Shear Stress and Shear Rates for ibidi µ-Slides Based on Numerical Calculations

This application note lists all the formulas to calculate the wall shear stress (WSS) in ibidi channel slides.

ibidi channel slides can be easily combined with any flow system due to the standardized Luer adapters. The shear stress calculations apply equally to all systems.

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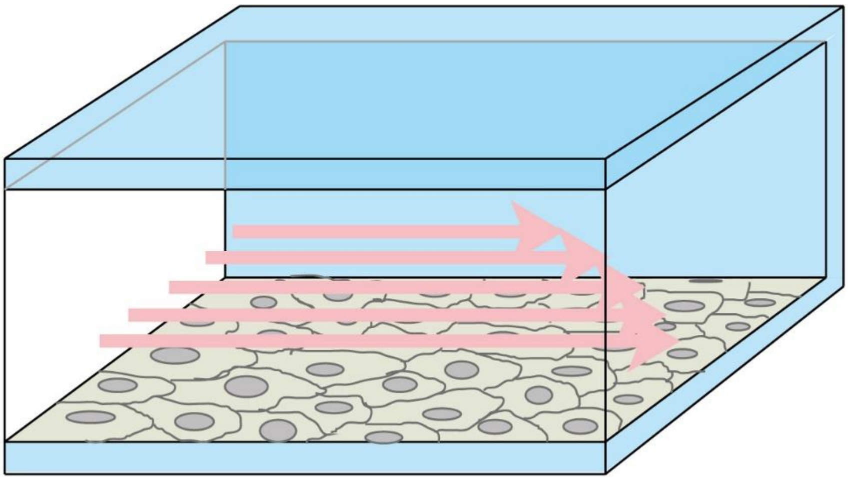


1. Wall Shear Stress Calculations for ibidi Channel Slides (Polymer Coverslip Bottom)

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

To calculate the wall shear stress correctly, you must know the viscosity of the perfused medium. In section 2 you will find more information about the viscosity determination.

1.1. Shear Stress in the µ-Slide I Luer Family

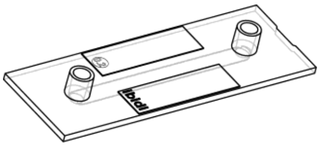
Nomenclature and units:

To use the following formulas, put in the values for flow rate, shear stress, and viscosity in the indicated units!

Φ	flow rate	ml/min
τ	shear stress	dyn/cm^2
η	dynamical viscosity	$dyn{\cdot}s/cm^2$

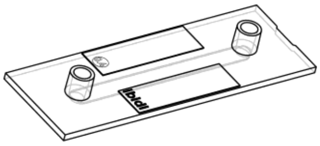
µ-Slide I $^{0.2}$ Luer

$$\boxed{\tau = \eta \cdot 512.9 \cdot \Phi}$$



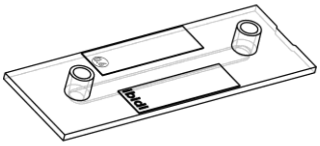
µ-Slide I $^{0.4}$ Luer

$$\boxed{\tau = \eta \cdot 131.6 \cdot \Phi}$$



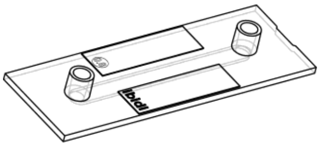
µ-Slide I $^{0.6}$ Luer

$$\boxed{\tau = \eta \cdot 60.1 \cdot \Phi}$$



µ-Slide I $^{0.8}$ Luer

$$\boxed{\tau = \eta \cdot 34.7 \cdot \Phi}$$



1.2. Shear Stress in µ-Slide VI $^{0.4}$, µ-Slide y-shaped, and µ-Slide III ^{3in1}

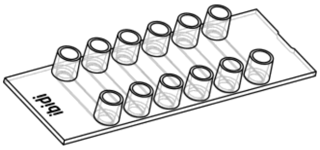
Nomenclature and units:

To use the following formulas correctly, put in the values for flow rate, shear stress, and viscosity in the indicated units!

Φ	flow rate	ml/min
τ	shear stress	dyn/cm²
η	dynamical viscosity	dyn·s/cm²

µ-Slide VI $^{0.4}$

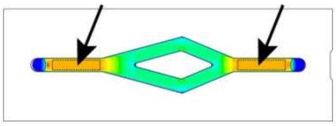
$$\boxed{\tau = \eta \cdot 176.1 \cdot \Phi}$$



µ-Slide y-shaped:

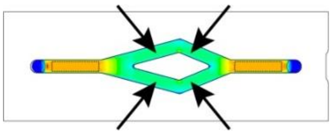
(single channel area)

$$\boxed{\tau = \eta \cdot 227.4 \cdot \Phi}$$



(branched area)

$$\boxed{\tau = \eta \cdot 113.7 \cdot \Phi}$$

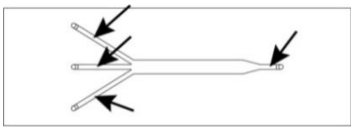


Numerical simulations and further details can be found in Application Note 18 "Shear Stress and Shear Rates in µ-Slide µ-Shaped".

µ-Slide III ^{3in1}:

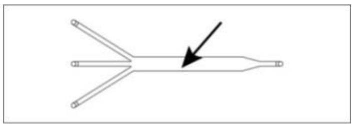
(1 mm channels)

$$\boxed{\tau = \eta \cdot 774.1 \cdot \Phi}$$



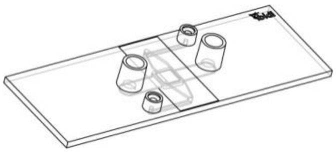
(3 mm channel)

$$\boxed{\tau = \eta \cdot 227.4 \cdot \Phi}$$



1.3. Shear Stress in µ-Slide Membrane ibiPore Flow

$$\boxed{\tau = \eta \cdot 131.6 \cdot \Phi}$$



1.4. Shear Stress in µ-Slide VI 0.1

Attention!
The flow rate is given in µl/min for µ-Slide VI $^{0.1}$!

µ-Slide VI $^{0.1}$

$$\boxed{\tau = \eta \cdot 10.7 \cdot \Phi \left[\frac{\mu l}{min}\right]}$$

2. Viscosity

As shown in the formulas in section 0, the shear stress in a rectangular channel is dependent on the viscosity and the flow rate of the perfused medium.

$$\boxed{\tau = \eta \cdot \text{Factor (dependent on Slide)} \cdot \Phi}$$

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

Before you start a cell culture experiment, measure the viscosity of your cell culture medium. Several viscometers can be used: U-tube viscometers, falling sphere viscometers, vibrational viscometers, rotational viscometers, and others.

Since the viscosity is highly temperature dependent, take care to measure the viscosity of your medium at the temperature used in your experiment!

Some typical values of dynamical viscosity:

	Temperature	Viscosity in dyn s/cm^2	Viscosity in mPa s
Water	20°C	0.01	1.002
Water	37°C	0.0068	0.684
Cell Culture Medium with 10% serum	37°C	~0.0072	~0.72
Cell Culture Medium with 0.2% Methyl Cellulose	37°C	~0.03	~3.0

3. Shear Rate Calculations for ibidi Channel Slides (Polymer Coverslip)

Do not confuse shear stress and shear rate! The shear stress is the force acting on the cell layer on the wall. The shear rate describes the velocity profile of the perfused medium.

Shear stress and shear rate are related by the following formula:

$$\boxed{\tau = \eta \cdot \gamma}$$

τ = shear stress
γ = shear rate
η = dynamical viscosity

The shear rate γ (1/s) at the wall of the channels can be defined with the following formulas.

µ-Slide I $^{0.2}$ Luer	$\gamma = 512.9 \cdot \Phi$	Φ in ml/ min
µ-Slide I $^{0.4}$ Luer	$\gamma = 131.6 \cdot \Phi$	Φ in ml/ min
µ-Slide I $^{0.6}$ Luer	$\gamma = 60.1 \cdot \Phi$	Φ in ml/ min
µ-Slide I $^{0.8}$ Luer	$\gamma = 34.7 \cdot \Phi$	Φ in ml/ min
µ-Slide VI $^{0.4}$	$\gamma = 176.1 \cdot \Phi$	Φ in ml/ min
µ-Slide y-shaped		
- branched area	$\gamma = 113.7 \cdot \Phi$	Φ in ml/ min
- single channel	$\gamma = 227.4 \cdot \Phi$	Φ in ml/ min
µ-Slide III ^{3in1}		
- 1 mm channel	$\gamma = 774.1 \cdot \Phi$	Φ in ml/ min
- 3 mm channel	$\gamma = 227.4 \cdot \Phi$	Φ in ml/ min
µ-Slide Membrane ibiPore Flow	$\gamma = 131.6 \cdot \Phi$	Φ in ml/ min
µ-Slide VI $^{0.1}$	$\gamma = 10.7 \cdot \Phi$	Φ in **µl**/ min

4. Experimental Aspects

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

- Cell type
- **Shear stress** (tissue and species specific)
- Medium and viscosity of the needed medium
- Available volume
- Available amount of cells
- Duration of the experiment
- Flow characteristics (continuous, one way, oscillating…)
- Required number of cells for downstream applications
- Coating of the surface (cell type dependent)
- More experimental details (e.g., addition of substances, time points of measurements)
- Experimental endpoints

Choosing the Right Slide

The selection of the slide determines the range of shear stress that can be applied, depending on the flow rate, by the respective pump. Generally the following rules-of-thumb can be applied:

- A small channel favours the generation of high shear stress values.
- A large channel favours the generation low shear stress values.

Based on the options of your pump, you can calculate which range of shear stress you will be able to apply.

Choosing the Right Flow Rate

Define the shear stress for your experimental setup. 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.

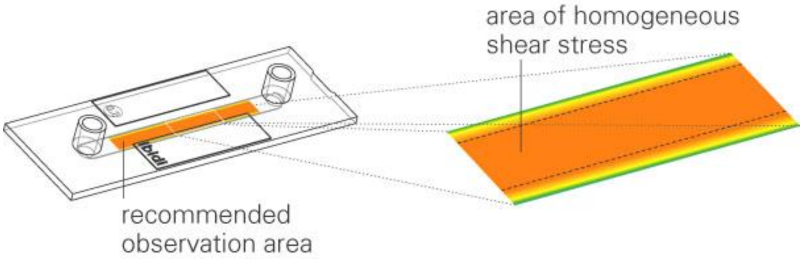
Choosing the Right Perfusion System (Pump)

Depending on the 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.

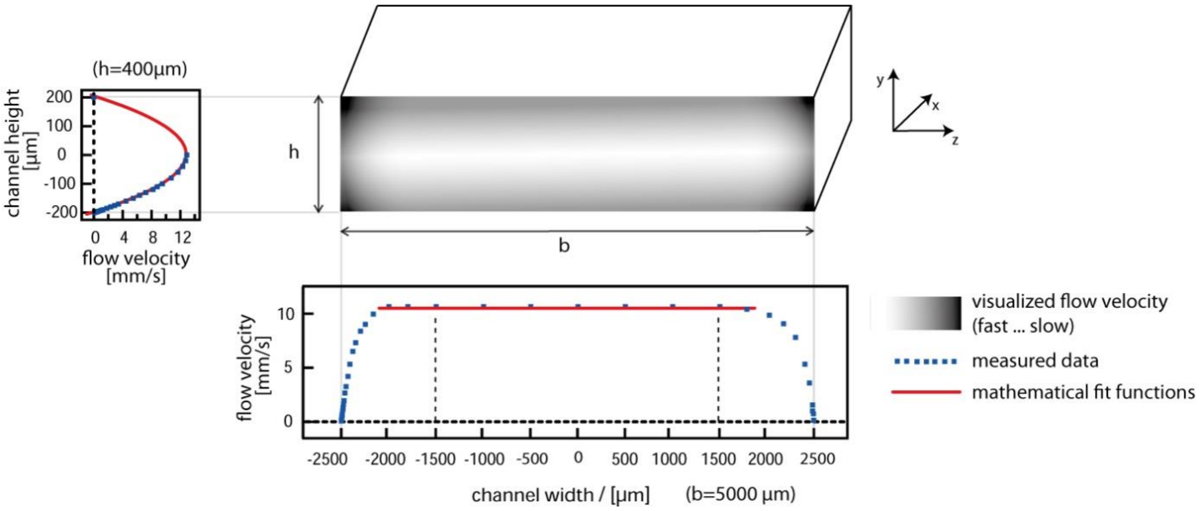
5. Area of Homogeneous Shear Stress

All shear stress calculations are only valid in regions away from the walls (see orange area below). Side effects near the wall are ignored. Observations should be done in a distance away from the walls 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).



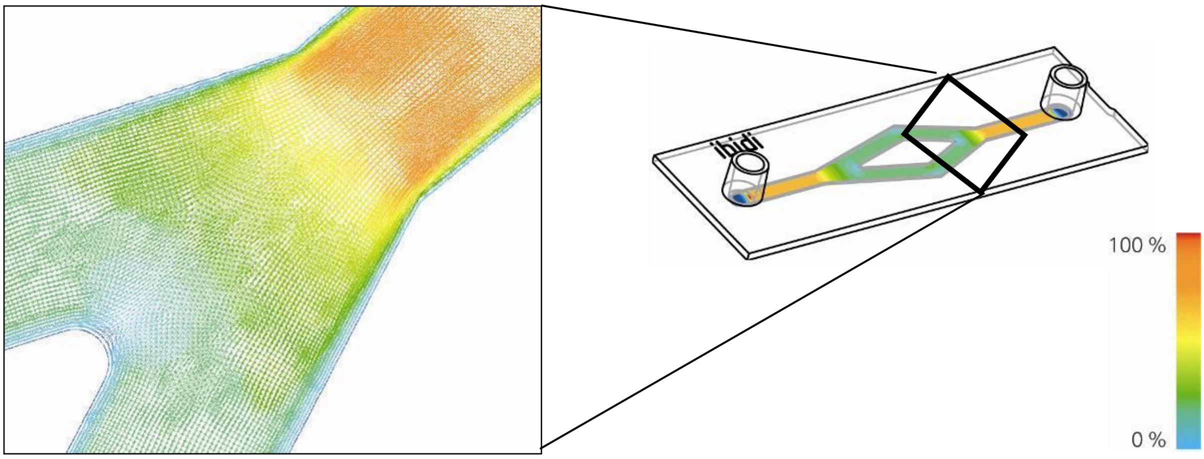
6. Flow Profile in y-Direction

All ibidi channel slides are characterized by parabola-shaped flow profiles in the y-direction. The flow profile inside µ-Slide I $^{0.4}$ Luer is shown below.



7. Shear Stress and Shear Rates in the µ-Slide y-shaped

The 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 the µ-Slide y-shaped, see Application Note 18 on ibidi.com.

8. Background Information

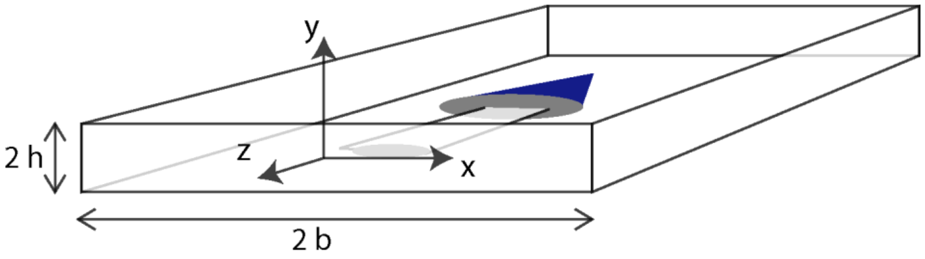
The local flow velocity v(x,y) is calculated by (Cornish 1928)$^{1)}$:

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

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.



Coordinate conventions: The coordinate cross is in the center of the channel. The y-axis is in the vertical direction, the x-axis in the 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 $\dfrac{dp}{dz}$ 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) and at the center of the channel (x=0) is:

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

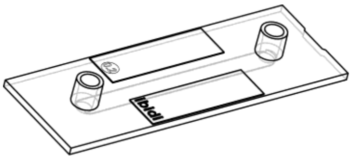
9. Lookup Tables for Shear Stress Values

These tables are suitable for a quick determination of the needed flow rate. The shear stress is calculated for medium at 37°C (viscosity of 0.0072 dyn·s/cm²).

Shear Stress table for µ-Slide I $^{0.2}$ Luer for viscosity η=0.0072 dyn·s/cm²:

τ [dyn/cm²]	Φ [ml/min]
0.1	0.03
0.2	0.05
0.3	0.08
0.4	0.11
0.5	0.14
0.6	0.16
0.7	0.19
0.8	0.22
0.9	0.24
1	0.27
1.2	0.32
1.4	0.38
1.6	0.43
1.8	0.49
2	0.54
2.2	0.60
2.4	0.65
2.6	0.70
2.8	0.76
3	0.81
3.5	0.95
4	1.08
4.5	1.22
5	1.35
5.5	1.49
6	1.62
7	1.90
8	2.17
9	2.44
10	2.71
11	2.98
12	3.25
13	3.52
14	3.79
15	4.06
16	4.33
18	4.87
20	5.42
22	5.96
24	6.50
25	6.77
30	8.12
35	9.48
40	10.83
45	12.19
50	13.54
55	14.89
60	16.25
65	17.60
70	18.96
75	20.31
80	21.66
85	23.02
90	24.37
95	25.73
100	27.08
105	28.43
110	29.79
115	31.14
120	32.49

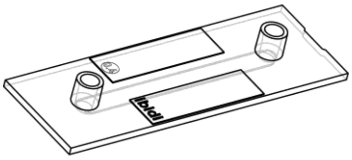
$$\tau\left[\frac{dyn}{cm^2}\right]=\eta\left[\frac{dyn\cdot s}{cm^2}\right]\cdot 512.9\cdot\Phi\left[\frac{ml}{min}\right]$$



Shear Stress table for µ-Slide I $^{0.4}$ Luer for viscosity η=0.0072 dyn·s/cm^2:

τ [dyn/cm²]	Φ [ml/min]
0.1	0.11
0.2	0.21
0.3	0.32
0.4	0.42
0.5	0.53
0.6	0.63
0.7	0.74
0.8	0.84
0.9	0.95
1	1.06
1.2	1.27
1.4	1.48
1.6	1.69
1.8	1.90
2	2.11
2.2	2.32
2.4	2.53
2.6	2.74
2.8	2.96
3	3.17
3.5	3.69
4	4.22
4.5	4.75
5	5.28
5.5	5.80
6	6.33
7	7.39
8	8.44
9	9.50
10	10.55
11	11.61
12	12.66
13	13.72
14	14.78
15	15.83
16	16.89
18	19.00
20	21.11
22	23.22
24	25.33
25	26.38
30	31.66
35	36.94
40	42.22
45	47.49
50	52.77
55	58.05
60	63.32
65	68.60
70	73.88
75	79.15
80	84.43
85	89.71
90	94.98
95	100.26
100	105.54
105	110.82
110	116.09
115	121.37
120	126.65

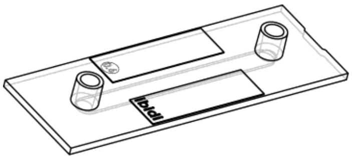
$$\tau\left[\frac{dyn}{cm^2}\right] = \eta\left[\frac{dyn\cdot s}{cm^2}\right]\cdot 131.6\cdot\Phi\left[\frac{ml}{min}\right]$$



Shear Stress table for µ-Slide I $^{0.6}$ Luer for viscosity η=0.0072 dyn·s/cm^2:

τ [dyn/cm²]	Φ [ml/min]
0.1	0.23
0.2	0.46
0.3	0.69
0.4	0.92
0.5	1.16
0.6	1.39
0.7	1.62
0.8	1.85
0.9	2.08
1	2.31
1.2	2.77
1.4	3.24
1.6	3.70
1.8	4.16
2	4.62
2.2	5.08
2.4	5.55
2.6	6.01
2.8	6.47
3	6.93
3.5	8.09
4	9.24
4.5	10.40
5	11.55
5.5	12.71
6	13.87
7	16.18
8	18.49
9	20.80
10	23.11
11	25.42
12	27.73
13	30.04
14	32.35
15	34.66
16	36.98
18	41.60
20	46.22
22	50.84
24	55.46
25	57.77
30	69.33
35	80.88
40	92.44
45	103.99
50	115.55
55	127.10
60	138.66
65	150.21
70	161.77
75	173.32
80	184.88
85	196.43
90	207.99
95	219.54
100	231.10
105	242.65
110	254.21
115	265.76
120	277.32

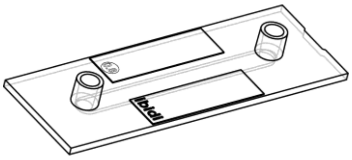
$$\tau\left[\frac{dyn}{cm^2}\right] = \eta\left[\frac{dyn\cdot s}{cm^2}\right]\cdot 60.1\cdot\Phi\left[\frac{ml}{min}\right]$$



Shear Stress table for μ-Slide I $^{0.8}$ Luer for viscosity η=0.0072 dyn·s/cm²:

τ [dyn/cm²]	Φ [ml/min]	τ [dyn/cm²]	Φ [ml/min]	τ [dyn/cm²]	Φ [ml/min]
0.1	0.40	3.5	14.01	25	100.06
0.2	0.80	4	16.01	30	120.08
0.3	1.20	4.5	18.01	35	140.09
0.4	1.60	5	20.01	40	160.10
0.5	2.00	5.5	22.01	45	180.12
0.6	2.40	6	24.02	50	200.13
0.7	2.80	7	28.02	55	220.14
0.8	3.20	8	32.02	60	240.15
0.9	3.60	9	36.02	65	260.17
1	4.00	10	40.03	70	280.18
1.2	4.80	11	44.03	75	300.19
1.4	5.60	12	48.03	80	320.20
1.6	6.40	13	52.03	85	340.22
1.8	7.20	14	56.04	90	360.23
2	8.01	15	60.04	95	380.24
2.2	8.81	16	64.04	100	400.26
2.4	9.61	18	72.05	105	420.27
2.6	10.41	20	80.05	110	440.28
2.8	11.21	22	88.06	115	460.29
3	12.01	24	96.06	120	480.31

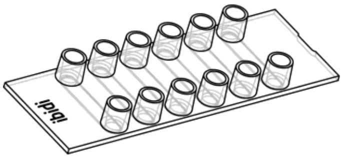
$$\tau\left[\frac{dyn}{cm^2}\right] = \eta\left[\frac{dyn\cdot s}{cm^2}\right]\cdot 34.7\cdot\Phi\left[\frac{ml}{min}\right]$$



Shear Stress table for μ-Slide VI $^{0.4}$ for viscosity η=0.0072 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	3.5	2.76	25	19.72
0.2	0.16	4	3.15	30	23.66
0.3	0.24	4.5	3.55	35	27.60
0.4	0.32	5	3.94	40	31.55
0.5	0.39	5.5	4.34	45	35.49
0.6	0.47	6	4.73	50	39.43
0.7	0.55	7	5.52	55	43.38
0.8	0.63	8	6.31	60	47.32
0.9	0.71	9	7.10	65	51.27
1	0.79	10	7.89	70	55.21
1.2	0.95	11	8.68	75	59.15
1.4	1.10	12	9.46	80	63.10
1.6	1.26	13	10.25	85	67.04
1.8	1.42	14	11.04	90	70.98
2	1.58	15	11.83	95	74.93
2.2	1.74	16	12.62	100	78.87
2.4	1.89	18	14.20	105	82.81
2.6	2.05	20	15.77	110	86.76
2.8	2.21	22	17.35	115	90.70
3	2.37	24	18.93	120	94.64

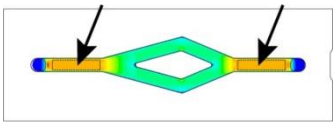
$$\tau\left[\frac{dyn}{cm^2}\right] = \eta\left[\frac{dyn\cdot s}{cm^2}\right]\cdot 176.1\cdot\Phi\left[\frac{ml}{min}\right]$$



Shear Stress table for µ-Slide y-shaped for viscosity η=0.0072 dyn·s/cm² (single channel area):

τ [dyn/cm²]	Φ [ml/min]	τ [dyn/cm²]	Φ [ml/min]	τ [dyn/cm²]	Φ [ml/min]
0.1	0.06	3.5	2.14	25	15.27
0.2	0.12	4	2.44	30	18.32
0.3	0.18	4.5	2.75	35	21.38
0.4	0.24	5	3.05	40	24.43
0.5	0.31	5.5	3.36	45	27.48
0.6	0.37	6	3.66	50	30.54
0.7	0.43	7	4.28	55	33.59
0.8	0.49	8	4.89	60	36.65
0.9	0.55	9	5.50	65	39.70
1	0.61	10	6.11	70	42.75
1.2	0.73	11	6.72	75	45.81
1.4	0.86	12	7.33	80	48.86
1.6	0.98	13	7.94	85	51.92
1.8	1.10	14	8.55	90	54.97
2	1.22	15	9.16	95	58.02
2.2	1.34	16	9.77	100	61.08
2.4	1.47	18	10.99	105	64.13
2.6	1.59	20	12.22	110	67.18
2.8	1.71	22	13.44	115	70.24
3	1.83	24	14.66	120	73.29

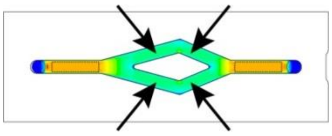
$$\tau\left[\frac{dyn}{cm^2}\right] = \eta\left[\frac{dyn\cdot s}{cm^2}\right]\cdot 227.4\cdot\Phi\left[\frac{ml}{min}\right]$$



Shear Stress table for µ-Slide y-shaped for viscosity η=0.0072 dyn·s/cm² (branched channel area):

τ [dyn/cm²]	Φ [ml/min]	τ [dyn/cm²]	Φ [ml/min]	τ [dyn/cm²]	Φ [ml/min]
0.1	0.12	3.5	4.28	25	30.54
0.2	0.24	4	4.89	30	36.65
0.3	0.37	4.5	5.50	35	42.75
0.4	0.49	5	6.11	40	48.86
0.5	0.61	5.5	6.72	45	54.97
0.6	0.73	6	7.33	50	61.08
0.7	0.86	7	8.55	55	67.18
0.8	0.98	8	9.77	60	73.29
0.9	1.10	9	10.99	65	79.40
1	1.22	10	12.22	70	85.51
1.2	1.47	11	13.44	75	91.62
1.4	1.71	12	14.66	80	97.72
1.6	1.95	13	15.88	85	103.83
1.8	2.20	14	17.10	90	109.94
2	2.44	15	18.32	95	116.05
2.2	2.69	16	19.54	100	122.15
2.4	2.93	18	21.99	105	128.26
2.6	3.18	20	24.43	110	134.37
2.8	3.42	22	26.87	115	140.48
3	3.66	24	29.32	120	146.58

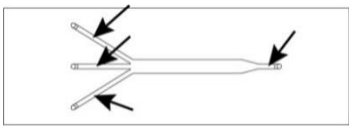
$$\tau\left[\frac{dyn}{cm^2}\right] = \eta\left[\frac{dyn\cdot s}{cm^2}\right]\cdot 113.7\cdot\Phi\left[\frac{ml}{min}\right]$$



Shear Stress table for µ-Slide III^{3in1} for viscosity η=0.0072 dyn·s/cm^2 (1 mm channels):

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	3.5	0.63	25	4.49
0.2	0.04	4	0.72	30	5.38
0.3	0.05	4.5	0.81	35	6.28
0.4	0.07	5	0.90	40	7.18
0.5	0.09	5.5	0.99	45	8.07
0.6	0.11	6	1.08	50	8.97
0.7	0.13	7	1.26	55	9.87
0.8	0.14	8	1.44	60	10.77
0.9	0.16	9	1.61	65	11.66
1	0.18	10	1.79	70	12.56
1.2	0.22	11	1.97	75	13.46
1.4	0.25	12	2.15	80	14.35
1.6	0.29	13	2.33	85	15.25
1.8	0.32	14	2.51	90	16.15
2	0.36	15	2.69	95	17.04
2.2	0.39	16	2.87	100	17.94
2.4	0.43	18	3.23	105	18.84
2.6	0.47	20	3.59	110	19.74
2.8	0.50	22	3.95	115	20.63
3	0.54	24	4.31	120	21.53

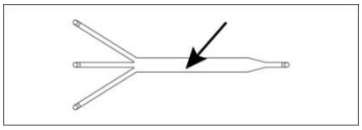
$$\tau\left[\frac{dyn}{cm^2}\right] = \eta\left[\frac{dyn \cdot s}{cm^2}\right] \cdot 774.1 \cdot \Phi\left[\frac{ml}{min}\right]$$



Shear Stress table for µ-Slide III^{3in1} for viscosity η=0.0072 dyn·s/cm^2 (3 mm channels):

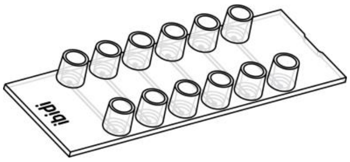
τ [dyn/cm^2]	Φ [ml/min]	τ [dyn/cm^2]	Φ [ml/min]	τ [dyn/cm^2]	Φ [ml/min]
0.1	0.06	3.5	2.14	25	15.27
0.2	0.12	4	2.44	30	18.32
0.3	0.18	4.5	2.75	35	21.38
0.4	0.24	5	3.05	40	24.43
0.5	0.31	5.5	3.36	45	27.48
0.6	0.37	6	3.66	50	30.54
0.7	0.43	7	4.28	55	33.59
0.8	0.49	8	4.89	60	36.65
0.9	0.55	9	5.50	65	39.70
1	0.61	10	6.11	70	42.75
1.2	0.73	11	6.72	75	45.81
1.4	0.86	12	7.33	80	48.86
1.6	0.98	13	7.94	85	51.92
1.8	1.10	14	8.55	90	54.97
2	1.22	15	9.16	95	58.02
2.2	1.34	16	9.77	100	61.08
2.4	1.47	18	10.99	105	64.13
2.6	1.59	20	12.22	110	67.18
2.8	1.71	22	13.44	115	70.24
3	1.83	24	14.66	120	73.29

$$\tau\left[\frac{dyn}{cm^2}\right] = \eta\left[\frac{dyn \cdot s}{cm^2}\right] \cdot 227.4 \cdot \Phi\left[\frac{ml}{min}\right]$$



Shear Stress table for µ-Slide VI $^{0.1}$ for viscosity η=0.0072 dyn·s/cm²:

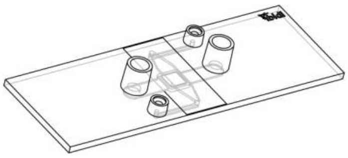
τ [dyn/cm²]	Φ [µl/min]	τ [dyn/cm²]	Φ [µl/min]	τ [dyn/cm²]	Φ [µl/min]
0.1	1.30	3.5	45.43	25	324.51
0.2	2.60	4	51.92	30	389.41
0.3	3.89	4.5	58.41	35	454.31
0.4	5.19	5	64.90	40	519.21
0.5	6.49	5.5	71.39	45	584.11
0.6	7.79	6	77.88	50	649.01
0.7	9.09	7	90.86	55	713.91
0.8	10.38	8	103.84	60	778.82
0.9	11.68	9	116.82	65	843.72
1	12.98	10	129.80	70	908.62
1.2	15.58	11	142.78	75	973.52
1.4	18.17	12	155.76	80	1038.42
1.6	20.77	13	168.74	85	1103.32
1.8	23.36	14	181.72	90	1168.22
2	25.96	15	194.70	95	1233.13
2.2	28.56	16	207.68	100	1298.03
2.4	31.15	18	233.64	105	1362.93
2.6	33.75	20	259.61	110	1427.83
2.8	36.34	22	285.57	115	1492.73
3	38.94	24	311.53	120	1557.63



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

Shear Stress table for µ-Slide Membrane ibiPore Flow for viscosity η=0.0072 dyn·s/cm²

τ [dyn/cm²]	Φ [ml/min]	τ [dyn/cm²]	Φ [ml/min]	τ [dyn/cm²]	Φ [ml/min]
0.1	0.11	3.5	3.69	25	26.38
0.2	0.21	4	4.22	30	31.66
0.3	0.32	4.5	4.75	35	36.94
0.4	0.42	5	5.28	40	42.22
0.5	0.53	5.5	5.80	45	47.49
0.6	0.63	6	6.33	50	52.77
0.7	0.74	7	7.39	55	58.05
0.8	0.84	8	8.44	60	63.32
0.9	0.95	9	9.50	65	68.60
1	1.06	10	10.55	70	73.88
1.2	1.27	11	11.61	75	79.15
1.4	1.48	12	12.66	80	84.43
1.6	1.69	13	13.72	85	89.71
1.8	1.90	14	14.78	90	94.98
2	2.11	15	15.83	95	100.26
2.2	2.32	16	16.89	100	105.54
2.4	2.53	18	19.00	105	110.82
2.6	2.74	20	21.11	110	116.09
2.8	2.96	22	23.22	115	121.37
3	3.17	24	25.33	120	126.65



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