta\frac{\Phi}{q}\sum_{n=0}^{\infty}\frac{(-1)^n b\pi}{(2n+1)^2}\left(\frac{2}{\pi}\right)^3\frac{\sinh\left[(2n+1)\frac{\pi y}{2b}\right]}{\cosh\left[(2n+1)\frac{\pi h}{2b}\right]}\cos\left[\frac{(2n+1)\pi x}{2b}\right]\Bigg|_{y=-h}$$

The cells typically attach to the bottom of the channel. The wall shear stress τ at the bottom of the channel (y=-h) is in the center of the channel (x=0):

$$\tau(x=0,y=-h)=\eta\frac{\Phi}{q}\left\{\sum_{n=0}^{\infty}\frac{(-1)^n b\pi}{(2n+1)^2}\left(\frac{2}{\pi}\right)^3\tanh\left[(2n+1)\frac{\pi h}{2b}\right]\right\}$$

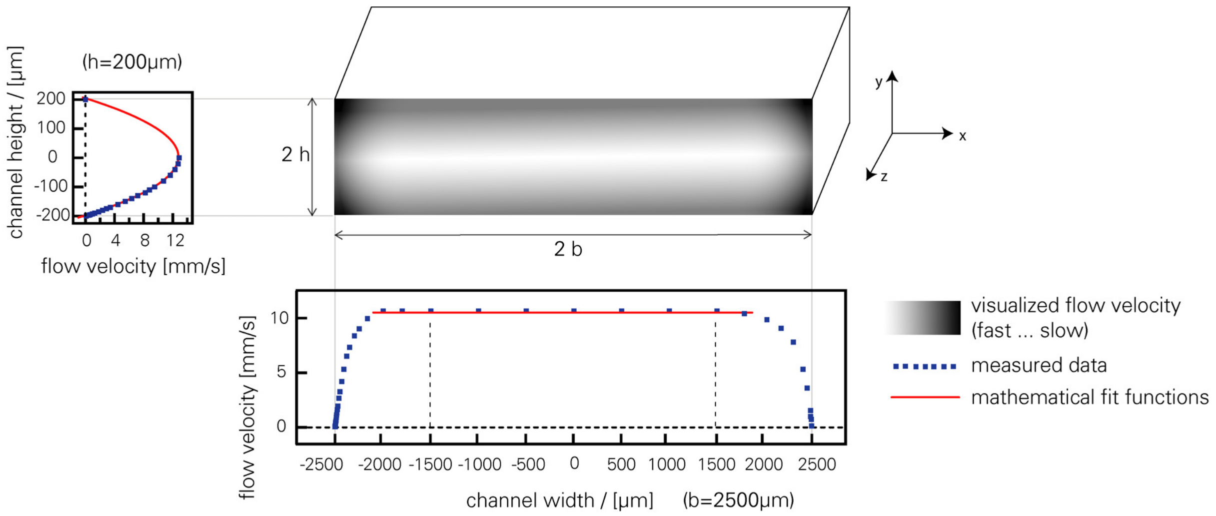
Area of homogeneous shear stress

All shear stress calculations are valid in the large area of width only. Side effects near the wall are ignored. Observations should be done at least in a distance comparable to the channel height. For example if the channel has a height of 400 µm the observation area showing a homogeneous flow profile will be about 400 µm from the side walls in the center region of the channel (orange area).



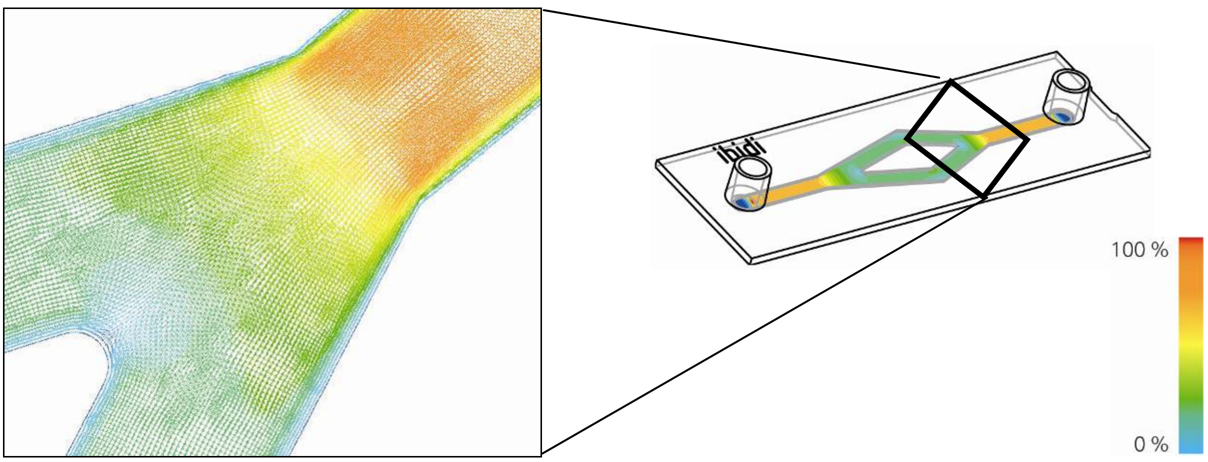
Flow profile in y-direction

All our channel slides are characterized by parabola shaped flow profiles in y-direction. The flow profile inside µ-Slide I [0.4] Luer is shown below.



Shear stress and shear rates in µ-Slide y-shaped

µ-Slide y-shaped was designed for studies of non-uniform shear stress. In the branched region the prevalent shear stress is approximately half of the regions with only the single channel.



For numerical simulations of µ-Slide y-shaped see Application Note 18 on www.ibidi.com.