

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

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OPTICAL TRAPPING AND MANIPULATION OF MICROCRYSTALLINE CELLULOSE
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WAN NOR SUHAILA BINTI WAN AZIZ

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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, whilst 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/cm² to 2.2 MW/cm², 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 fodioid 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/cm^2 hingga 2.2 MW/cm^2 , 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 mikrozarrah fibrosa, seperti MCCM, boleh dimikrokawal secara optik bagi aplikasi mikroalat.



TABLE OF CONTENTS

DECLARATION OF ORIGINAL WORK	Page ii
DECLARATION OF THESIS	iii
ACKNOWLEDGMENT	iv
ABSTRACT	v
ABSTRAK	vi
TABLE OF CONTENTS	vii
LIST OF TABLES	xii
LIST OF FIGURES	xiii
LIST OF SYMBOLS	xxiv
LIST OF CONSTANTS	xxv
LIST OF ABBREVIATIONS	xxvi
APPENDIX LIST	xxvii
CHAPTER 1 INTRODUCTION	
1.1 Introduction	1
1.2 Background of the Research	2
1.2.1 Microcrystalline Cellulose	2
1.2.2 Viscosity Measurement of Microcrystalline Cellulose	4
1.2.3 Optical Tweezers	6
1.2.4 Microfluidic Devices	9
1.2.5 Optical Tweezers in Microfluidic Applications	12



1.3	Problem Statement	14
1.4	Research Questions	16
1.5	Research Objectives	17
1.6	Research Significances	18
1.7	Scope of the Research	19
1.8	Summary of the Research	20

CHAPTER 2 LITERATURE REVIEW

2.1	Introduction	22
2.2	Optical Trapping	24
2.2.1	Principle of the Optical Tweezers	28
2.2.2	Type of the Optical Tweezers	31
2.2.3	Optical Tweezers and their Application	38
2.2.4	Calibration of the Optical Tweezers	39
2.2.5	Refractive Index in Optical Trapping Perspective	49
2.2.6	Optical Trapping in Mie Regime	53
2.2.7	Optical Trapping of Irregular Shape and Fibrous Particle	54
2.2.8	Light Polarization in Optical Trapping	57
2.2.9	Optical Birefringence in Optical Trapping	65
2.2.10	Optical Manipulation in Optical Trapping	67
2.2.11	Optical Torque in Optical Trapping	71
2.2.12	Optical Stiffness in Optical Trapping	76
2.3	Microtool Applications	78
2.3.1	Available Techniques in Microtools	79
2.3.2	Optical tweezers as a Microtool	82





2.4	Cellulose and Its Application	86
2.4.1	Microcrystalline Cellulose	86
2.4.2	Applications of the Microcrystalline Cellulose	88
2.4.3	The Rheological Properties of Microcrystalline Cellulose	90
2.4.4	The Potential of Microcrystalline Cellulose and Optical Tweezers in Microtool Applications	92
2.4.5	Optical Tweezers and Microfluidics Application	96
2.5	Summary	102

CHAPTER 3 RESEARCH METHODOLOGY

3.1	Introduction	103
3.2	Flowchart of the Research	104
3.3	Sample Preparation	108
3.3.1	Viscosity Measurement Using Rheometer	110
3.3.2	Size Determination using Optical Microscopy	113
3.3.3	Optical Trapping	116
3.3.4	Test Cell Construction	117
3.4	Rheometer	119
3.4.1	Rheometer Measurement Procedure	119
3.4.2	Viscosity Measurement using Rheometer	122
3.5	The Optical Tweezers System Setup	128
3.5.1	Performance of the Optical Tweezers System	131
3.5.2	Power Density Versus Current	132
3.5.3	Performance Test	134
3.5.4	Circularly Polarized Laser	142



3.6	Scattering Light Analysis on QPD	143
3.6.1	QPD in Motion Detection	144
3.6.2	Oscilloscope	146
3.7	Optical Trapping of a single MCCM	147
3.7.1	Effective Radius Analysis of the Optical Trapping	149
3.8	Optical Manipulation of Single MCCM	153
3.9	Optical Control of a Single MCCM	156
3.9.1	Piezostage Control	157
3.10	Trajectory Analysis	160
3.10.1	Particle Tracking	161
3.10.2	Scattering Light Analysis	165
3.11	Cross-polarization view	166
3.12	Summary	167

CHAPTER 4 RESULTS AND DISCUSSION

4.1	Introduction	169
4.2	Viscosity Measurement using Rheometer	171
4.2.1	The Optimization of Sample Preparation by Sonication Process	171
4.2.2	Viscosity Measurement using Rheometer for Different Concentration	177
4.3	Size Determination using Optical Microscopy	181
4.3.1	Microcrystalline Cellulose Microcluster (MCCM)	181
4.4	Performance of the Optical Tweezers System	183
4.4.1	Optical Density of the Optical Trapping	183
4.4.2	Performance Test of the Optical Trapping	186

4.5	Optical Trapping of Microcrystalline Cellulose Microcluster (MCCM)	189
4.6	Optical Manipulation of Microcrystalline Cellulose Microcluster (MCCM)	194
4.7	Optical Control of Microcrystalline Cellulose Microcluster (MCCM)	202
4.8	Summary	205

CHAPTER 5 CONCLUSION AND RECOMMENDATIONS

5.1	Introduction	207
5.2	Conclusion	208
5.3	Implication	210
5.4	Recommendation	211
5.5	Microtool Application Ideas	212
5.5.1	Microtransporter	212
5.5.2	Micropump	213
5.5.3	Microvalve	214
5.5.4	Microsensor	215
5.6	Summary	216

REFERENCES	217
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APPENDIX	232
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LIST OF TABLES

No. Tables		Page
2.1	Optical birefringence of selected material at 590nm.	66
3.1	The sample preparation parameters in this research for objective 1, objective 2, objective 3, and objective 4.	105
3.2	The summarised details for the viscosity testing procedure condition.	126
4.1	The viscosity values of microcrystalline cellulose solution at different temperatures and concentrations of 60 minutes sonication time.	180
4.2	The laser current-power calibration and power density used in this research.	186
4.3	The corner frequency, f_c , according to the laser power density obtained from the performance test.	188
4.4	The upper, P_{dU} and lower, P_{dL} limit of laser power density, P_d for five range sizes of microcrystalline cellulose microcluster (MCCM) had stable optical trapping.	193
4.5	Rotational analysis on 0.82 μm of microcrystalline cellulose microcluster (MCCM).	199
4.6	Rotational analysis on 4 different effective radius " r " of microcrystalline cellulose microcluster (MCCM) with manipulated laser power density for right handed (clockwise direction) circularly polarized light.	200





LIST OF FIGURES

No. Figures		Page
1.1	Molecular structure of microcrystalline cellulose.	3
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.	7
1.3	Vectorial force analysis for the situation in Figure 1.2 (a).	7
1.4	Vectorial force analysis for the situation in Figure 1.2 (b).	8
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).	10
1.6	A microfluidic-based immunoassay for prostate cancer detection (Meyer & Gorin, 2019).	11
1.7	Hydrogel-based microvalve (Lin et al., 2021).	11
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).	13
1.9	Optical tweezers used to study adsorption kinetics on a single microparticle surface in a microfluidic channel.	14
2.1	The illustration showed the basic principles of optical trapping for a simple gradient force optical tweezer (Bunea & Glückstad, 2019).	25
2.2	A schematic diagram of a common optical tweezers' setup. Optical trapping is achievable by a laser beam which is tightly focused using a high numerical aperture objective lens. The image of the sample on a camera is also used by the lens simultaneously (Polimeno et al., 2018).	30





2.3	The tools most commonly used to manipulate single molecules or organelles in cells. (a) A tip attached to the cantilever of an atomic force microscope probes the adhesion of a surface receptor. The laser reflected from the cantilever provides information about the bending of the cantilever. (b) An optical trap consists of a single, tightly focused laser beam that traps a lipid granule transported by the molecular motor dynein in a living cell. (c) External magnets forming magnetic tweezers allow the rotation of a magnetic probe attached to DNA in the nucleus of the living cell (Norregaard et al., 2017).	33
2.4	The illustration of the examples of optical trapping methods.	36
2.5	The example of the optical trap calibration. (a) Response of the position-sensitive detector (PSD), (b) the position of a trapped bead along the x axis and the respective histogram is well-fit by a Gaussian, (c) the power spectrum of the position signal together with fittings to a Lorentzian function for x, y, and z respectively and (d) in the Stokes drag calibration method (Hernández Candia et al., 2013).	48
2.6	Representation of a single-beam optical tweezers trapping a particle in the focus of a narrowly focused beam.	50
2.7	The calcite is the example of naturally birefringent material (Böhm et al., 2019).	52
2.8	Typical objects that are trapped in optical manipulation experiments. The trapping wavelength is in the visible or near-infrared spectral region (Pesce et al., 2020).	53
2.9	Most commonly handles used for in vivo manipulation techniques of single molecules in living cells. Optical tweezers have a variety of handles, from large micron-sized dielectric beads to small metal and semiconductor nanoparticles to naturally occurring lipid granules and organelles. In contrast, magnetic tweezers can only trap and manipulate magnetizable objects (Norregaard et al., 2017).	55
2.10	The captured image of a diamond-particle-tagged mesophyll protoplast. The rotation of 360° achieved in a common optical tweezer setup. The black object labeled D in (a) is the diamond particle, the scattered laser light is labeled L, and the mesophyll protoplast cell is labeled C (Sun et al., 2001).	57





2.11	Light polarisation illustration.	58
2.12	Phase shift between two perpendicular linearly polarised light resulting in the non-linearly polarised light.	59
2.13	Chiral superstructure assembly using circularly polarized light (Kim et al., 2019).	61
2.14	Manipulation of high refractive index transparent particles with light (Favre-Bulle et al., 2019).	62
2.15	The optical birefringence illustration.	65
2.16	Demonstration of the typical rotation of a beam when the pivot is trapped by optical tweezers (Lin et al., 2011).	70
2.17	Video snapshots of disc-shaped vaterite particles recorded by optical tweezer apparatus (W. Liu et al., 2020).	71
2.18	Torque illustration.	72
2.19	Optical torque generation in isotropic and anisotropic materials (Riccardi & Martin, 2023).	73
2.20	Observation on a rotating calcite crystal using optical tweezers.	74
2.21	Basic diagram of angular optical tweezers (Bustamante et al., 2021).	74
2.22	(a) Illustration of a rotating silver nanowire. (b) Dark-filed optical images of silver nanowires rotated as several frames (Yan & Scherer, 2013).	75
2.23	Calixarene of various microcluster sizes held using an optical tweezer.	76
2.24	Optical tweezers behave as a Hookean spring (Hou & Cheng, 2013).	78
2.25	Design concept for a fiber optic actuator. A stimulus-responsive gel coupled to a passive mechanical assembly actuates mechanical tools via swelling and decongesting of the gel. (Kaufman et al., 2023).	80
2.26	The illustration of the rotor configuration for single target control (Būtaitė et al., 2019).	81
2.27	Examples of 3D printed micro tools with spherical grips	82





that can be optically manipulated and serve different purposes (Bunea & Glückstad, 2019).

- 2.28 Direct versus indirect manipulation using Optical Tweezers, (a) solution of cells and silica beads, (b) the cell is trapped directly, while the cell is trapped indirectly using the gripper, (c) the cells are being transported to their desired goal locations, and (d) the cells are released at the goal locations; the cell that was directly trapped is damaged, while the indirectly transported cell is still alive (Chowdhury et al., 2014). 83
- 2.29 Process involved DNA molecules in microfluidics. (a) Microtool solution is filled into a tool-stock microchamber. (b) Chromosomal DNA molecules are introduced. DNA molecules are trapped and the flow extends them. (c) Optical tweezers loads a microtool showing contact between target site of an extended DNA molecule and the tool to initiate enzymatic reaction (Masuda et al., 2021). 85
- 2.30 Snapshots of moving two groups of microparticles into arrays with an artificial potential field-based controller using a robot-aided optical tweezers system. (a) 0 s; (b) 1 s; (c) 3.5 s; (d) 4.5 s (H. Chen & Sun, 2012). 85
- 2.31 Automated transportation of two yeast cells and one MC3T3-E1 cell using a robot-aided cell manipulation system equipped with holographic optical tweezers (Hu et al., 2017). 85
- 2.32 Life cycle of microcrystalline cellulose-based polymer bio-composites. 86
- 2.33 Scheme of the common steps needed to produce microcrystalline cellulose from cellulose source materials. 87
- 2.34 The examples microcrystalline cellulose biocomposites applications (Trache et al., 2016b). 90
- 2.35 Graphical representation of several factors that affect the viscosity of cellulose solution and the compressive strength of HS-MCC hydrogel according to different concentration of TBAF in DMSO (Choe et al., 2018b). 92
- 2.36 Products manufactured with microfluidics derived from cellulose. 93
- 2.37 Example of application for cellulose are as a component 95





in the manufacture of microfluidic chips and as a microfluidic building block.

- 2.38 Above is the 3D design of the system, and below is the cross-section of the system (Kampmann et al., 2018). 96
- 2.39 The left figure is the concept of the system. The right figure shows a bead held by an optical trap distorting a lipid membrane. 97
- 2.40 The left figure illustrates the microfluidic chip, and the right figure illustrates the action of optical tweezers (Zheng et al., 2022). 98
- 2.41 Sorting cell using optical tweezers. (Kelothe et al., 2018). 98
- 2.42 Optical manipulation of a rod-shaped bacteria in a microfluidic chip. (Zhang et al., 2019). 100
- 2.43 Application idea of using optical tweezers for microrheology (Robertson-Anderson, 2018). 101
- 3.1 Five stages in this research. 104
- 3.2 Microcrystalline cellulose powder. The 20 cent coin served as a reference. 108
- 3.3 Microcrystalline cellulose solution preparation. 109
- 3.4 Microcrystalline cellulose diluted in deionized water with concentrations of 1% w/w, 3% w/w, 5% w/w and 10% w/w used in the research as respectively; (a) without sonication process, (b) with sonication process of 5 minutes, (c) with sonication process of 15 minutes, (d) with sonication process of 30 minutes, (e) with sonication process of 60 minutes and (f) with sonication process of 90 minutes. 110
- 3.5 The experiment setup for the sonication process using a sonicator, QSonica. 112
- 3.6 The microcrystalline cellulose solution in vials are immersed in a beaker for sonication process using a sonicator, Branson 2800. 113
- 3.7 Microcrystalline cellulose diluted in deionized water with concentrations of 0.1% w/w, 1% w/w, 3% w/w, 5% w/w and 10% w/w with a sonication time of 60 minutes was prepared for size determination using optical microscopy. 114





3.8	The optical microscope to visually observe the size distribution of MCCM formation.	115
3.9	Microcrystalline cellulose solution under optical microscopy. The concentration used was 0.1% w/w, 20 \times .	116
3.10	The sample preparation before undergoing the measurement process using the optical tweezer system. The microcrystalline cellulose solution was dropped onto a microscope slide and then placed onto a piezostage, as indicated by the yellow arrow.	117
3.11	The upper view of test cell configuration. Vertical rectangles are double-sided tape. Seal the edges of the coverslip with nail polish and label the test cell. The coin functions as a reference.	118
3.12	The lateral view of test cell configuration.	118
3.13	The two drops of microcrystalline cellulose solution on the microscope slide before putting the cover slip on it.	118
3.14	Rheometer components and setup.	119
3.15	The correct steps for the initial procedures to avoid errors in performing the viscosity measurement test for the microcrystalline cellulose solution.	120
3.16	The installation of cone plate geometry; (a) removing geometry cover, (b) installing the cone plate geometry, respectively.	121
3.17	Illustration for the calibration step.	121
3.18	The rheometer component and the step-by-step setup of the rheometer system from calibration to sample placement for viscosity measurement.	122
3.19	The truncation height between cone-type geometry and Peltier plate. Appropriate sample filling is advisable, avoid under or overfilling to have the correct measurement.	124
3.20	Configuration of initial temperature parameter for the procedure condition.	126
3.21	The 10% w/w microcrystalline cellulose solution (about 200 μ m thick) will be mounted between cone plate geometry (60 mm in diameter, 1 $^\circ$ in angle). The bottom Peltier plate is fixed to the rheometer, and the upper cone	127





plate rotates.

3.22	The 10% w/w microcrystalline cellulose solution condition after testing is finished.	127
3.23	The view of the hardware part of the optical tweezers setup.	129
3.24	The actual working environment of the optical tweezers system.	130
3.25	Optical tweezers system on the isolated anti-vibration table.	130
3.26	The compact laser diode driver for controlling the laser power. The laser power can be manipulated in terms of current (mA).	131
3.27	The measurement of laser power used the optical power meter as respectively; (a) at the objective lens pupil, (b) before the objective lens, (c) overview of the laser power measurement setup.	133
3.28	QPD adjustment.	135
3.29	The APT program for the visualization of the QPD signal. The position of 2 μm trapped polystyrene bead is adjusted to the centre of the QPD.	135
3.30	The modification of the data before uploading it into the custom-made program, OSCal.	136
3.31	The initial interface of the OSCal before uploading a QPD signal data acquired from the oscilloscope.	137
3.32	Selecting the directory of the data file stored in the computer and changing the data type to upload into OSCal program.	138
3.33	Choosing the data to be uploaded into OSCal.	139
3.34	The voltage signal obtained from QPD is displayed in OSCal.	139
3.35	The step for Lorentzian fitting.	140
3.36	The corner frequency, f_c , for a 0.6 MW/cm ² laser power density of 2.0 μm polystyrene bead.	141
3.37	Wave plates location in the laser path.	143





3.38	The quadrant photodiode, QPD (Thorlabs PDQ80A) for motion detection. a) The turning knob for the y plane and b) the turning knob for the x plane.	144
3.39	The schematic diagram shows the connection between QPD and APT programs installed on the computer.	145
3.40	A brief representation of the position detection by QPD. Each quadrant produces a voltage signal that is a function of the incident light intensity.	146
3.41	The oscilloscope (Yokogawa DL6054) connected with QPD for signal observation and data collection.	147
3.42	The illustration shows that optical trapping can be achieved in three dimensions.	149
3.43	A single trapped MCCM on the xy plane was perpendicular to the laser beam direction.	150
3.44	The image scale setting for the effective radius measurement in this research.	151
3.45	The measurement of the MCCM length in x plane, l_x .	152
3.46	The measurement of the MCCM length in y plane, l_y .	152
3.47	The optical tweezer system with a quarter waveplate. A pair of polarizers (P1 and P2) are inserted to form a cross-polarisation view.	155
3.48	Piezostage module in the optical tweezers.	158
3.49	APT controlling system.	158
3.50	Trajectory analysis flowchart.	160
3.51	Particle tracking using Tracker.	162
3.52	Setting of the length of the calibration stick (blue color) and calibration axes (violet color).	163
3.53	The setting of creating point of mass to track the motion using Tracker program.	163
3.54	The popup of the autotracker appeared once located the starting point of mass. The track data and graph were automatically recorded on the right side of the Tracker program once the search button is clicked.	164





3.55	The step by step of the particle tracking using Tracker program to analyse the time taken from peak to peak of the plotted data.	165
3.56	QPD signal of a rotated MCCM in an optical trap.	165
3.57	Cross polarization view schematic.	166
3.58	Polarizers location for cross-polarisation view.	167
4.1	The viscosity of microcrystalline cellulose solution of concentration 1% w/w, 3% w/w, 5% w/w, 10% w/w and deionised water (0% w/w) at 24 °C in temperature with a variation of sonication time 0 minute, 5 minutes, 30 minutes, 60 minutes and 90 minutes measured using a rheometer.	171
4.2	The viscosity of microcrystalline cellulose solution of concentration 1% w/w, 3% w/w, 5% w/w, 10% w/w and deionised water (0% w/w) at 24 °C in temperature with a variation of sonication time 0 minute measured using a rheometer.	172
4.3	The viscosity of microcrystalline cellulose solution of concentration 1% w/w, 3% w/w, 5% w/w, 10% w/w and deionised water (0% w/w) at 24 °C in temperature with a variation of sonication time 5 minutes measured using a rheometer.	173
4.4	The viscosity of microcrystalline cellulose solution of concentration 1% w/w, 3% w/w, 5% w/w, 10% w/w and deionised water (0% w/w) at 24 °C in temperature with a variation of sonication time 30 minutes measured using a rheometer.	174
4.5	The viscosity of microcrystalline cellulose solution of concentration 1% w/w, 3% w/w, 5% w/w, 10% w/w and deionised water (0% w/w) at 24 °C in temperature with a variation of sonication time 60 minutes measured using a rheometer.	175
4.6	The viscosity of microcrystalline cellulose solution of concentration 1% w/w, 3% w/w, 5% w/w, 10% w/w and deionised water (0% w/w) at 24 °C in temperature with a variation of sonication time 90 minutes measured using a rheometer.	176
4.7	Variations of viscosity with microcrystalline cellulose concentration at different temperature.	178





4.8	The viscosity of microcrystalline cellulose solution 1% w/w, 3% w/w, 5% w/w, 10% w/w and deionised water (0% w/w) of sonication time 60 minutes as measured using a rheometer.	179
4.9	Microscopic view of MCC solutions under optical microscopy with magnification 20 times for concentration; (a) 0.1% w/w, (b) 1% w/w, (c) 3% w/w, (d) 5% w/w, and (e) 10% w/w respectively.	182
4.10	The relationship between the laser power and the current of the laser before entering the objective lens.	184
4.11	The relationship between the laser power and the current of the laser at the objective lens pupil.	185
4.12	The relationship between the laser power density, P_d and the laser's corner frequency, f_c of the 2.0 μm polystyrene beads.	187
4.13	Images of five different range sizes of a single optically trapped microcluster of microcrystalline cellulose in water were captured with a CCD camera. The red dotted arrow was the direction of the polarization state of the laser.	192
4.14	Image sequence of the 0.62 μm MCCM capturing into optical tweezers' trap at 30 Hz recording video.	194
4.15	The birefringence characteristic of single MCCM. (a) A single MCCM without cross-polarization (b) A single MCCM with cross-polarization.	195
4.16	The example of the non-birefringence characteristic material. (a) A single polystyrene bead without cross-polarization (b) Invisibility of polystyrene bead with cross-polarization.	195
4.17	The tracker program used to analyse the time for 3.34 μm trapped microcrystalline cellulose microcluster (MCCM) to complete a 2π rotation at a laser power density of 0.6 MW/cm^2 .	197
4.18	The 3.34 μm trapped microcrystalline cellulose microcluster (MCCM) in clockwise rotations at a 0.6 MW/cm^2 laser power density.	197
4.19	Illustrated QPD signal from the oscilloscope for the circular polarised of trapped microcrystalline cellulose microcluster (MCCM) to determine the average time for	198



complete 2π rotation.

4.20	Rotational analysis on 4 different effective radius " r " of microcrystalline cellulose microcluster (MCCM) with manipulated laser power density for clockwise circularly polarized light.	199
4.21	The angular velocity, ω , versus laser power density graph was plotted for optical manipulation of 4 different trapped MCCM sizes. The ω versus P graph for right circular polarization (clockwise).	201
4.22	The micro-control of MCCM at 0.6 MW/cm^2 .	203
4.23	The x-axis trajectory of the MCCM from the Figure 4.22.	203
4.24	The micro-control of MCCM at 2.2 MW/cm^2 .	204
4.25	The x-axis trajectory of the MCCM from the Figure 4.24.	205
5.1	Microtransporter application idea of an optically trapped single MCCM.	213
5.2	Micropump application idea of an optically trapped single MCCM.	214
5.3	Microvalve application idea of an optically trapped single MCCM.	215
5.4	Microsensor application idea of an optically trapped single MCCM.	216

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
η	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

- A Knowledge Dissemination
- B System Specification



CHAPTER 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).

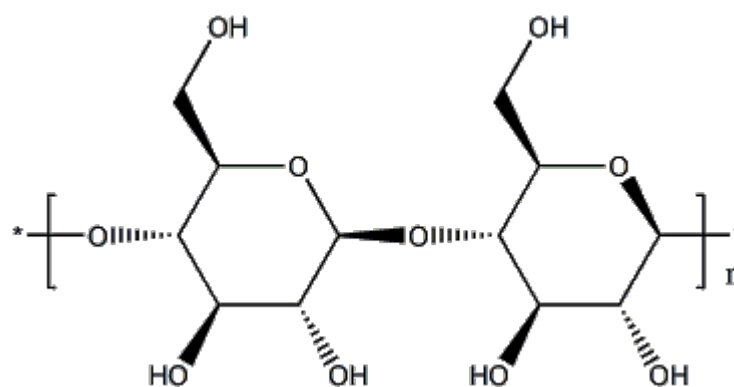


Figure 1.1. Molecular structure of microcrystalline cellulose.

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 concentration-





dependent 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 involving 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.



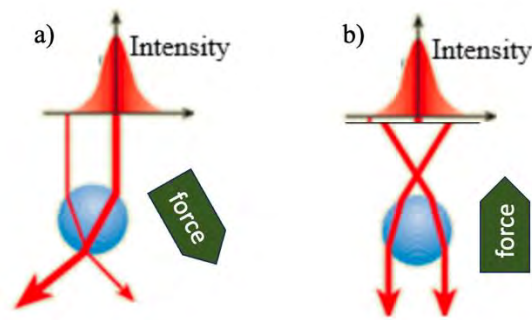


Figure 1.2. Rays pathway of the laser beam (a) when the bead is off-axis in parallel rays and (b) in the axis centre in focused rays.

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 $\Delta \mathbf{p}_1 = \mathbf{p}_{1,out} - \mathbf{p}_{1,in}$. To conserve the momentum, the same amount of momentum is transferred to the bead, giving arise to the reaction, \mathbf{F}_1 on the bead. Figure 1.3 (b) shows the same effect in the lower-intensity ray. Therefore, \mathbf{F}_1 and \mathbf{F}_2 total up to \mathbf{F}_R , which directs toward the laser axis as in Figure 1.3 (c).

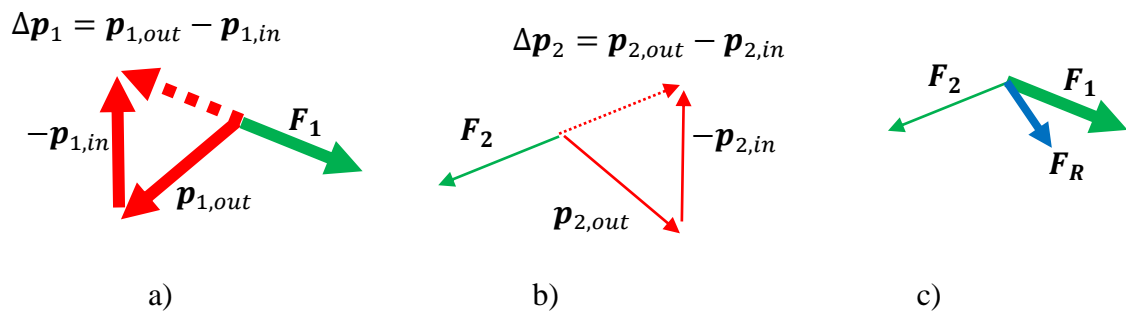


Figure 1.3. Vectorial force analysis for the situation in Figure 1.2 (a).

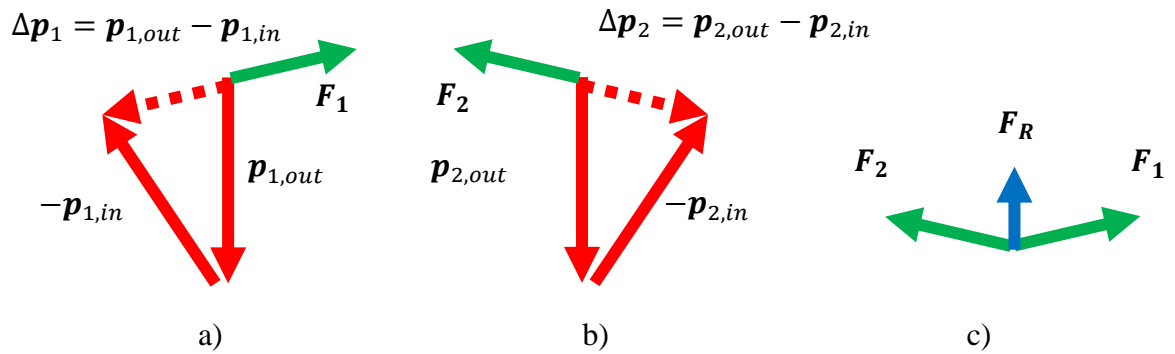


Figure 1.4. Vectorial force analysis for the situation in Figure 1.2 (b).

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 $\Delta \mathbf{p}_1 = \mathbf{p}_{1,out} - \mathbf{p}_{1,in}$. To conserve the momentum, the same amount of momentum is transferred to the bead, giving rise to the reaction, \mathbf{F}_1 on the bead. The same effect occurs to the left incoming ray in Figure 1.4 (b). Therefore, \mathbf{F}_1 and \mathbf{F}_2 total up to \mathbf{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).

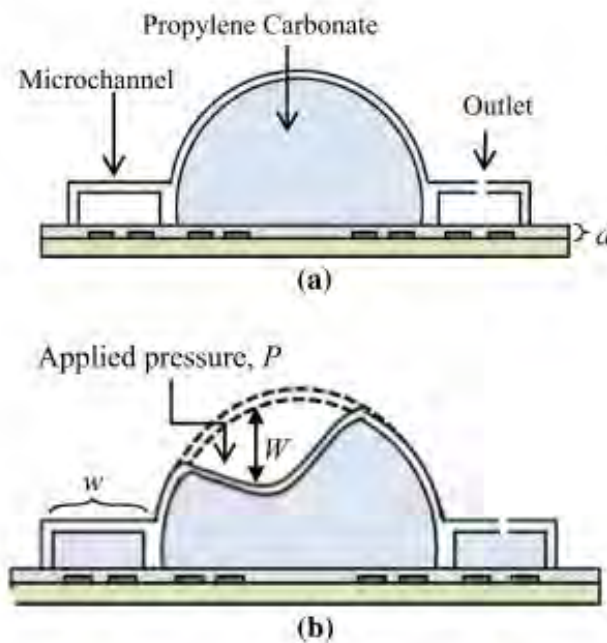


Figure 1.5. A capacitive-based pressor sensor using spiral microchannel, (a) cross-sectional view before applied pressure and (b) the deflection of the dome structure due to an applied pressure (Shahripul Azeman et al., 2020).

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 on the optical density of the deposited film.

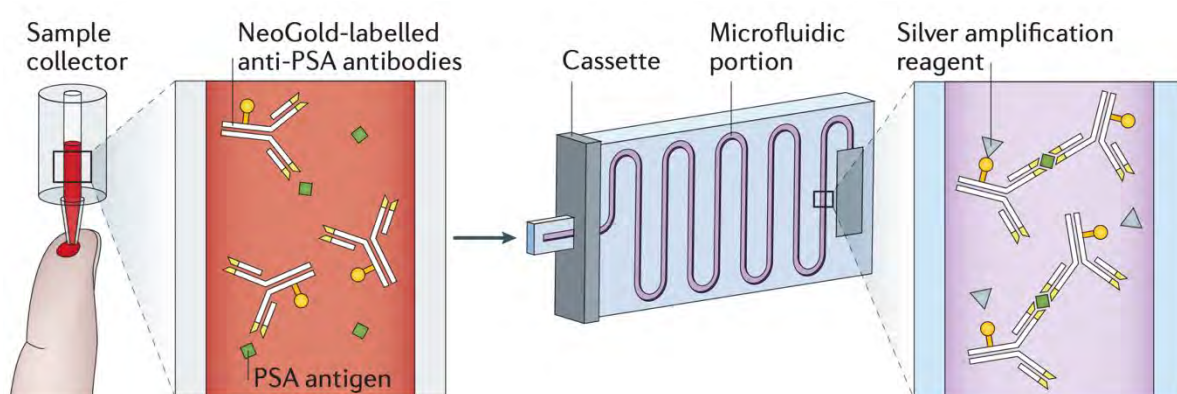


Figure 1.6. A microfluidic-based immunoassay for prostate cancer detection (Meyer & Gorin, 2019).

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.

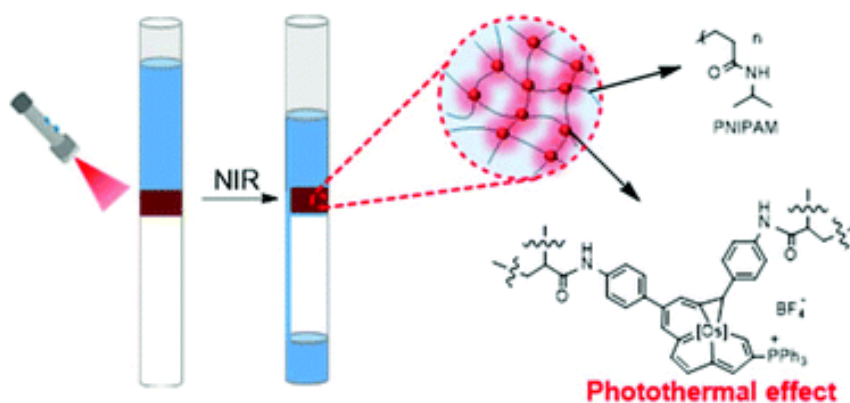


Figure 1.7. Hydrogel-based microvalve (Lin et al., 2021).

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 $\mu\text{m/s}$ 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.



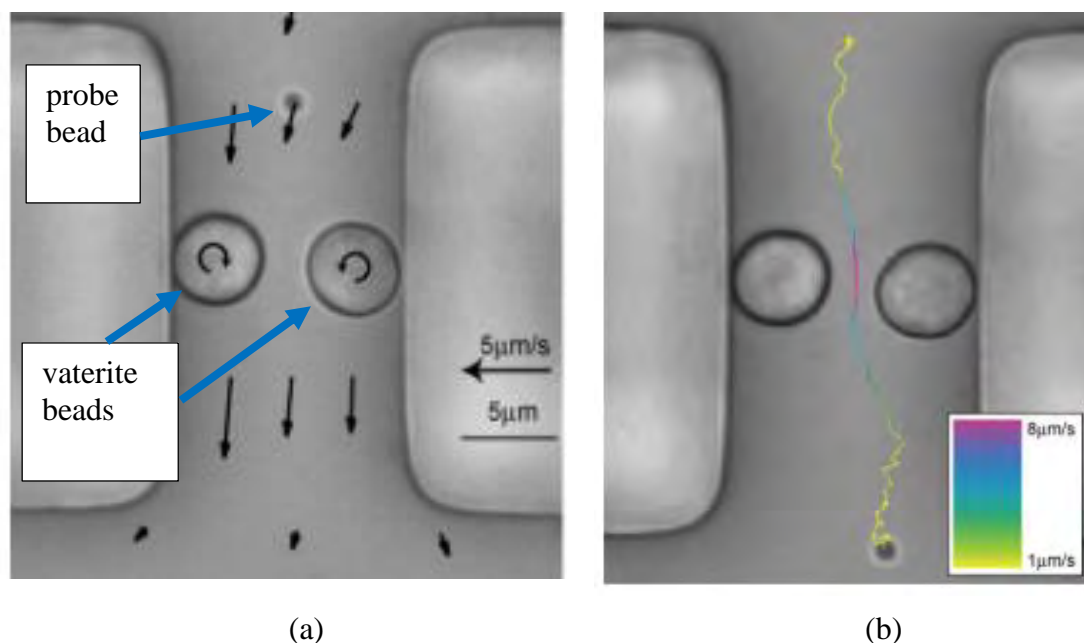


Figure 1.8. An optically driven micropump, (a) A circularly polarised laser rotates a pair of 6-micrometre vaterite beads to induce flow and (b) The trace of the probe bead is used to quantify the flow in the micropump (Leach et al., 2006).

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.

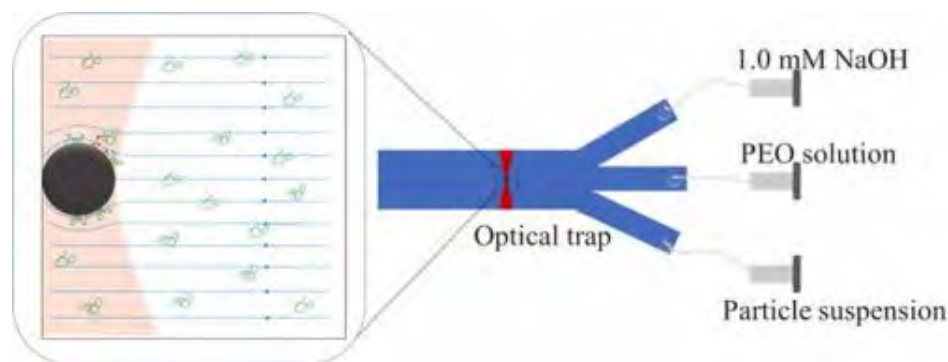


Figure 1.9. Optical tweezers used to study adsorption kinetics on a single microparticle surface in a microfluidic channel.

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.

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-like 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.

