OPTICAL TRAPPING AND MANIPULATION OF MICROCRYSTALLINE CELLULOSE MICROCLUSTER (MCCM) FOR MICROTOOL APPLICATIONS

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SULTAN IDRIS EDUCATION UNIVERSITY

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ABSTRACT

This research endeavours to employ optical trapping technique for manipulating a single microcrystalline cellulose microcluster (MCCM) in solution. The viscosity of low concentration microcrystalline cellulose (MCCM) solutions was assessed to identify optimal concentrations for optical tweezer applications. These solutions were prepared via the sonication method, and their viscosity was measured using a rheometer. Utilizing optical microscopy, MCCM formation was observed to determine suitable size ranges for optical trapping. A single MCCM was successfully trapped using a 976nm linearly polarized laser with a numerical aperture of 1.4, whist manipulation was achieved employing a circularly polarized laser. The translation motion of the MCCM was facilitated by a piezostage system. Trajectories of the MCCM were analyzed through visual observation via a CCD camera and scattering light detection with a quadrant photodiode (QPD). The findings indicated that solutions with concentrations below 1% *w/w* were optimal for optical trapping. MCCM ranging from 0.5 μm to 4.0 μm were effectively trapped within a laser power density range of 0.6 MW/cm^2 to 2.2 MW/cm^2, with the additional capability of rotation using the circularly polarized laser. In conclusion, this research demonstrates the feasibility of employing optical techniques, in conjunction with a piezostage, to achieve simultaneous linear translation and rotational motion of a single microcrystalline cellulose microcluster. This research implies that a single cellulose microcluster and fibrous microparticle, such as MCCM, can be optically micro-controlled for microtool applications.

PEMERANGKAPAN DAN MANIPULASI OPTIK MIKROGUGUSAN SELULOSA MIKROHABLUR UNTUK APLIKASI MIKROALAT

ABSTRAK

Kajian ini bertujuan untuk menggunakan teknik pemerangkapan optik bagi memanipulasikan kluster mikroselulosa mikrohablur (MCCM) tunggal dalam larutan. Kelikatan larutan selulosa mikrohablur (MCCM) pada kepekatan rendah diukur untuk mengenal pasti kepekatan optimum bagi kegunaan penyepit optik. Larutan-larutan ini disediakan melalui kaedah sonikasi dan kelikatannya diukur menggunakan reometer. Dengan menggunakan mikroskopi optik, pembentukan MCCM diperhatikan untuk menentukan julat saiz yang sesuai bagi pemerangkapan optik. MCCM tunggal diperangkap menggunakan laser terkutub linear 976nm pada bukaan berangka 1.4, manakala manipulasi dicapai dengan menggunakan laser terkutub bulatan. Pergerakan MCCM secara translasi dilakukan menggunakan sistem pentas piezo. Trajektori MCCM dianalisis melalui pemerhatian visual melalui kamera CCD dan pengesanan cahaya serakan dengan fodiod kuadran (QPD). Penemuan menunjukkan bahawa larutan dengan kepekatan di bawah 1% *w/w* adalah optimal bagi pemerangkapan optik. MCCM dalam julat 0.5 μm hingga 4.0 μm berjaya diperangkap dengan berkesan dalam julat ketumpatan kuasa laser 0.6 MW/cm² hingga 2.2 MW/cm², dengan kebolehan tambahan putaran menggunakan laser terkutub bulatan. Kesimpulannya, kajian ini menunjukkan kebolehan menggunakan teknik optik, bersama-sama dengan piezopentas, untuk mencapai pergerakan translasi dan putaran secara serentak bagi kluster mikroselulosa mikrohablur tunggal. Kajian ini mencadangkan bahawa kluster mikroselulosa tunggal dan mikrozarah fibrosa, seperti MCCM, boleh dimikrokawal secara optik bagi aplikasi mikroalat.

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LIST OF SYMBOLS

SYMBOLS	MEANING	UNITS
P_d	laser power density	MW/cm^2
P_{dL}	laser power density lower limit	MW/cm^2
P_{dU}	laser power density upper limit	MW/cm^2
ω	angular velocity	Rad/s
l_x	lengths in *x* plane	µm
l_y	lengths in *y* plane	µm
T	absolute temperature	K
t	time	s
γ	coefficient of friction	N s/m
k_T	optical stiffness	pN/m
"r"	effective radius	m
Ƞ	fluid viscosity	Kg/m^3
f_c	corner frequency	Hz
F_g	gradient force	N
F_s	scattering force	N
λ	wavelength	m

LIST OF CONSTANTS

SYMBOLS	MEANING	UNITS
k_B	Boltzmann constant	J/K
π	Pi constant	---

LIST OF ABBREVIATIONS

OSCal	Optical Stiffness Calculator
CCD	Charged Coupled Device
ET	Equipartition Theorem
FFT	Fast Fourier Transform
MCCM	Microcrystalline cellulose microcluster
NA	Numerical Aperture
OT	Optical Tweezers
PSD	Power Spectrum Density
QPD	Quadrant Photodiode
WD	Working Distance
USB	Universal Serial Bus

APPENDIX LIST

CHAPTER 1

INTRODUCTION

1.1 Introduction

This chapter gives a brief introduction to the research. The chapter begins with the research background, followed by the problem statement's presentation. Several objectives were identified to guide this research in order to address the challenge highlighted in the problem statement. In this chapter, the brief description of the optical trapping and microcrystalline cellulose are explained. Consequently, the significant of the research and scope will also be described in this chapter. Finally, this chapter is concluded with the summary of the thesis.

1.2 Background of the Research

1.2.1 Microcrystalline Cellulose

Microcrystalline cellulose (MCC) is widely used in various industrial fields such as medicine, cosmetics, pharmaceuticals, and polymer composite. Due to its novelty, non-toxicity properties, economic value, biodegradation, mechanical properties, surface area, and biocompatibility, the interest in microcrystalline cellulose has increased (Bai & Li, 2009; Cataldi et al., 2014; Gómez Hoyos et al., 2013; J.-K. Kim, 1993; Rafiee & Keshavarz, 2015; Trache et al., 2016). For example, the properties of hydrogels facilitate their usage in bio-related applications, including drug delivery systems, tissue-engineering scaffolds, wound dressing, and biomedical devices (Choe et al., 2018; Peppas et al., 2006; Seliktar, 2012; Sun et al., 2012; Zhao, 2014). The Hydrogels' imperfect mechanical properties would have limitations that require high-strength properties (Kamata et al., 2014). Therefore, cellulose can be a suitable biopolymer for synthesising with outstanding mechanical properties (Choe et al., 2018).

Due to the inherent crystalline structure, cellulose exhibits high strength, high stiffness, and low density (H. Zhang & Liu, 2008). It is possible to synthesise microcrystalline cellulose hydrogel by controlling the viscosity of cellulose solutions. The information on the viscosity of microcrystalline cellulose is essential for a small-scale to industrial scale in a diverse field to optimize quality. It can directly affect the final product (J.-K. Kim, 1993).

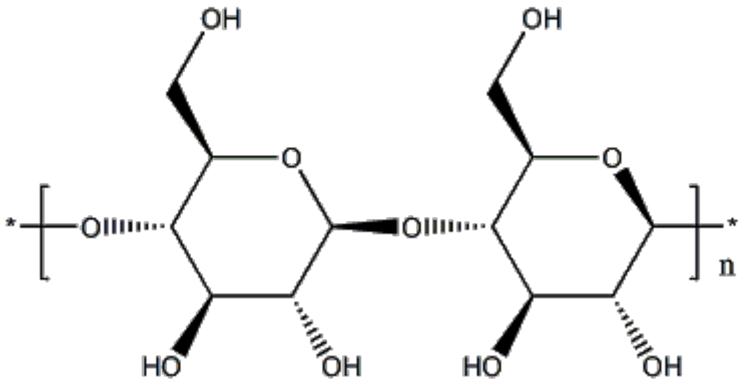


Figure 1.1. Molecular structure of microcrystalline cellulose.

MCC with the molecular formula $(C_{12}H_{20}O_{10})n$, as shown in Figure 1.1, is commercially available in a free-flowing powder form of white appearance. MCC poses limitations needed for some applications compared to other natural polysaccharide polymers, such as low wettability, moisture absorption, and limitation in processing temperature (Trache et al., 2016). In the previous research on cellulose-filled engineering thermoplastics, scientists believed cellulose as a reinforcement or additive did not give encouraging results. The materials exhibited severe discolouration and cellulose thermal degradation at temperatures needed to process these engineering thermoplastics. However, recently researchers have looked again at cellulose-filled engineering thermoplastic and suggested that microcrystalline cellulose-filled nylon composites are relevant in thermally challenging areas due to the higher mechanical properties and lower density, such as engine covers, intake manifolds and radiator end tanks (Kiziltas et al., 2014). It is also essential to know and observe the temperature dependence due to the limitation of microcrystalline cellulose in processing temperature to optimize the product's quality and cost-effectiveness in various industrial processes (Trache et al., 2016). The viscosity value expects to decrease due to the increasing temperature for all liquids. However, modifications of viscosity value are essential as they could influence the operational cost of several stages in the industrial process, such as mixing and fluid transport (Riyanto et al., 2015).

This research further explores the potential of microcrystalline cellulose with the combination of optical tweezers technology. At low concentrations of microcrystalline cellulose in water, a single microcluster of microcrystalline cellulose can be used as a microtool. The microtool can be designed as a microvalve or microcarrier in microfluidic channels.

1.2.2 Viscosity Measurement of Microcrystalline Cellulose

Microcrystalline cellulose (MCC) is composed of small crystalline particles and possesses unique rheological properties that influence its behavior in solution. Understanding the viscosity of MCC solutions is crucial for optimizing processes such as manufacturing, formulation, and processing of MCC-based products.

Viscosity measurement is a fundamental rheological characterization technique used to assess the flow behavior of fluids or suspensions. In the case of MCC solutions, viscosity plays a significant role in determining their flow properties, stability, and performance in various applications. Rheometers are commonly employed instruments for measuring viscosity, offering precise control over experimental conditions and providing valuable insights into the rheological behavior of complex fluids like MCC solutions. Rajeev et al. (2018) investigated the viscosity behavior of MCC solutions at different water concentration range. Their research revealed the concentrationdependent viscosity profile of MCC solutions, highlighting the importance of viscosity measurements for optimizing processing parameters in MCC-based formulations.

The recent research, G. H. Zhao et al. (2011) explored the rheological properties of microcrystalline cellulose (MCC) and sodium carboxymethyl cellulose (Na-CMC) and their impact as stabilising and suspending agents in pharmaceutical formulations. Their research emphasized the need for accurate viscosity measurements to ensure product quality and performance. As example the requirement of the spraying action for applications in intranasal spray delivery, the viscosity required to be low at high shear rates. A comprehensive research have been conducted on the rheological characteristics of MCC dispersions in different solvent systems. It provided insights into the effect of solvent composition on the viscosity of MCC solutions, aiding in the formulation design for various applications (Yohana Chaerunisaa et al., 2020).

The importance of rheological analysis in optimizing manufacturing processes for MCC-derived products have been demonstrated by investigate the influence of processing parameters on the viscosity of MCC suspensions during the fabrication of microcrystalline cellulose-based materials envolving field of 3D printing of hydrogels and aerogels (Barrulas & Corvo, 2023). Boran et al. (2016) evaluated the viscosity behavior of MCC solutions under shear and extensional flow conditions using advanced rheological techniques. Their research contributed to a better understanding of the rheological properties of MCC and its applications in industries such as food, pharmaceuticals, and biotechnology.

These studies collectively underscore the significance of viscosity measurement using rheometers in characterizing MCC solutions and optimizing their performance in various industrial applications. By building upon these insights, the present research aims to further elucidate the viscosity behavior of MCC solutions and its implications for microtool applications in conjunction with optical tweezers.

1.2.3 Optical Tweezers

Optical tweezers are applied to facilitate the micromanipulation of a particle using light. It required laser light with high-intensity values, which is focused through a high numerical aperture objective lens. Light momentum changes when it is absorbed, reflected, and refracted by a transparent object. The momentum changes are conserved with the reaction force on the object. Optical tweezers can be established just by using a single laser source. Two main forces dominate in optical tweezers: the gradient force and the scattering force. The scattering force always pushes particles away from the source.

Meanwhile, the gradient force is caused by the variation of light intensity in space. The more step the intensity change, the stronger the force will be occurred. The balance between these two forces establishes a stable optical trap which can be used for various applications.

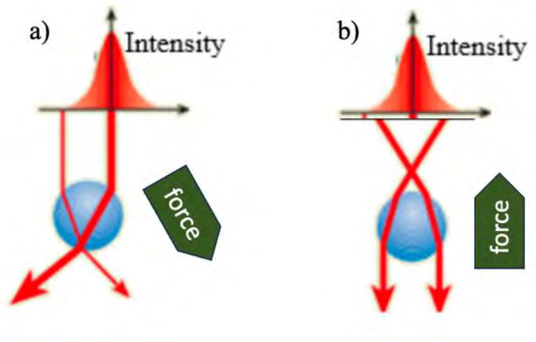


Figure 1.2. Rays pathway of the laser beam (a) when the bead is off-axis in parallel rays and (b) in the axis centre in focused rays.

Figure 1.2 illustrates the two situations of a spherical dielectric bead that established a gradient optical force using a laser with a Gaussian intensity profile. In Figure 1.2 (a), two parallel rays of different intensities pass through the bead. Both undergo twice refractions. Figure 1.3 shows the vectorial force analysis for the situation. Figure 1.3 (a) shows that the momentum of higher intensity ray changes by $\Delta \boldsymbol{p}_1 = \boldsymbol{p}_{1,out} - \boldsymbol{p}_{1,in}$. To conserve the momentum, the same amount of momentum is transferred to the bead, giving arise to the reaction, $\boldsymbol{F}_1$ on the bead. Figure 1.3 (b) shows the same effect in the lower-intensity ray. Therefore, $\boldsymbol{F}_1$ and $\boldsymbol{F}_2$ total up to $\boldsymbol{F}_R$, which directs toward the laser axis as in Figure 1.3 (c).

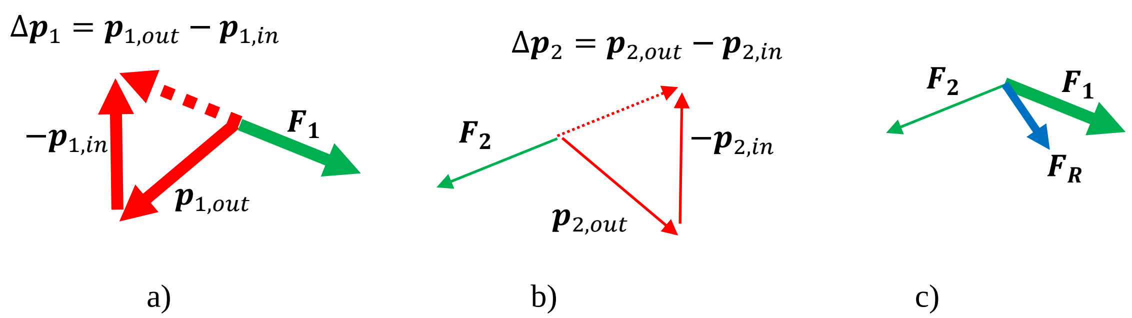


Figure 1.3. Vectorial force analysis for the situation in Figure 1.2 (a).

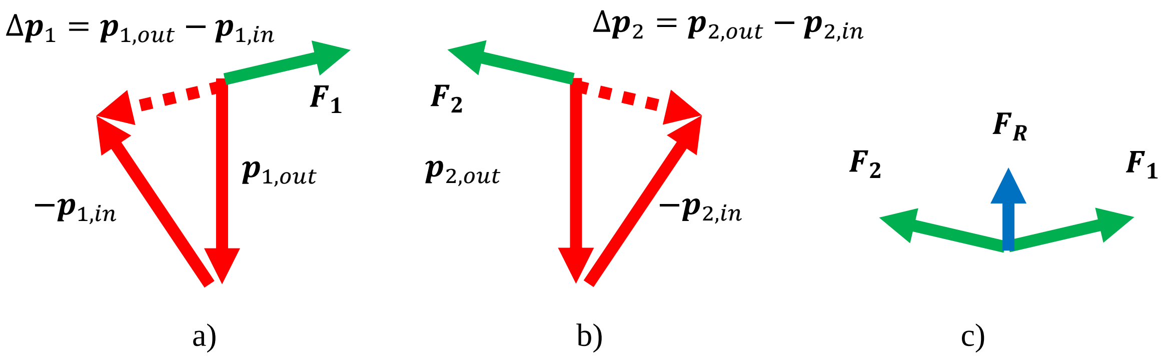


Figure 1.4. Vectorial force analysis for the situation in Figure 1.2 (b).

Figure 1.4 shows the vectorial force analysis for the situation in Figure 1.2 (b). The entering rays are focused and have the same intensity. Figure 1.4 (a) shows that the momentum of the right incoming ray changes by $\Delta \boldsymbol{p}_1 = \boldsymbol{p}_{1,out} - \boldsymbol{p}_{1,in}$. To conserve the momentum, the same amount of momentum is transferred to the bead, giving arise to the reaction, $\boldsymbol{F}_1$ on the bead. The same effect occurs to the left incoming ray in Figure 1.4 (b). Therefore, $\boldsymbol{F}_1$ and $\boldsymbol{F}_2$ total up to $\boldsymbol{F}_R$, which directs toward the laser axis as in Figure 1.4 (c). Therefore, a particle can experience a force pushed back directly to the laser beam if the beam is strictly focused (Dholakia et al., 2002). The introductory analysis gives an idea of the arising optical forces due to the nature of the light-carrying momentum. Further explanation will be discussed in Chapter 2.

Optical tweezers or optical traps are practicably the most flexible for single-particle molecule manipulation techniques. They simultaneously measure the three-dimensional displacement of the trapped particle with sub-nanometer accuracy and sub-millisecond time resolution. Moreover, it also can exert forces exceeding 100 pN on particles ranging in microns to nanometer size. These attributes make them suitable for the measurement of motion and force. The particles can now be trapped, observed, oriented and guided by the optical tweezers. Optical trapping could impact the bioengineering field, for example in aiming at micro-robotic surgeons (A. I. Bunea & Glückstad, 2019). Optical tweezers can be used in microfluidic devices as a probe enabling selective control of microparticles (Kumar et al., 2020). With these capabilities of optical tweezers, this research explores the usage of optical tweezers for controlling a fibrous irregular shape of MCC.

1.2.4 Microfluidic Devices

Microfluidics devices usually have channel dimensions of tens to hundreds of micrometres and can process fluids in small quantities from 1 attolitre up to 1 nanolitre. Microfluidic devices offer the potential to automate a broad range of physical, chemical and biological operations with high efficiency, repeatability and reproducibility. Among the methods of fabricating a microfluid device are micro-cutting, ultrasonic machining, electro-discharge machining, micro-electrochemical machining, laser ablation and electron beam machining (Scott & Ali, 2021). An example of a microfluidic device is a capacitive-based pressure sensor using a spiral microchannel inspired by a fish cupula structure (Shahripul Azeman et al., 2020). Figure 1.5 shows the cross-section of the sensor. An applied pressure will deflect the liquid-containing dome. The propylene carbonate, an electrolyte, is used as a flexible moveable liquid to fill the spiral microchannel around the dome. The capacitance of the microchannel changes as detected by electrodes beneath it according to liquid displacement. The dome-shaped sensor with a spiral microchannel was fabricated using Polydimethylsiloxane (PDMS).

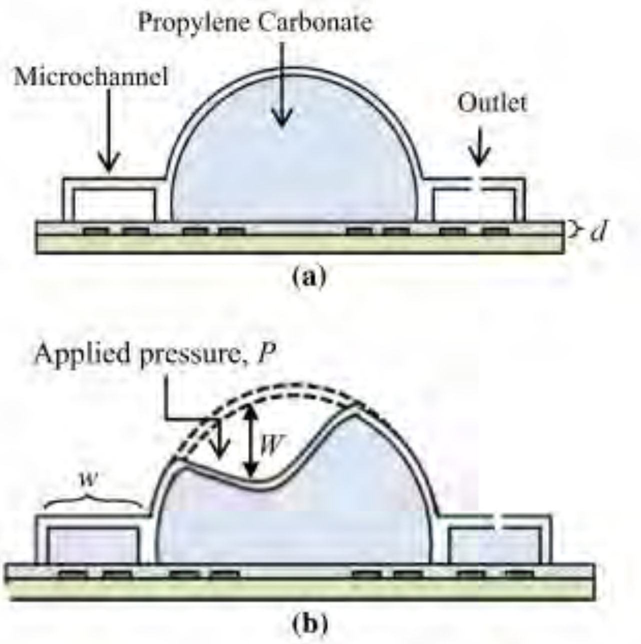


Figure 1.5. A capacitive-based pressor sensor using spiral microchannel, (a) cross-sectional view before applied pressure and (b) the deflection of the dome structure due to an applied pressure (Shahripul Azeman et al., 2020).

In addition to physical quantity detection, microfluidic devices can be tailored for biochemical sensing. Figure 1.6 shows such devices, a microfluidic-based immunoassay for prostate cancer detection (Meyer & Gorin, 2019). A substantial volume of blood is collected by a sample collector containing antibodies. The sample connects to a cassette to channel the blood-containing liquid through the microfluidic portion. The silver amplification reagents in the microfluidic portion react with active substances labelled to the antibodies to deposit a silver metallic film at the end of the channel. This film is inserted in a light path for quantitative measurement. The deposition of the film interferes with the light transmission. The detection method is based n the optical density of the deposited film.

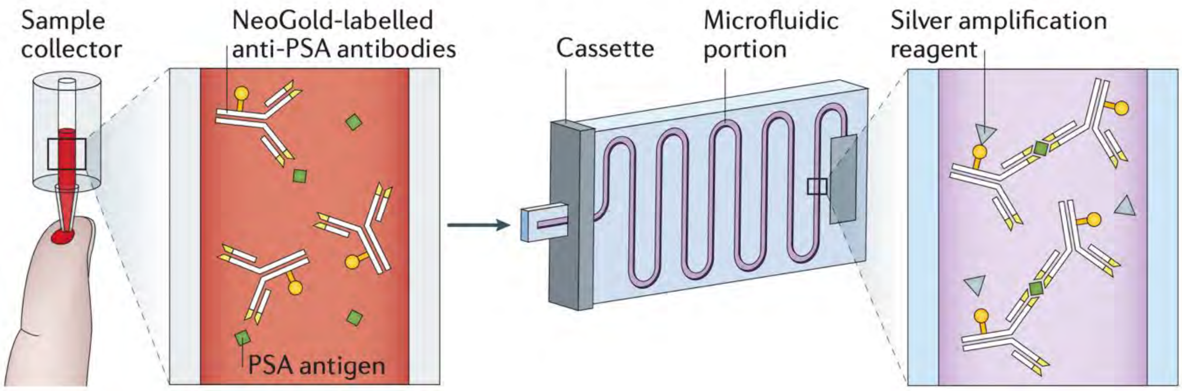


Figure 1.6. A microfluidic-based immunoassay for prostate cancer detection (Meyer & Gorin, 2019).

Other than acting as a sensor, microfluidic devices include microactuators. Such an example is shown in Figure 1.7. In this device, a photosensitive hydrogel functions as a microvalve in a microchannel. The functional metal-containing polymer hydrogel shrinks when illuminated with near-infrared light and returns to its original size once the illumination stops, thus limiting the liquid flow. Therefore, the microvalve can control a microflow using non-contact and non-mechanical methods.

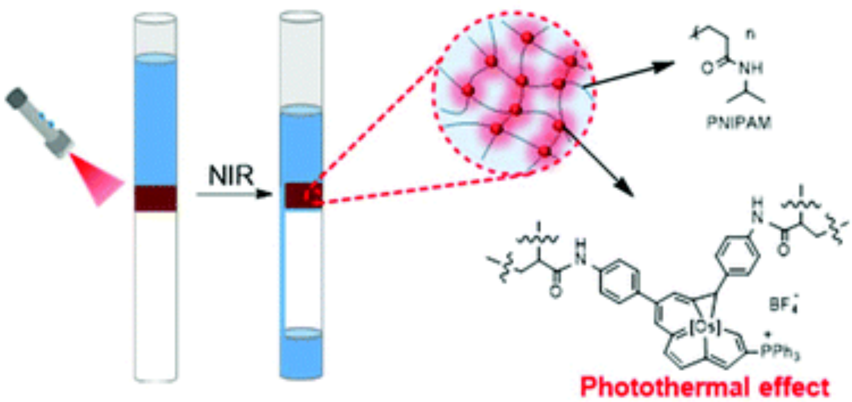


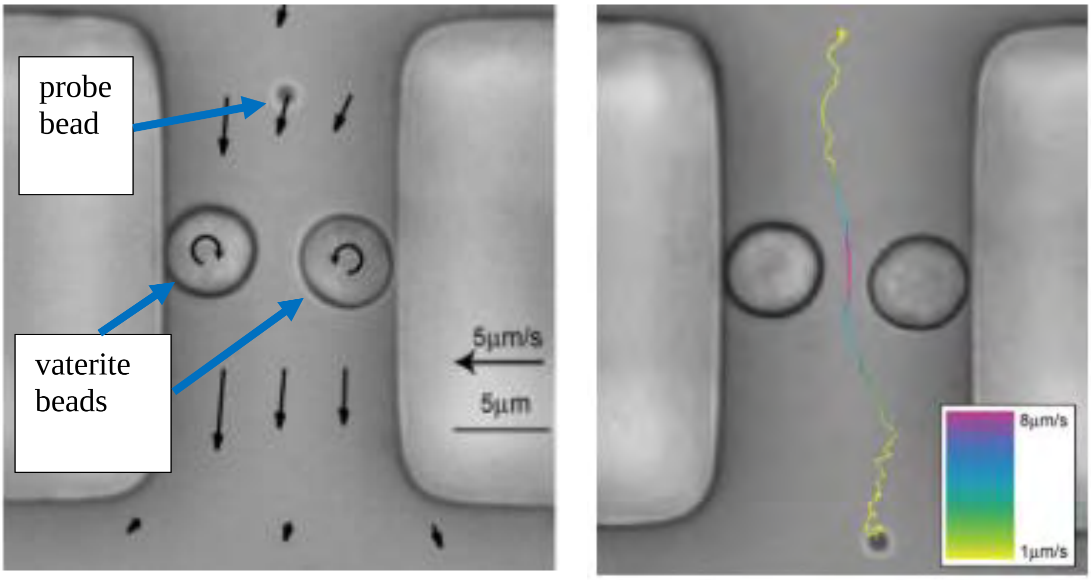
Figure 1.7. Hydrogel-based microvalve (Lin et al., 2021).

The examples described above indicated the wide possible microsensor and microactuators, called microtools based on microfluidics devices. The motivation for the miniaturization in microfluidic devices calls for challenges and solutions for advanced fabrication, manipulation and detection methods.

1.2.5 Optical Tweezers in Microfluidic Applications

The potential of using optical tweezers for microtool applications in microfluidics devices has been forecasted as earlier as its invention (Ashkin, 1970). For example, a pair of spherical vaterite particles trapped in two separate optical tweezers were used as an optically driven micropump, as shown in Figure 1.8 (Leach et al., 2006). The birefringence property of the vaterite enables optical torque using circularly polarised light to induce flow in the microfluidic channel of tens micrometer space. The circularly polarised light was produced by introducing wave plates in the light path.

In Chapter 4, it can be shown that the microcrystalline cellulose used in this research also shows the birefringence property, which can be orientated and rotated using a specific state of polarised light. Figure 1.8 (a) shows that the vaterite pair is rotated to induce a downward flow. A flow rate of up to 5 μm/s can be induced in the microchannel using 1064nm optical tweezers. It is also interesting that the flow can be made reversible by tuning up the direction of the vaterite rotation.



(a) (b)

Figure 1.8. An optically driven micropump, (a) A circularly polarised laser rotates a pair of 6-micrometre vaterite beads to induce flow and (b) The trace of the probe bead is used to quantify the flow in the micropump (Leach et al., 2006).

In the recent research, the kinetics of poly(ethylene oxide) (PEO) adsorption onto the surface of an immobilized silica microparticle of diameter 1 micron in a controlled flow and solution environment, was studied using optical tweezers and microfluidics as shown in Figure 1.9 (Geonzon et al., 2022). The polymer adsorption kinetics was evaluated by the layer thickness on the single microparticle by measuring the optical trap stiffness under predetermined liquid flow rates. As the PEO solution is introduced in the microchannel, it will adsorb onto the particle surface depending on the ionic concentration in the surrounding set by introducing sodium hydroxide solution. In this experiment, the optical tweezers function as an actuator which remotely holds the microparticle in an optical trap and as a sensing probe which measures the change in hydrodynamics drag due to the thickening of the adsorption layer. As the layer becomes thicker, the bead displacement due to the flow decreases as the hydrodynamic drag increases.

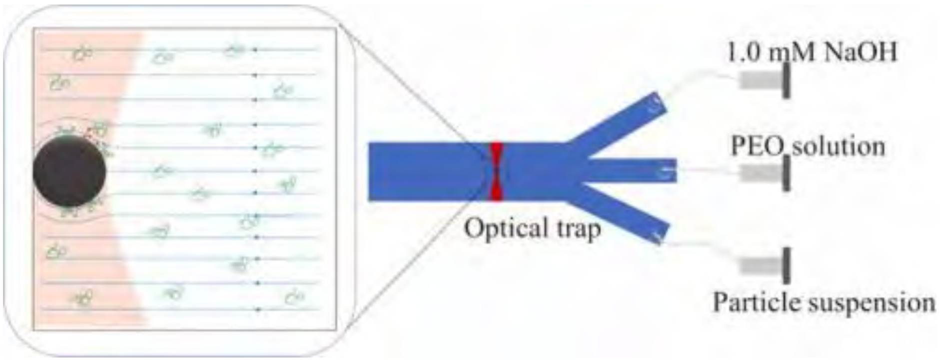


Figure 1.9. Optical tweezers used to study adsorption kinetics on a single microparticle surface in a microfluidic channel.

The above-mentioned example of the combination of optical tweezers and microfluidics shows various possible microtools applications which require non-contact and remote control and detection at micro- and nano-scale.

1.3 Problem Statement

The biodegradable and non-toxic nature of microcrystalline cellulose microclusters presents promising potential for various applications, including microtool applications in combination with optical tweezers, such as drug carriers and microvalves in fluidic devices (Trache et al., 2016). However, conventional micro-control methods like magnetic tweezers are not applicable to microcrystalline cellulose due to its non-magnetic properties, and even magnetic microprobes cannot be attached to it without altering its physical characteristics. Although cellulose ink can be manipulated with micropipettes at a resolution of 3 μm, using mechanical contact control may distort the cellulose microstructure (Herranen et al., 2019).

Furthermore, fibrous structures like microcrystalline cellulose pose challenges for optical tweezers due to the necessity of the controlled particles being optically transparent, homogeneous, and spherical in shape (Herranen et al., 2019). Nonetheless, recent studies have demonstrated the optical control of irregularly shaped and porous particles, suggesting a potential avenue for manipulating fibrous and irregularly shaped microcrystalline cellulose clusters using optical tweezers (Mahadi, Ayop, & Supian, 2022); Mahadi, Ayop, Mat Yeng, et al., 2022).

This research aims to investigate the feasibility of optically controlling microcrystalline cellulose microclusters, potentially paving the way for novel applications of cellulose-like materials in microtool technologies. By exploring this direction, this research are seek to address the limitations of conventional micro-control methods and unlock new possibilities for utilizing microcrystalline cellulose in microscale applications.

Recent literature supports the importance of understanding the rheological properties of cellulose-based materials for microtool applications. For instance, studies by Rajeev et al. (2018) and G. H. Zhao et al. (2011) highlight the significance of viscosity measurements in optimizing optical trapping procedures for colloidal suspensions.

Current advancements in optical trapping techniques have been reported in the literature. For example, the research by Lin et al. (2011) demonstrates approaches to enhance the trapping efficiency of microparticles in colloidal solutions, which could provide insights into optimizing optical trapping of MCCM.

The utilization of circularly polarized light for optical manipulation has been investigated in recent research. Studies by Shi et al. (2022) and Mahadi, Ayop, & Supian (2022) showcase the efficacy of circular polarization in precisely controlling the movement of microscale particles, providing a potential method for the optical manipulation of MCCM.

For instance, research by J. Li et al. (2022) demonstrates the integration of optical manipulation with piezostage systems for achieving precise translation and rotation control of microscale objects. This recent literature highlights advancements in achieving precise microcontrol of particles using optical techniques and offering insights into potential methodologies for controlling MCCM.

1.4 Research Questions

These research questions align with the research objectives and aim to address specific aspects of the optical trapping and manipulation of microcrystalline cellulose microclusters, contributing to the broader understanding of their potential as microtools in combination with optical tweezers. The research questions are as below:

i. What is the relationship between the concentration of microcrystalline cellulose microcluster (MCCM) solutions and their viscosity profiles, as measured using a rheometer? How does the viscosity of MCCM solutions vary with different concentrations? What is the viscosity range suitable for optical trapping procedures of MCCM?

ii. How can optical tweezers be optimized to efficiently trap a single MCCM within the size range of 0.5 μm to 4.0 μm in a 1% *w/w* MCCM solution? What are the parameters influencing the efficiency of optical trapping for MCCM? How can the optical trapping efficiency be improved for MCCM falling within the specified size range?

iii. What is the efficacy of circularly polarized light in the optical manipulation of a single MCCM? How does the use of circularly polarized light influence the manipulation capabilities of MCCM? Can circularly polarized light effectively control the movement and position of MCCM in solution?

iv. How can precise translation and rotation microcontrol of a single MCCM within a 2 μm shift range be achieved using optical techniques, potentially in conjunction with piezostage systems? What optical techniques are suitable for achieving precise translation and rotation control of MCCM? How can piezostage systems be integrated with optical techniques to enhance microcontrol capabilities for MCCM?

1.5 Research Objectives

This research aimed to optically trap and manipulate a single microcrystalline microcellulose microcluster (MCCM). This research was done to broaden the potential of cellulose-based as microtools in combination with optical tweezers. Specifically, these research objectives are:

i. to measure the viscosity of various concentrations of MCCM solutions using rheometer and identify the viscosity range suitable for optical trapping procedures,

ii. to enhance optically trap a single MCCM within the size range of 0.5 to 4.0 μm in a 1% *w/w* MCCM solution by utilizing optical tweezers,

iii. to approach the optical manipulation of the single MCCM using circularly polarised light, and

iv. to achieve precise translation and rotation microcontrol of the single MCCM within a 2 μm shift range by employing optical techniques, possibly in conjunction with piezostage systems.

1.6 Research Significances

This research was conducted to optical micro-control of the fibrous and irregularly shaped microcrystalline cellulose microcluster. The significance of this research is as follows.

i. The trapping MCC microcluster is challenging because of its physical geometry. Every single MCC has a unique fibrous and irregular shape. A systematic research on the optical manipulation of the MCC, such as reported in this research, contributes to the knowledge of trapping cellulose-liked particles for various intended applications.

ii. These optical tweezers require only a minimal sample, which is in the order of microliter (μL). This reduces sample preparation costs, especially for the expensive or limited sample.

iii. MCC is a biodegradable and non-toxic material which can be embedded in a microfluidic device with optical manipulation technique. Optical tweezers offer non-contact mechanical control over a single microcluster. Multiple control over several microclusters is also possible with optical gratings.

iv. Explores the possibility of optically controlling the microcrystalline cellulose microcluster, which could open a new direction in cellulose-like material usage for microtool applications.

1.7 Scope of the Research

This research focuses on the optical trap and manipulating a single microcrystalline cellulose microcluster (MCCM) in a solution. The microcrystalline cellulose is tested using an optical tweezer with changing physical properties such as size and laser power density. The optical tweezers used in this research were Thorlabs Modular Optical Tweezers System OTKB/M. A single MCCM trapped using a linearly polarised laser with wavelength 976nm at numerical aperture 1.4 and limited laser power densities from 0.6 MW/cm² to 2.2 MW/cm². The type of cellulose used in this research was microcrystalline cellulose in deionized water without additional surfactant or derivatives. The rheometer was used to determine the optimal sonication time for microcrystalline cellulose solutions based on the viscosity trend for further use in optical trapping and manipulation. The sonication time in this research was set to 60 minutes for microcrystalline cellulose solution preparation. The suitable size range for microcrystalline cellulose microcluster (MCCM) formation and the ideal concentration used in optical trapping were determined based on optical microscopy observation. The trapping and manipulating process of the MCCM was performed within an effective radius of 0.5 μm to 4.0 μm. Smaller MCCM was challenging to observe using the current setup as the resolution limit of the objective lens use is 0.5 μm. A larger MCCM is not interested in the research since high laser power is required to perform such an experiment and is not cost-effective.

1.8 Summary of the Research

This thesis consists of five chapters. The first chapter of this research explained the background, problem statement, objectives, significance, and scope of the research. The second chapter has briefly explained the principle of the optical tweezer, calibration of the optical trapping and its applications, microtools applications, and microcrystalline cellulose and its potential in microtool applications. The third chapter describes the methodology used in this research. It is divided into microcrystalline cellulose sample preparation and optical tweezers assembly. The sample is also examined with a rheometer for viscosity measurement. The microcrystalline cellulose microcluster

(MCCM) is also examined under optical microscopy for size observation. For the optical tweezer, the polarization control of the laser is described. The manipulation of the MCCM angular velocity analysis of the rotated trapped microcrystalline cellulose microcluster will be described in detail. The following section, Chapter 4, discusses the findings obtained from the research. The microcrystalline cellulose microcluster (MCCM) was produced and was optically trapped and manipulated using optical tweezers. The effective radius "r", angular velocity, ω of the trapped MCCM were determined using the procedure described in Chapter 3, Research Methodology. The final section concludes the finding and objectives of the research and provides recommendations for further studies that could be improved in future.