Shear stress and shear rates for µ-Slides y-shaped based on Computational Fluid Dynamics (CFD)

The shear stress is based the dynamical viscosity of water at 22 °C, η = 0.01 dyne·sec/cm² (=1 mPa·sec = 1cP).

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

1) Introduction

The µ-Slide y-shaped provides regions of **uniform laminar flow**, and regions of **non uniform laminar flow**. Non uniform laminar flow is characterized by flow velocity gradients in small sub millimeter regions.

Please keep in mind that there is no turbulent flow in µ-Slide y-shaped!

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2) Computational Fluid Dynamics (CFD) Characteristics

The CFD calculation was done by ANSYS FLUENT Flow Modeling Software. The parameters are stationary, isothermal, laminar, water assumed to be incompressible, density of water 1000 kg/m³, viscosity 0.001 kg/(m sec), and at given flow of mass = 1.001 ml/min. Calculated is the velocity in 1 µm distance from the bottom.

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3) Using this document: calculating shear stress

It is assumed that the shear stress is proportional to the velocity calculated in 1 µm distance from the bottom. The value of 100 % velocity is defined as 0.00024 m/sec which is the velocity in the uniform flow region for the single channels. In this region the shear stress is 2.274 dyne/cm² at a flow rate of 1ml/min. For calculating the shear stress in another region one needs to take the velocity indicated by the color scale, for example 0.00018 m/sec for the yellow region and use the formula:

$$\tau[\frac{\text{dyne}}{\text{cm}^2}] = \frac{\text{velocity from color [m/sec]}}{\text{velocity 100 \% = 0.00024 m/sec}} \cdot 2.274 \frac{\text{dyne / cm}^2}{\text{1 ml/min}} \cdot \Phi[\frac{\text{ml}}{\text{min}}]$$

<u>calculation example:</u>
flow rate: 2 ml/min
region: yellow region 0.00018 m/sec

$$\tau[\frac{\text{dyne}}{\text{cm}^2}] = \frac{\text{0.00018 m/sec}}{\text{0.00024 m/sec}} \cdot 2.274 \frac{\text{dyne / cm}^2}{\text{1 ml/min}} \cdot 2 \frac{\text{ml}}{\text{min}} = 3.4\ \text{dyne/cm}^2$$

4) Regions of uniform laminar shear stress

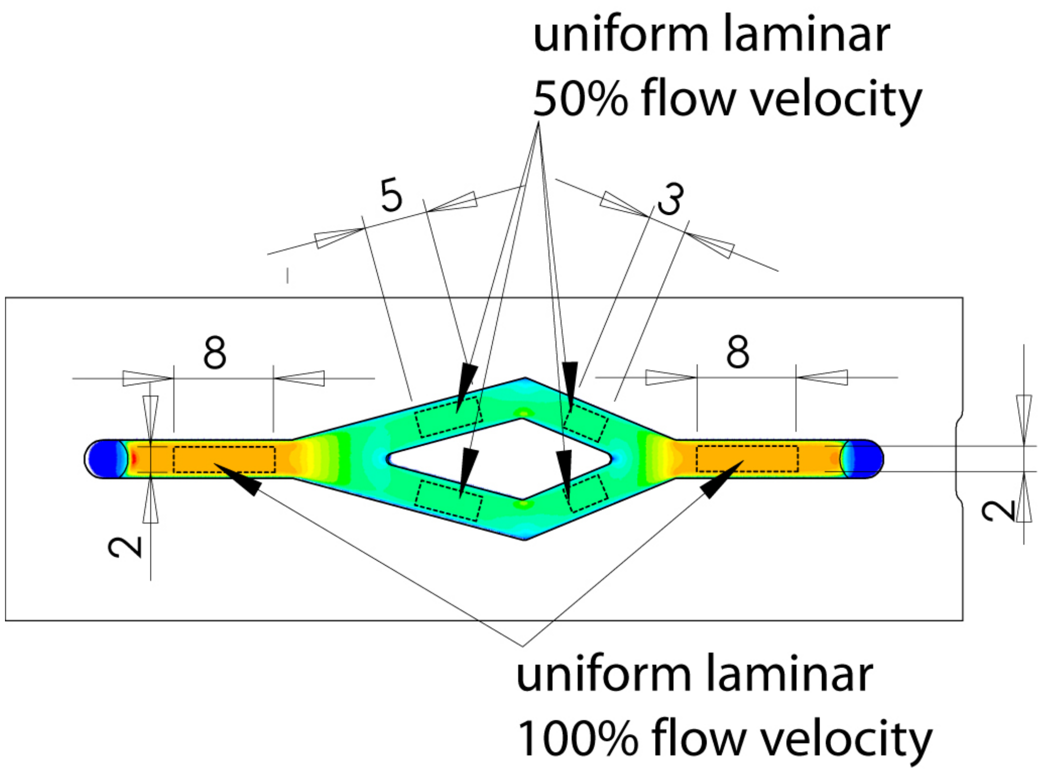


Fig. 1: Bottom view of µ-Slide y-shaped. The dashed rectangles are indicating zones of uniform laminar flow and therefore also uniform laminar shear stress. The flow and shear stress in the orange regions is exactly twice as high as in the green regions because the flow is exactly half in the regions between the branching points (yellow), compared to the regions between inlets (big blue spots on both ends) and the branching points.

a) Uniform laminar region in one channel section; 100 % flow velocity

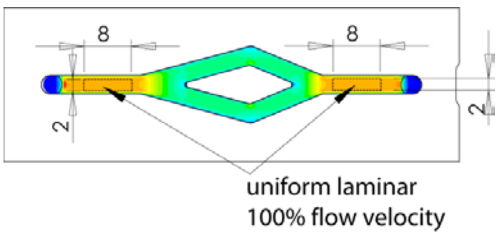
for viscosity of η = 0.01 dyne·sec/cm²

Shear stress

$$\tau[\frac{dyne}{cm^2}] = 2.274\ \Phi[\frac{ml}{min}]$$

Shear rate

$$\gamma[sec^{-1}] = 227.4\ \Phi[\frac{ml}{min}]$$



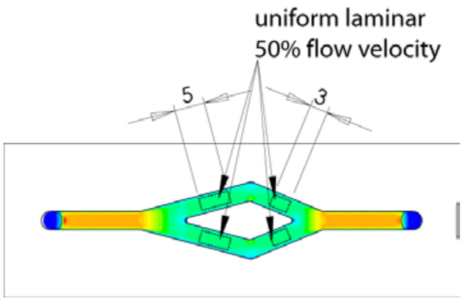
for any viscosity η given in [dyne·sec/cm²]

Shear stress

$$\tau[\frac{dyne}{cm^2}] = \eta\,[\frac{dyne \cdot sec}{cm^2}] \cdot 227.4\ \Phi[\frac{ml}{min}]$$

b) Uniform laminar region in double channel section; 50 % flow velocity

for viscosity of η = 0.01 dyne·sec/cm²



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

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

for any viscosity η given in [dyne·sec/cm²]

Shear stress $$\tau[\frac{dyne}{cm^2}] = \eta\ [\frac{dyne \cdot sec}{cm^2}] \cdot 113.7\ \Phi[\frac{ml}{min}]$$

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5) Regions of non uniform laminar shear stress

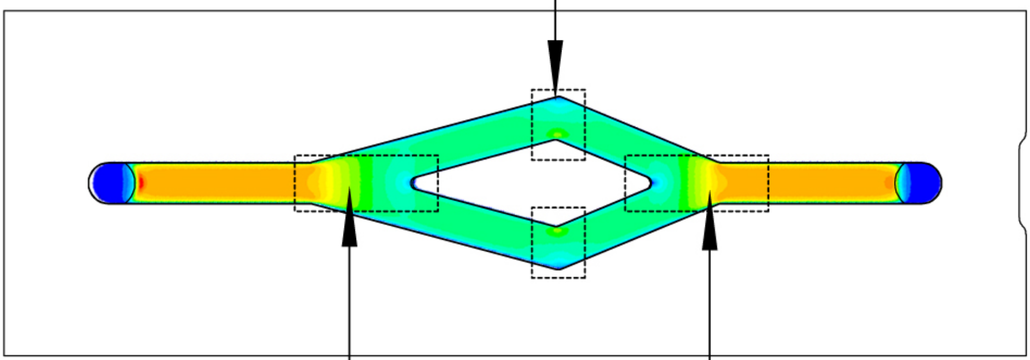


Fig. 2: Bottom view of µ-Slide y-shaped. The dashed rectangles are indicating zones of non uniform laminar flow and therefore also non uniform laminar shear stress. There are three different regions: on the left side is a branching region with an opening angle of 45°. On the right side the branching region provides a 45° opening angle. The both kink regions are symmetrical.

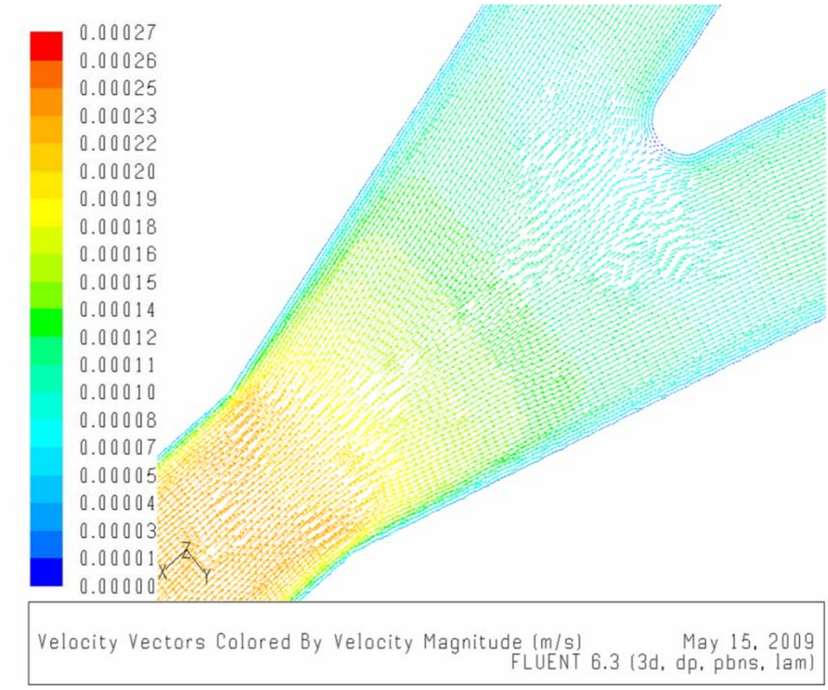


Fig. 3: Calculated data for the 30° branching region. The arrows are indicating the flow direction. The color scale gives the velocity in [m/sec].

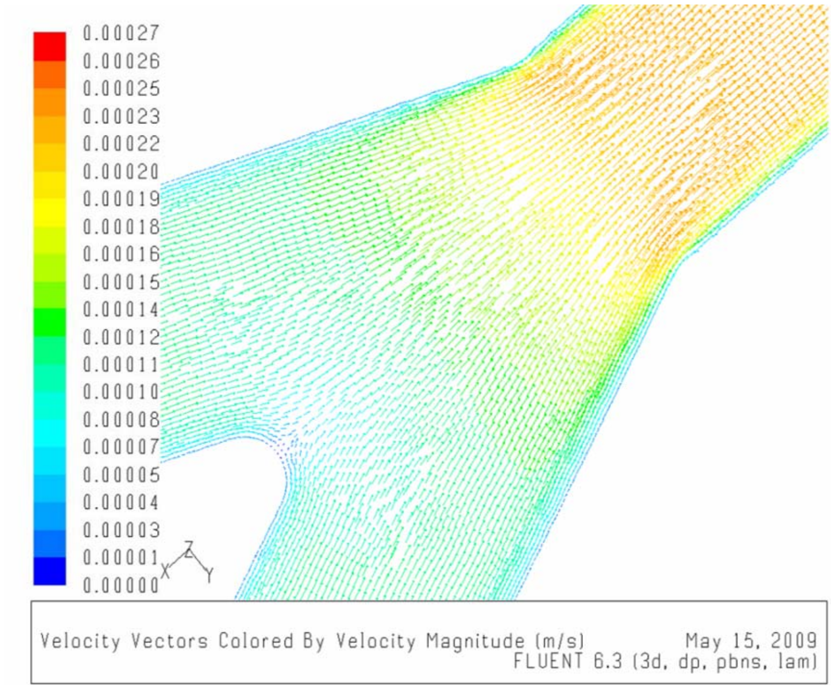


Fig. 4: Calculated data for the 45° branching region. The arrows are indicating the flow direction. The color scale gives the velocity in [m/sec].

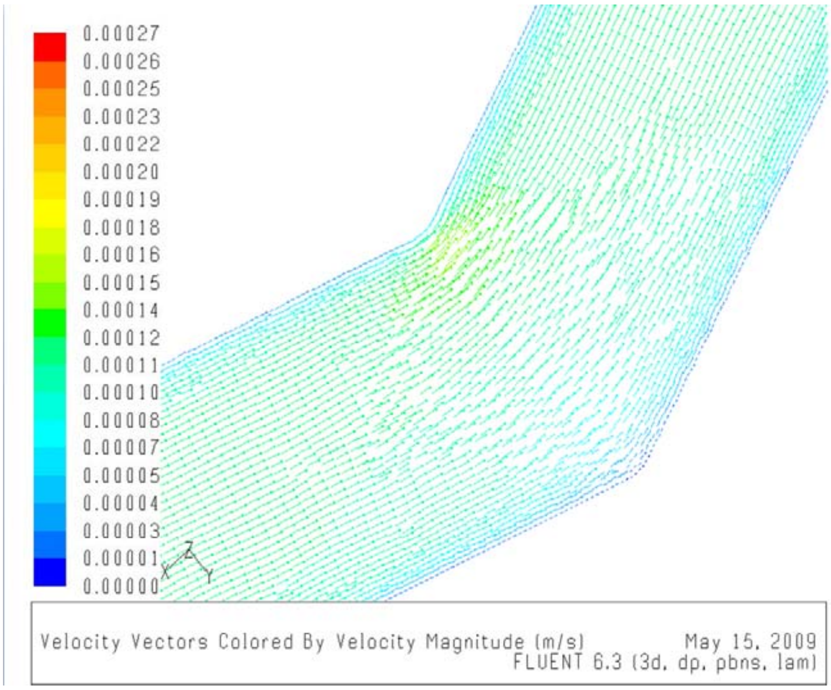
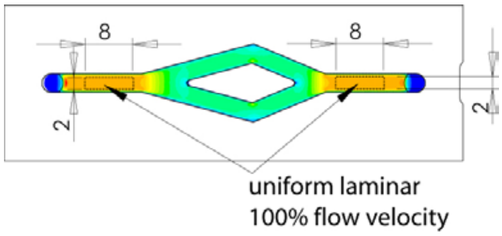


Fig. 5: Calculated data for the 45° branching region. The arrows are indicating the flow direction. The color scale gives the velocity in [m/sec].

6) Shear stress tables



Shear stress table - single channel region, uniform flow at η=0.01 dyne·s/cm²:

$$\tau[\frac{dyne}{cm^2}] = 2.2744\ \Phi[\frac{ml}{min}]$$

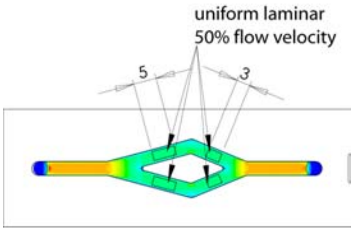
τ[dyne/cm²]	Φ[ml/min]	τ[dyne/cm²]	Φ[ml/min]	τ[dyne/cm²]	Φ[ml/min]
0,1	0,04	4	1,76	25	10,99
0,2	0,09	5	2,20	30	13,19
0,3	0,13	6	2,64	35	15,39
0,4	0,18	7	3,08	40	17,59
0,5	0,22	8	3,52	45	19,79
0,6	0,26	9	3,96	50	21,98
0,7	0,31	10	4,40	55	24,18
0,8	0,35	11	4,84	60	26,38
0,9	0,40	12	5,28	65	28,58
1,0	0,44	13	5,72	70	30,78
1,2	0,53	14	6,16	75	32,98
1,4	0,62	15	6,60	80	35,17
1,6	0,70	16	7,03	85	37,37
1,8	0,79	17	7,47	90	39,57
2,0	0,88	18	7,91	95	41,77
2,2	0,97	19	8,35	100	43,97
2,4	1,06	20	8,79	105	46,17
2,6	1,14	21	9,23	110	48,36
2,8	1,23	22	9,67	115	50,56
3,0	1,32	23	10,11	120	52,76

Shear rate table - single channel region:

$$\gamma[sec^{-1}] = 227.44\ \Phi[\frac{ml}{min}]$$

γ[1/sec]	Φ[ml/min]	γ[1/sec]	Φ[ml/min]	γ[1/sec]	Φ[ml/min]
5	0,02	600	2,64	7000	30,78
10	0,04	700	3,08	7500	32,98
20	0,09	800	3,52	8000	35,17
30	0,13	900	3,96	8500	37,37
40	0,18	1000	4,40	9000	39,57
50	0,22	1250	5,50	9500	41,77
125	0,55	1500	6,60	10000	43,97
150	0,66	1750	7,69	10500	46,17
175	0,77	1800	7,91	11000	48,36
200	0,88	1850	8,13	11500	50,56
225	0,99	1900	8,35	12000	52,76
250	1,10	2000	8,79	12500	54,96
275	1,21	2500	10,99	13000	57,16
300	1,32	3000	13,19	13500	59,36
325	1,43	3500	15,39	14000	61,55
350	1,54	4000	17,59	14500	63,75
375	1,65	4500	19,79	15000	65,95
400	1,76	5000	21,98	15500	68,15
450	1,98	5500	24,18	16000	70,35
500	2,20	6000	26,38	16500	72,55

Application Note 18



Shear Stress table - double channel region
uniform flow at η=0.01 dyne·s/cm²:

$$\tau[\frac{dyne}{cm^2}] = 1.1372\ \Phi[\frac{ml}{min}]$$

τ[dyne/cm²]	Φ[ml/min]	τ[dyne/cm²]	Φ[ml/min]	τ[dyne/cm²]	Φ[ml/min]
0,1	0,09	4	3,52	25	21,98
0,2	0,18	5	4,40	30	26,38
0,3	0,26	6	5,28	35	30,78
0,4	0,35	7	6,16	40	35,17
0,5	0,44	8	7,03	45	39,57
0,6	0,53	9	7,91	50	43,97
0,7	0,62	10	8,79	55	48,36
0,8	0,70	11	9,67	60	52,76
0,9	0,79	12	10,55	65	57,16
1,0	0,88	13	11,43	70	61,55
1,2	1,06	14	12,31	75	65,95
1,4	1,23	15	13,19	80	70,35
1,6	1,41	16	14,07	85	74,74
1,8	1,58	17	14,95	90	79,14
2,0	1,76	18	15,83	95	83,54
2,2	1,93	19	16,71	100	87,94
2,4	2,11	20	17,59	105	92,33
2,6	2,29	21	18,47	110	96,73
2,8	2,46	22	19,35	115	101,13
3,0	2,64	23	20,23	120	105,52

Shear rate table - double channel region:

$$\gamma[sec^{-1}] = 113.72\ \Phi[\frac{ml}{min}]$$

γ[1/sec]	Φ[ml/min]	γ[1/sec]	Φ[ml/min]	γ[1/sec]	Φ[ml/min]
5	0,04	600	5,28	7000	61,55
10	0,09	700	6,16	7500	65,95
20	0,18	800	7,03	8000	70,35
30	0,26	900	7,91	8500	74,74
40	0,35	1000	8,79	9000	79,14
50	0,44	1250	10,99	9500	83,54
125	1,10	1500	13,19	10000	87,94
150	1,32	1750	15,39	10500	92,33
175	1,54	1800	15,83	11000	96,73
200	1,76	1850	16,27	11500	101,13
225	1,98	1900	16,71	12000	105,52
250	2,20	2000	17,59	12500	109,92
275	2,42	2500	21,98	13000	114,32
300	2,64	3000	26,38	13500	118,71
325	2,86	3500	30,78	14000	123,11
350	3,08	4000	35,17	14500	127,51
375	3,30	4500	39,57	15000	131,90
400	3,52	5000	43,97	15500	136,30
450	3,96	5500	48,36	16000	140,70
500	4,40	6000	52,76	16500	145,09