ME 141A Final

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1 Short Answer Questions

1. Nanofluidic channels have bigger electric double layers to channel height ratios than microfluidic channels with the same solution in it.

2. Nanofluidic channels with finite EDLs allow for separation and concentration of ions in solution. The EDL causes positive ions to aggregate on the walls of the channel, and negative ions to flow over the positive ones.

3. Nanoshells are of interest primarily to treat cancer. Nanoshells can be coated with antibodies or proteins to target cancerous cells. When exposed to a particular frequency of infrared radiation, the nanoparticles heat up, killing the surrounding cancer cells.

4. Gold nanorods vary in color from red to blue depending on the length of the nanorod. The longer the nanorod, the longer the wavelength of light is reflected.

5. Carbon nanotubes have been extremely useful in medical therapy. Applications vary from drug delivery to cancer treatment to biosensing.

6. The zeta potential is the potential measured across the electric double layer, which is formed by ions in solution aggregating on a solid surface. The zeta potential is influenced by the valences of the ionic components, the molarity of each component in solution, temperature, and the properties of the suspending fluid, such as relative permittivity.

7. Cells can be focused in a microfluidic channel using three different methods: spiral microfluidics, flow fractionation, and serpentine channels.

8. Stokes flow is a reduction of the Navier-Stokes equation for fluid flow at $\text{Re} \ll 1$, such that any inertial effects are negligible. Stokes flow is thus characterized by the following equation:

$$0 = -\nabla P + \mu \nabla^2 \mathbf{V} + \mathbf{f}$$
$$0 = \nabla \cdot \mathbf{V}$$

   This impacts the engineering of devices using viscous fluids, thin films, or microchannels.

2 Long Answer Questions

2.1 Commercially available microfluidic device

One microfluidic device currently on the market is the mixing chip, which are manufactured by Darwin Microfluidics [2]. Mixing chips take two or more fluid inlets and flow them through microchannels until they both meet in the same channel, impinging with each other and mixing. The mixture then leaves through another port at the end of the channel. These chips are especially useful for flow observation and controlled concentrations of ions and cells.

2.2 Currently unavailable microfluidic device

The vesicle puncture device from the design problem in homework 3/4 is one example of a microfluidic device that cannot be commercially viable. While the device may be useful for studying the mechanics of the cell membrane, or for transvection of low numbers of a variety of cells, there are far too many precise controls and fabrication steps required for the device to compete against other transfection devices.

3 Cell Transfection Device

	Vesicle Penetrator	Kytopen	In2Cell	Ultrasound
Device size	<1mm	~10cm	~1-10cm	>20cm
Fabrication Complexity	Multiple materials and fab. processes	Mostly off-the-shelf components, some custom	Almost entirely off-the-shelf components	Exclusively off-the-shelf components
Required process control	Precise positioning of vesicles and actuation	Timing of electric pulses with fluid flow	Flow rate via syringes	Ultrasonic bath settings
Throughput	~uL/min	~50mL/min	~50mL/min	~mL/min
Efficiency	Allows for single-cell transfection	Reliable, but no feedback to ensure transfection	Reliable, but no feedback to ensure transfection	Only works for specific cells + transfectants
Tuning	Can adjust actuation rate, actuation depth	Can modify flow rate	Can modify flow rate	none

Figure 1: Comparison of Vesicle Puncture, Kytopen [4], In2Cell [3], and ultrasonic transvection methods [1]. Green is a better attribute, red is worse.

Evaluating the features and performance of the devices listed in Figure 1, the best technology to buy out would be In2Cell, as there is less complication with peripheral systems, fewer custom components, and more relaxed process control requirements than the next best competitor, Kytopen. Furthermore, the technology can be implemented in a small enough device to encourage high throughput, parallel operations, unlike the Kytopen or ultrasonic methods.

4 Coronavirus Detection

4.1 Flaws and Unanswered Questions

This idea for coronavirus detection can theoretically work, but there are some flaws with the procedure. For example, if the detection method is simply taking pictures with a microscope, the current placement of detector B makes it impossible to distinguish beads flowing in the channel from those adhered to the wall. Additionally, there is no guarantee Protein A will stay in its designated portion of the channel, and potentially diffuse to the detection point 1, skewing the measurement results.

There is also the issue of accessibility. While the chip and the proteins are readily produced, this test requires microscopes, cameras, and image processing capabilities to be functional. Many well-prepared labs across the country may have those capabilities, but for widespread testing to be reasonable, test kits should be distributed far and wide with minimal required additional equipment.

Additionally, the validity of this design hinges on some unanswered questions.

1. What is the inlet concentration of Proteins A and B? Inlet volumes of both protein solutions?
2. What is the anticipated concentration of coronaviruses in a given saliva sample? What concentration signifies a positive case?
3. Are the test kits reusable? If so, how are the channels cleared out to ensure no false positives?

4.2 Redesign and Improvements

Assuming the polystyrene beads with Protein B can stick perfectly to the wall with Protein A, provided the coronavirus is present, then the test becomes significantly more feasible by following the Protein B step with a Milli-Q water rinse of the channel. This way, the polystyrene beads would no longer be present in the portion of the channel at Detector 1, but they would still be present on the walls at Detector 2. After a water rinse of the channel, if any polystyrene beads remain at Detector 2, it is because the coronavirus acts as an adhesive to bind Protein A and Protein B, allowing the bead to adhere to the silicon dioxide wall. This eliminates the need for image processing, two cameras, and two microscopes per test, as the observer no longer needs to distinguish the concentration of Detector 1 from Detector 2.

The redesign, then, is as follows:

- Remove Detector 1
- Remove both cameras and imaging software: a human observer can easily identify the presence of polystyrene beads through an optical microscope
- Introduce a water rinse from the Protein B reservoir through the channel to the waste reservoir
- Add a sterilization purge through the chip to allow for reusability, significantly driving down cost and resource demand

Appendix A Acknowledgement

I confirm that the work I submit is my own and my own only.

References

[1] Yizhi Song et al. "Ultrasound-mediated DNA transfer for bacteria". In: *Nucleic Acids Research* (Aug. 2007).

[2] *Darwin Microfluidics*. Mar. 2020. URL: `https://darwin-microfluidics.com/collections/micromixers-chips`.

[3] *In2Cell*. Mar. 2020. URL: `http://www.in2cell.com/technology`.

[4] *Kytopen*. Mar. 2020. URL: `https://kytopen.com/#technology`.