Investigation of Particle Steering for Different Cylindrical Permanent Magnets in Magnetic Drug Targeting

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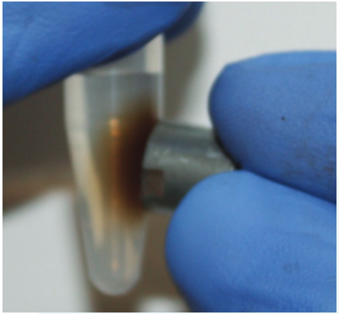
Overview

- Magnetic Drug Targeting
- Fundamentals
- Observed Model
- Results and Discussion
- Conclusion and Outlook

Magnetic Drug Targeting

- New promising cancer treatment
- Cancer-drug is bounded to magnetic nanoparticles
- Particles are pulled into tumor with a magnet
- Enables local chemotherapeutic treatment



Magnetic nanoparticles[1]

⇒ Effectiveness of the treatment depends on a successful navigation of the particles through the cardiovascular system.

[1] H. Unterweger; et al. "Development and characterization of magnetic iron oxide nanoparticles with a cisplatin-bearing polymer coating for targeted drug delivery," International Journal of Nanomedicine, 5 August 2014.

Fundamentals

- Superparamagnetic nanoparticles
- Motion of one particle (Newton's second law):

$$m_\mathrm{p} \frac{\mathrm{d} v_\mathrm{p}}{\mathrm{d} t} = F_\mathrm{m} + F_\mathrm{f}$$

- Magnetic force F_m:

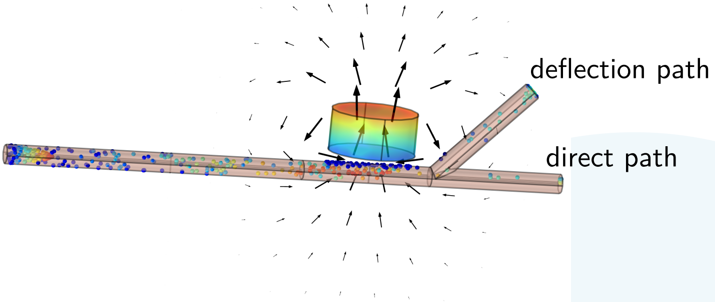
$$F_\mathrm{m} = \frac{4\pi r_\mathrm{p}^3}{3} \frac{\mu_0 \, 3\left(\chi_\mathrm{p} - \chi_\mathrm{f}\right)}{3 + \left(\chi_\mathrm{p} - \chi_\mathrm{f}\right)} H \cdot \nabla H$$

- Drag force F_f:

$$F_\mathrm{f} = -6\pi\eta r_\mathrm{p}\left(v_\mathrm{p} - v_\mathrm{f}\right)$$

symbol	label
m_p	particle mass
$v_\mathrm{p,f}$	particle/fluid velocity
r_p	particle radius
μ_0	permeability of vacuum
$\chi_\mathrm{p,f}$	susceptibility of particle/fluid
H	magnetic field
η	fluid viscosity

Observed Model



- Transport from the left to the right within a 45° bifurcation vessel
- Particle packets of 5×100 particles
- Velocity of one particle is depicted by its color: red corresponds to a high and blue to a low normalized particle velocity

Simulation Parameters

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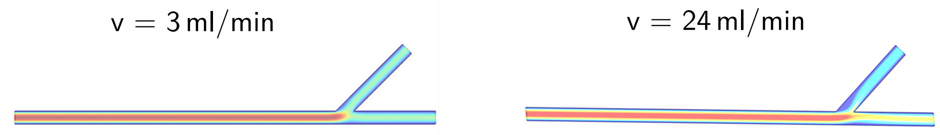
category	symbol	value	unit	label
vessel	r_v	2	cm	radius
	L	13	cm	length
	μ_f	1	—	relative permeability of the fluid
particle	r_p	350	nm	radius
	ρ	2000	kg/m^3	density
	μ_p	4000	—	relative permeability
magnet	V	3	cm^3	volume
	M_sat	10^6	A/m	saturation magnetization
varied	v	3,6,12,24	ml/min	fluid velocity
	rtl	0.5,1,2	—	magnet's radius to length ratio

Results: Influence of the Fluid Velocity



- Normalized velocity profile of the setup. The red color corresponds to a high and blue to a low normalized velocity
- Before the bifurcation: parabolic velocity profile
- At the bifurcation: turbulence $\longleftrightarrow$ increasing with velocity
- Higher velocity in the middle of vessel $\rightarrow$ greater drag force

Results: Influence of the Gravitational Force

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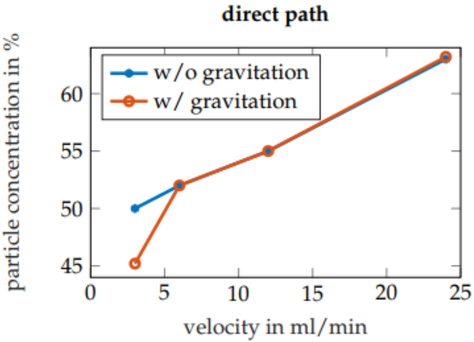

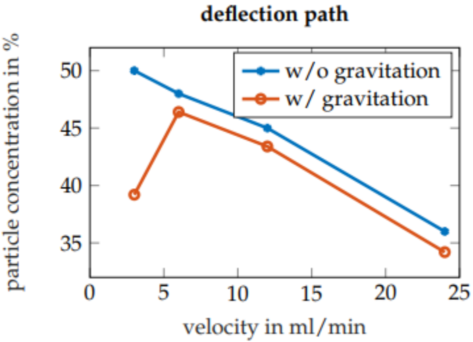

- Influence of the gravitational force decreases with an increasing fluid velocity
- Impact in direct path only observable for $v = 3\,\text{ml/min}$

Results: Influence of the Magnet

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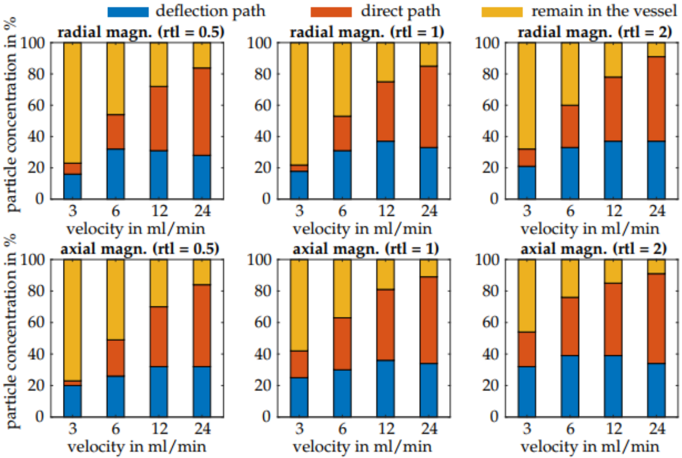

- For lower velocities magnetic field is too strong $\rightarrow$ most particles trapped by magnet
- Magnetization directions: higher impact of magnet for radial magnetization
- Smaller rtl-value has greater influence on particle propagation

Discussion

- Particle steering depends on numerous parameters
- Influence of gravitation can be neglected for higher fluid velocities
- Particles in upper branch are trapped by magnet, the ones in the lower middle take desired direction
- For a fix fluid velocity and magnet, there must be an optimal zone to guide particles in the desired direction
- Deflection of particles towards a desired direction is difficult by using only one simple permanent magnet

Conclusion and Outlook

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- Replacing permanent magnet by electromagnet, to fit applied magnetic field strength and its gradient to current fluid velocity
- To solve the trapping problem, the magnet can be switched on and off
- Figure out „optimal zone“ for particle navigation
- Further optimization will be done

Thank you for your attention ☺

Questions?