Design a Monitoring System For Pathogen Detection Using Microfluidic Technology

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Abstract: Waterborne pathogens affect all waters globally and proceed to be a ongoing concern. The act to provide clean water by filtration is effective although has concerns. Previous methods for detection and removal of pathogens consist of a high test time, a high sample consumption, very expensive and require specialist operators. This paper investigates the design of an active microfluidic technology to prototype a smart monitoring system to detect waterborne pathogen movement. Results provide areas of opportunities to fabricate microchannels with a high recovery rate (88%) to embedded sensors e.g. optical fiber sensors to detect pathogens at certain flow rates. Major advantages defeat drawbacks by reducing test time and sample consumption whilst being less expensive.

1. Introduction

1.1. Waterborne pathogen

Due to the increasing concern for water scarcity it is expected that by 2025, half of the world's population will endure 'water-stressed' areas [1]. This is due to climate change affecting both the developing and developed world. Already 1.1 billion people lack access to clean water and 2.7 billion have a water shortage for at least one month of the year, exposing waterborne diseases such as cholera, typhoid fever and hepatitis A [2]. As a result, approximately 525,000 children under the age of five die annually from diarrhea diseases alone. According to the World Health Organization (WHO), lower respiratory infections and diarrheal diseases are the top 2 causes of deaths in low-income countries in 2016. From this, 11 - 20 million people get an illness due to typhoid fever, and 128,000 - 161,000 people die from this annually [2]. Typhoid fever is caused by the Enterobacteriaceae Salmonella Typhimurium which typically is around 2 - 5 µm in size. In addition to this, the developed world suffers from pathogens such as *Cryptosporidium* which can survive months within waters [3]. This particular pathogen causes gastrointestinal and respiratory illnesses, although the death rate is much lower than typhoid fever. Bridle [3] has previously established that research has been conducted to identify advances in obtaining results of waterborne pathogen movements. With compliance of WHO, waterborne pathogens have to be carefully monitored and analyzed to implement the safety of water intake. Considering this, microfluidic devices can take a very small sample and conduct a process to analyses the safety of water through an experimental monitoring method.

1.2. Microfluidic technology

In the past two decades, microfluidic systems have been intensely researched to advance applications in field of chemistry, biology, genomics, proteomics, pharmaceuticals, biodefense [3] emerging as a powerful useful technology. Large processes that once were carried out in bulky, slow, expensive equipment are now processed on a single miniaturized chip. Microfluidic chips are purposely designed to monitor the movement of cells, pathogens or nanoparticles within the microchannels, allowing easy detection and removal methods under controlled conditions. In addition, microchannels typically have a width of 100-800 µm which allows advantages of sample consumption to be reduced, whilst also increasing the speed of results. This increasing efficiency and an inexpensive process [4]. Microfluidic chips are subjected to two categories, Active mixers and Passive mixers. An active mixer is where the fluid is driven through by micro-valves or micro-pumps unlike passive mixers where the fluid is driven from centrifugal channels or decreasing the size of the channels to accelerate the fluid.

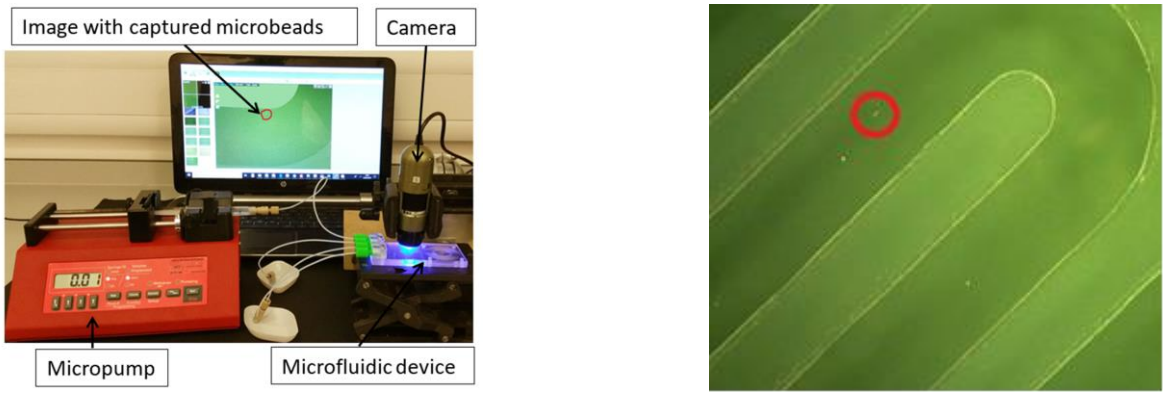
1.3. Research aim

This research aims to design a smart monitoring system to detect a waterborne pathogen cell using microfluidic technology. The sample was driven through the designed microfluidic device at a selected flow rate on a micro-pump. The pathogen movement was tracked by a high quality camera at a perspective angle. With repeated experiments and alterations of the input flow rate, the output is hypothesized to find a consistent 'track line' that the pathogen travels within the channel so a separation channel can be fabricated to remove the pathogen from the sample.

2. Sample preparation procedure

2.1. Methodology

To monitor the movement of a waterborne pathogen, a micro-pump (The Aladdin single-syringe infusion) drives a sample of 3ml through a microfluidic device. To simulate the movement of pathogen inside the microfluidic channel, a polymer fluorescent green microsphere beads are used with a range size of 1 - 5 µm. A USB microscopic camera (The Dino-Lite AM4515T8 Edge 700x~900) was set up and positioned at a perspective angle. The camera emits an ultraviolet light source causing the fluorescent microspheres to reflect to the camera. As shown in Figure 1 (a), the camera was secured in a position using a clamp to obtain a perspective view of the microfluidic device. The camera's focus point was altered to output a clear view of the microfluidic channels on the software. 500 µg of polymer fluorescent green microspheres were diluted and mixed into a 50 ml test tube containing tap water. This allowed the sample to be withdrawn easily with the use of a BD Plastipak 3ml max syringe. The tubing was connected to the input port of the microfluidic device. Tubes were connected to the output ports of the microfluidic device to release the wastage processed. Figure 1 (b) shows an image of a microbead inside the microfluidic channel.



a) b)

Fig.1 : a) The system setup includes a syringe pump and a USB camera with 500-900 times zoom; b) Image detection of the microbeads of 1-5 µm within the microfluidic channel.

2.2. Velocities tests

Flow rates were tested from 5 - 235 µL/min (in increments of 10 µL/min) to find the most probable flow path for a pathogen cell. Videos from the camera stored the movement of the fluorescent bead within the microchannel at a rated flow rate in increments of 30 µL/min. A highlighted bead expresses the motion of which it travels at a specific flow rate. Flow rates between 5 - 35 µL/min resulted in no movement of particles therefore were not included. The movement is processed from the images using Matlab allowing analysis of where most beads flow in terms of the 0.8 mm diameter channel.

3. Results and discussion

3.1. Detection

The objective was to monitor the movement of waterborne pathogen cells using microfluidic technology. During the tests, the micro-pump was configured at an estimated flow rate of 75 µL/min to investigate the possibility of detection. The test redeemed to show a clear microbead detection as demonstrated by the result highlighted in Figure 2.

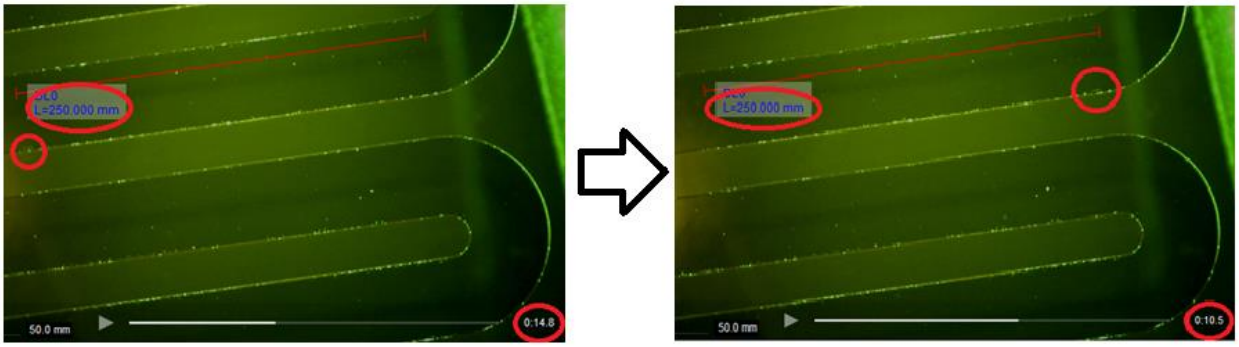


Fig. 2. Velocity measurement of the microbeads travelling within the microfluidic channel.

3.2. Flow rate analysis

As this method detects the movement of a fluorescent bead, it allowed further testing to conclude on finding a single flow rate of which a pathogen cell with consistently flow on the same path. This provides an opportunity of removing the pathogen from the sample. Matlab Simulation was used to calculate the highest probable chances microspheres are going to travel at specific flow rates as shown in Figure 3 (a).

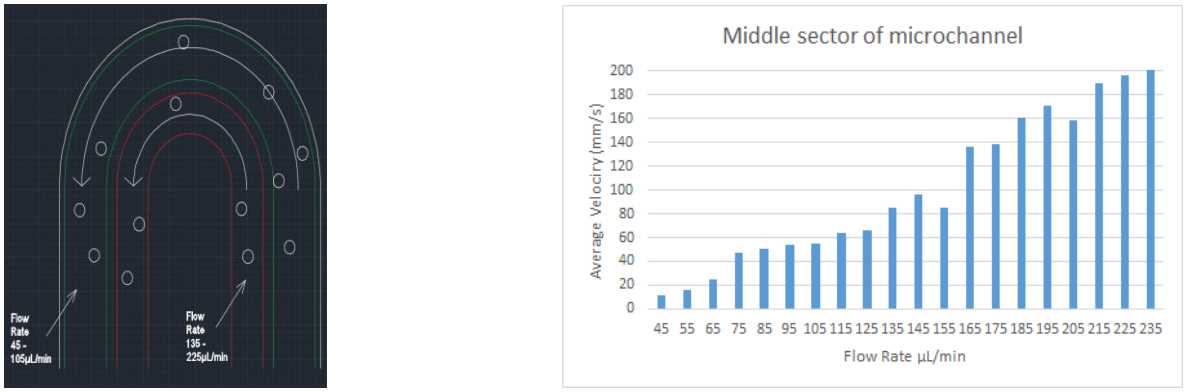


Fig. 3: a) Matlab simulation of the movement inside the channel; b) Average velocity calculation in the middle sector of the microfluidic channel.

Results from collected data show that the microsphere movement is towards the outside of the microchannel at the slower flow rate (45 µL/min) and towards the inside of the microchannel at higher flow rate (225 µL/min). From the videos taken by the camera, Figure 3 (b) shows gathered data from the movement of the microsphere. In addition, from the Matlab script used to compare between image frames (), at a slower flow rates of 45 - 105 µL/min the microsphere has a higher probability of 88% to be recovered at 0.4 - 0.8 mm of the microchannel. Whereas at faster flow rates of 135 - 225 µL/min, the recovery rate has a probability of 69% at 0.0 - 0.4 mm of the microchannel.

4. References

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