

Microfluidics

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May 1st, 2015

Abstract

The following application note discusses microfluidics and their importance in creating a self-suffusing surgical tool to be utilized in unsanitary surgical conditions. Microfluidics is still a developing science due to the recent discovery of its effectiveness within many fields of study.

Keywords

Microfluidics, macrofluidics, laminar, turbulent, Reynolds number

Introduction

Microfluidics is the science and technology of systems that process nano-sized or smaller amounts of fluids utilizing channels on the scale of tens to hundreds of micrometers. This area of study is still in the early stages of development due to the recent spark in research. Scientists are beginning to discover the endless possible application capabilities due to the various advantages of microfluidics.

Discussion

There are four primary areas of science responsible for contributing to the advancements in the study of microfluidics; molecular analysis, biodefense, molecular biology, and microelectronics. They each provided a problem in which microfluidics served as a viable solution to resolve. In the case of molecular analysis, microfluidics were utilized in microanalytical methods such as gas-phase chromatography, high-pressure liquid chromatography, and capillary electrophoresis. These all combined to revolutionize chemical analysis through providing higher resolution and sensitivity through small sample amounts. This furthered the interest to seek additional applications of microscale analysis methods within biochemistry and chemistry.

The use of microfluidics in molecular biology began being implemented around the 1980's, during the increase in the study of genomics. It provided an avenue to surpass problems with high-throughput DNA sequencing by producing results with higher sensitivity and resolution than previous results.

Next biodefense served as an additional research area utilizing microfluidics in the 1990's after the conclusion of the cold war. At this time, the Defense of Advanced Research

Projects Agency (DARPA) under the direction of the US Department of Defense created a series of programs focused on developing field-deployable microfluidic systems. They were designed to serve as detectors for biological and chemical threats as these types of weapons were a major military and terrorist threat.

Lastly microelectronics related microfluidics to the technologies used in silicon microelectronics and in microelectromechanical systems. These four areas of study helped increase the research in microfluidics due to the solutions they provided for each division of science.

The differences of microfluidics when compared to macrofluidics include surface tension, fluidic resistance, energy dissipation and the Reynolds number being the most significant. The Reynolds number is a ratio between inertial and viscous forces. It can be calculated using the following formula with the defined parameters below.

$$Re = \frac{\rho VD}{\mu},$$

where

ρ (rho) is the fluid density,

V is the mean fluid velocity,

D is the pipe diameter and

μ (mu) is the fluid viscosity.

Equation 1: Reynolds number calculation.

This equation is dependent on the density and velocity of the fluids being used and measures the force due to momentum of the fluid. Viscosity, which is the measure of resistance to gradual deformation due to shear stress, is also used in calculating the Reynolds number. The formula for calculating viscosity can be found below with the defined variables below.

$$\tau = \mu \frac{du}{dy},$$

where

τ (tau) is the shearing stress,

μ (mu) is the absolute or dynamic viscosity, and

$\frac{du}{dy}$ is the velocity gradient.

Equation 2: Viscosity calculation.

Based on the value of the Reynolds number calculated, a system will produce different types of flow patterns. When a Reynolds number falls below 2100, the fluid will produce a laminar flow which is a characteristic of microfluidic systems. In this case, the fluids will move in a constant parallel motion without a mixing of substances. However, if the number calculated is above 4000, this indicates a turbulent flow which is representative of a macrofluidic system. This means the fluids will tend to flow in a circular pattern due to inertial forces dominating the movement. A diagram showing the movement pattern of each type of flow can be found below.

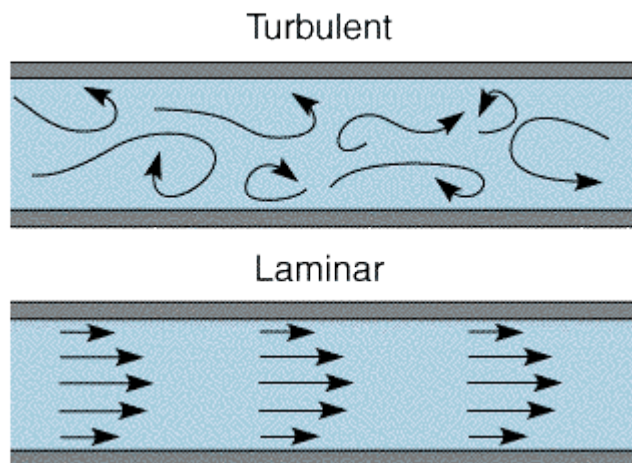


Figure 1: Comparison of Turbulent vs. Laminar Flow.

A Reynolds number which falls between these two values ($2100 \leq Re \leq 4000$) indicates a transitional flow, which as its name suggests, is a combination of both flow patterns as the fluid transitions from one type to the other.

With the challenge of creating a surgical tool for use in unsanitary conditions, microfluidics will be utilized to deliver the antimicrobial to the surface of the tool. The tool selected to be created is Mary Mayo needle holders as shown in the image below.

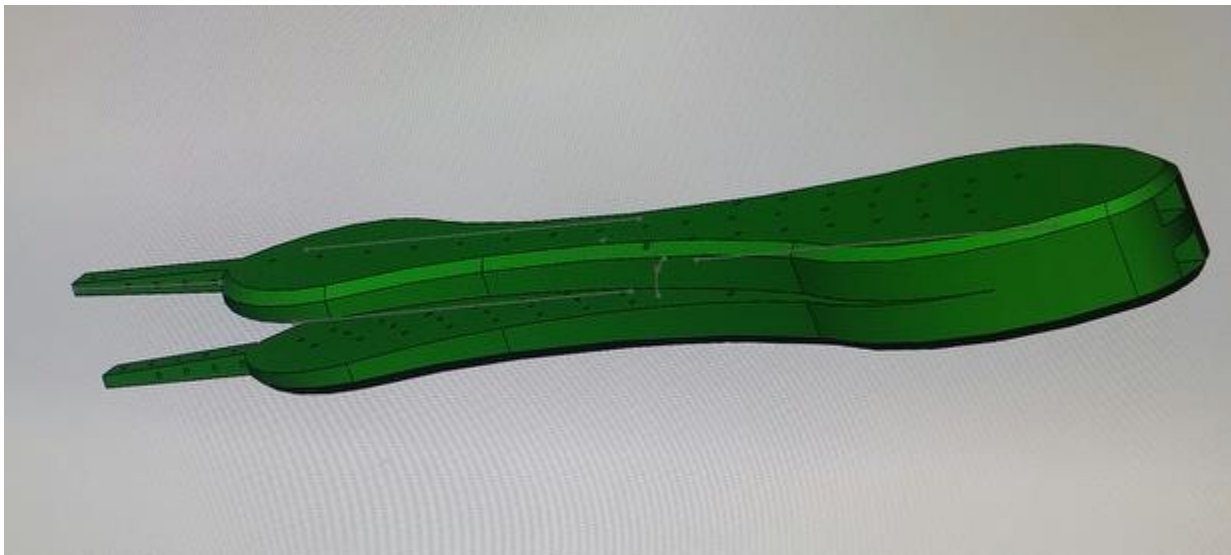


Figure 2: Mary Mayo needle holders designed in SolidWorks.

This image was created using SolidWorks software in which a main central channel will run down each side of the tool. The surface of the tool contains holes the size of $7\text{ }\mu\text{m}$ which will allow the cleaning substance (chlorhexidine) to be continuously suffused. A pressure bag will be used to create the required flow rate. The antimicrobial will be held in an IV bag, with the pressure bag encasing it. An air pump will be used to pump air into the pressure bag which will increase the pressure inside the IV bag holding the antimicrobial. The increased pressure will create the proper flow rate needed to suffuse the tool. A microcontroller along with a pressure sensor will be used to monitor the amount of pressure being applied throughout the surgery.

Conclusion

Microfluidics is a relatively new field which was developed from its uses in molecular analysis, biodefense, molecular biology, and microelectronics. Microfluidics function using a laminar flow while macrofluidics utilize a turbulent flow. This is the primary difference that separates these two types of fluidics and can be determined by calculating the Reynolds number for a substance. Microfluidics is advantageous for many applications and will be utilized to create a self-suffusing surgical tool. This will allow a controlled amount of antimicrobial to be continuously delivered to the surface of the tool throughout a surgery.

References

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