Siringability

$$\Delta P = \frac{Q\cdot 8\cdot \eta\cdot l}{\pi\cdot R^4}$$

$$Q = 0,2\ \frac{ml}{s} = 2\cdot 10^{-7}\ \frac{m^3}{s}$$

$$L_{motor} = \tau\cdot\vartheta$$

$$L_{worm} = F_{worm} \bullet \Delta x_{worm} = P\cdot A\cdot pitch\cdot n°\ threads\cdot n°\ motor\ RPM$$

$$pitch = 2mm$$

$$n°\ threads = 4$$

$$n°\ motor\ RPM = \frac{\vartheta}{2\pi}$$

To assess whether the torque delivered by the motor is suitable to deliver the drug, we consider the following condition:

$$L_{motor} \geq L_{worm}$$

$$L_{motor} = L_{worm} \rightarrow \tau\cdot\vartheta = P\cdot A\cdot pitch\cdot n°\ threads\cdot \frac{\vartheta}{2\pi}$$
$$\rightarrow \tau = P\cdot A\cdot pitch\cdot n°\ threads\cdot \frac{1}{2\pi}\cdot dissipative\ effect$$

$$A = \pi\cdot R^2 = \pi\cdot\left(6.5\cdot 10^{-3}\ m\right)^2 = 1,327\cdot 10^{-4}\ m^2$$

$$P = \Delta P + P_{vene}$$

$$P_{vene} = 20\ mmHg = 2666,45\ Pa$$

$$\Delta P = \Delta P_{syringe} + \Delta P_{catheter} + \Delta P_{needle}$$

We consider water delivery:

$$\eta = 8,9 * 10^{-4} Pa * s$$

1) Syringe Pressure:

$$R_{syringe} = 6,5\ mm = 6,5\cdot 10^{-3}\ m$$

$$l_{syringe} = 37.67\ mm = 37.67\cdot 10^{-3}\ m$$

$$\Delta P_{syringe} = \frac{Q\cdot 8\cdot\eta\cdot l}{\pi\cdot R^4} = \frac{2\cdot 10^{-7}\frac{m^3}{s}\cdot 8\cdot 8,9*10^{-4} Pa*s\cdot 37.67\cdot 10^{-3}\ m}{\pi\cdot(6,5\cdot 10^{-3}\ m)^4} = 9,57\cdot 10^{-3}\ Pa$$

2) Catheter Pressure:

$$R_{catheter} = 5\ mm = 5\cdot 10^{-3}\ m$$

$$l_{catheter} = 1,5\ m$$

$$\Delta P_{catheter} = \frac{Q \cdot 8 \cdot \eta \cdot l}{\pi \cdot R^4} = \frac{2 \cdot 10^{-7} \frac{m^3}{s} \cdot 8 \cdot 8,9 * 10^{-4} Pa * s \cdot 1,5\ m}{\pi \cdot \left(5 \cdot 10^{-3}\ m\right)^4} = 1,088\ Pa$$

3) Needle (22GG) Pressure:

$$R_{needle} = 0.7\ mm = 0.7 \cdot 10^{-3}\ m$$

$$l_{needle} = 32\ mm = 32 \cdot 10^{-3}\ m$$

$$\Delta P_{needle} = \frac{Q \cdot 8 \cdot \eta \cdot l}{\pi \cdot R^4} = \frac{2 \cdot 10^{-7} \frac{m^3}{s} \cdot 8 \cdot 8,9 * 10^{-4} Pa * s \cdot 32 \cdot 10^{-3}\ m}{\pi \cdot \left(0.7 \cdot 10^{-3}\ m\right)^4} = 60,411\ Pa$$

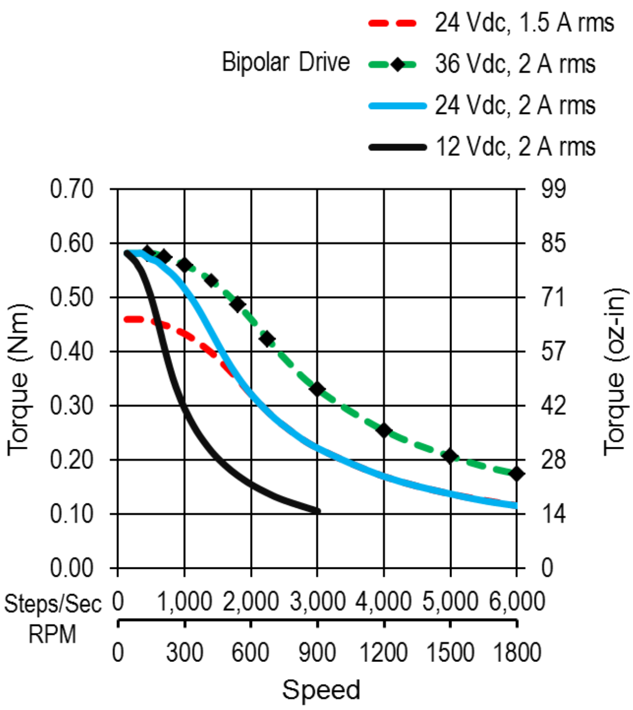
$$\Delta P = \Delta P_{syringe} + \Delta P_{catheter} + \Delta P_{needle} = 9,57 \cdot 10^{-3}\ Pa + 1,088\ Pa + 60,411\ Pa = 61,51\ Pa$$

$$P = \Delta P + P_{vene} = 61,51\ Pa + 2666,45\ Pa = 2727,96\ Pa$$

$$\tau = P \cdot A \cdot step \cdot n°\ threads \cdot \frac{1}{2\pi} = 2727,96\ Pa \cdot 1,327 \cdot 10^{-4}\ m^2 \cdot 2 \cdot 10^{-3}\ m \cdot 4 \cdot \frac{1}{2\pi} = 4,6 \cdot 10^{-4}\ Nm$$

$$v_{motore} = micro\_stepping\ number \cdot \frac{Q}{A} = 2 \cdot \frac{2 \cdot \frac{10^{-7} m^3}{s}}{\pi * \left(6,5 \cdot 10^{-3}\ m\right)^2} = 3.014 \cdot 10^{-3} \frac{m}{s} = 3.014 \frac{mm}{s}$$

$$v_{motore\_RPM} = v_{motore} \bullet \frac{30}{\pi} \bullet \frac{1}{R_{worm}} = 3.014 \cdot 10^{-3} \frac{m}{s} \bullet \frac{30}{\pi} \bullet \frac{1}{4 \cdot 10^{-3}\ m} = 7,2\ \text{rpm} = 0.12\ \text{rps}$$
$$= 48\ \text{pps}$$

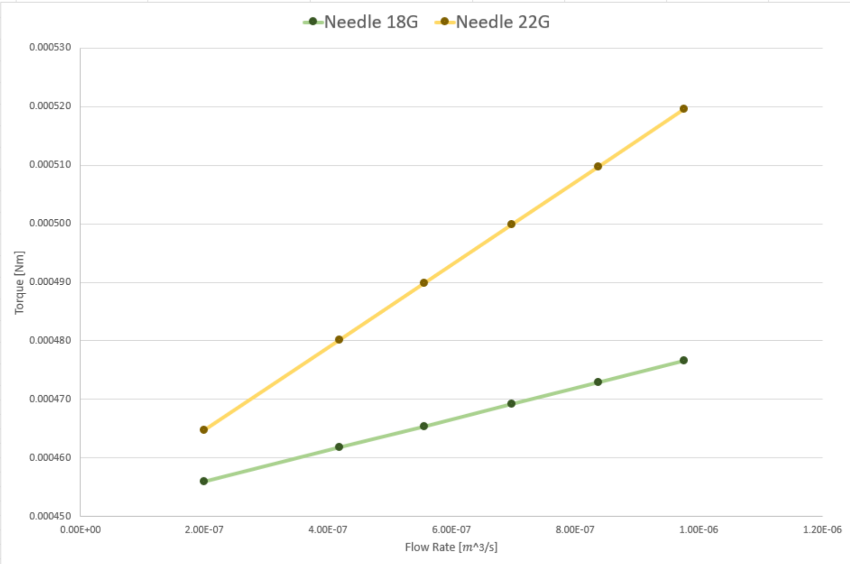


For a velocity of 7,2 rpm, from the graph we can observe a torque approximately equal to the maximum torque (0.59 Nm). The torque obtained for our application ($4,6\cdot10^{-4}\,Nm$) is less than the maximum torque that can be delivered by the motor at this speed.

This demonstration can be applied to any drug that has the same rheological properties as water.

We calculate the torque that the motor must generate to allow the drug to be injected into the vein, considering increasing flows:

Q (m^3/s)	Syringe Pressure	Catheter Pressure	Needle Pressure (18G)	Needle Pressure (22G)	ΔP (18G)	ΔP (22G)	P1 (18G)	P2 (22G)	τ (18G)	τ (22G)
2.00E-07	0.0104	23.2076	8.3065	60.4112	31.5245	83.6292	2697.9745	2750.0792	0.000456	0.000465
4.185E-07	0.0218	48.5619	17.3814	126.4105	65.9650	174.9942	2732.4150	2841.4442	0.000462	0.000480
5.558E-07	0.0289	64.4939	23.0838	167.8829	87.6066	232.4057	2754.0566	2898.8557	0.000465	0.000490
6.975E-07	0.0363	80.9365	28.9690	210.6842	109.9417	291.6570	2776.3917	2958.1070	0.000469	0.000500
8.371E-07	0.0436	97.1353	34.7669	252.8513	131.9458	350.0302	2798.3958	3016.4802	0.000473	0.000510
9.766E-07	0.0508	113.3226	40.5607	294.9881	153.9342	408.3616	2820.3842	3074.8116	0.000477	0.000520



Two types of needles are evaluated in detail:

Needle 18G

• Needle radius: 1.2 mm

• Needle length: 38 mm

$$P_{needle1} = \frac{Q\cdot8\cdot\eta\cdot l_{ago1}}{\pi\cdot(R_{ago1})^4}$$

Needle 22G

• Needle radius: 0.7 mm

• Needle length: 32 mm

$$P_{needle2} = \frac{Q\cdot8\cdot\eta\cdot l_{ago2}}{\pi\cdot(R_{ago2})^4}$$

Working conditions:

$$\tau_{motor} < \tau_{motor_{max}} = 0.59\ Nm$$

$$\tau = P \cdot A \cdot step \cdot n° \ threads \cdot \frac{1}{2\pi} < \tau_{motor_{max}}$$

$$P < \frac{\tau_{motor_{max}} \bullet 2\pi}{A \cdot step \cdot n° \ threads}$$

$$P = \Delta P + P_{veins}$$

$$\Delta P + P_{veins} < \frac{\tau_{motor_{max}} \bullet 2\pi}{A \cdot step \cdot n° \ threads}$$

$$\Delta P < \frac{\tau_{motor_{max}} \bullet 2\pi}{A \cdot step \cdot n° \ threads} - P_{veins}$$

$$\Delta P = \Delta P_{syringe} + \Delta P_{catheter} + \Delta P_{needle}$$

We determine a relationship to determine the size of the needle to be used in our application:

$$\Delta P_{needle} < \frac{\tau_{motor_{max}} \bullet 2\pi}{A \cdot step \cdot n° \ threads} - P_{veins} - \Delta P_{syringe} - \Delta P_{catheter}$$

$$\Delta P_{needle} = \frac{Q \cdot 8 \cdot \eta \cdot l}{\pi \cdot R^4}$$

$$\frac{l}{R^4} < \frac{\pi \cdot \left(\frac{\tau_{motor_{max}} \bullet 2\pi}{A \cdot step \cdot n° \ threads} - P_{veins} - \Delta P_{syringe} - \Delta P_{catheter}\right)}{Q \cdot 8 \cdot \eta}$$

We determine a relationship to establish the allowable viscosity value:

$$\Delta P = \eta\left(\frac{Q \cdot 8 \cdot l_s}{\pi \cdot R_s^4} + \frac{Q \cdot 8 \cdot l_c}{\pi \cdot R_c^4} + \frac{Q \cdot 8 \cdot l_n}{\pi \cdot R_n^4}\right) < \frac{\tau_{motor_{max}} \bullet 2\pi}{A \cdot step \cdot n° \ threads} - P_{veins}$$

$$\eta < \frac{\frac{\tau_{motor_{max}} \bullet 2\pi}{A \cdot step \cdot n° \ threads} - P_{veins}}{\left(\frac{Q \cdot 8 \cdot l_s}{\pi \cdot R_s^4} + \frac{Q \cdot 8 \cdot l_c}{\pi \cdot R_c^4} + \frac{Q \cdot 8 \cdot l_n}{\pi \cdot R_n^4}\right)}$$