OPTICAL TRAPPING OF ORGANIC SOLVENTS IN THE FORM OF MICRODROPLETS IN WATER

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UNIVERSITI PENDIDIKAN SULTAN IDRIS

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OPTICAL TRAPPING OF ORGANIC SOLVENTS IN THE FORM OF MICRODROPLETS IN WATER

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ABSTRACT

This research aimed to develop a procedure to optically trap organic solvents in the form of microdroplet and to evaluate its optical stiffness based on the corner frequency, f_c. The selected organic solvents were 1,2-dichlorobenzene, acetonitrile, chloroform, ethanol, ethyl acetate and toluene. Microdroplets in water solution were prepared by ultrasonication for 2 minutes. Microdroplets in the range of 2 to 3 µm in diameter were then trapped by using 915 nm laser at power densities of 6.3, 7.4 and 8.4 MW/cm^2 with laser spot size 1.1 µm. A quadrant photodiode (QPD) was used to collect the scattered light from the single trapped microdroplet. The signal was analysed using custom made software named OSCal to determine f_c of the optical trap. The results showed that 1,2-dichlorobenzene, chloroform and toluene formed stable microdroplets in water. Thus, these microdroplets can be optical trapped. The optical stiffness as judged by f_c is within 1 to 10 pN/µm. To conclude, only solvent with very low water solubility can form microdroplet solution and f_c depends on the laser power density, type of solvent and microdroplet size. This research implies that it can provide the information needed by other researchers in choosing the suitable organic solvent for applications requiring an optical trapping technique.

PEMERANGKAPAN OPTIK BAGI PELARUT ORGANIK BERBENTUK MIKROTITIS DI DALAM AIR

ABSTRAK

Kajian ini bertujuan untuk membangunkan satu prosedur untuk pemerangkapan optik bagi pelarut organik berbentuk mikrotitis dan menilai kekakuan optik berdasarkan frekuensi penjuru, f_c. Pelarut organik yang digunakan ialah 1,2-diklorobenzena, asetonitril, kloroform, etanol, etil asetat dan toluena. Mikrotitis dalam air telah disediakan dengan teknik ultrasonik selama 2 minit. Mikrotitis dalam julat diameter 2 hingga 3 μm diperangkap dengan menggunakan laser 915 nm pada ketumpatan kuasa 6.3, 7.4 dan 8.4 MW/cm^2 dengan saiz titik laser 1.1 μm. Fotodiod kuadran (QPD) digunakan untuk mengesan cahaya terserak daripada satu mikrotitis yang terperangkap. Isyarat tersebut dianalisis menggunakan perisian yang dibuat khas bernama OSCal untuk menentukan f_c bagi perangkap optik tersebut. Hasil kajian menunjukkan bahawa 1,2- diklorobenzena, kloroform dan toluena telah membentuk mikrotitis yang stabil di dalam air. Oleh itu, mikrotitis berkenaan boleh diperangkap secara optik. Kekakuan optik yang diperolehi dengan menggunakan f_c adalah dalam lingkungan 1 hingga 10 pN/μm. Sebagai kesimpulan, hanya pelarut dengan kelarutan air yang sangat rendah boleh membentuk larutan mikrotitis dan f_c bergantung kepada ketumpatan kuasa laser, jenis pelarut dan saiz mikrotitis. Kajian ini memberi implikasi terhadap perkembangan penyelidikan melalui maklumat yang diperlukan oleh penyelidik lain dalam memilih pelarut organik yang sesuai untuk aplikasi yang memerlukan teknik pemerangkapan optik.

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LIST OF SYMBOLS

SYMBOLS	**MEANING**	**UNITS**
t	time	s
γ	coefficient of friction	$\mathrm{Ns/m}$
k_T	optical stiffness	$\mathrm{pN/\mu m}$
r	bead's radius	m
η	fluid viscosity	$\mathrm{kg/m^3}$
D	coefficient of diffusion	$\mathrm{V^2/s}$
f_c	corner frequency	Hz
F_g	gradient force	N
F_s	scattering force	N
λ	wavelength	m

LIST OF CONSTANT

SYMBOL	MEANING	UNITS
π	pi constant ($^{22}/_{7}$)	---

LIST OF ABBREVIATIONS

ASCII	American Standard Code for Information Interchange
BS	Boltzmann Statistics
CCD	Charged Coupled Device
ET	Equipartition Theorem
NA	Numerical Aperture
OT	Optical Tweezers
PSD	Power Spectrum Density
QPD	Quadrant Photodiode
USB	Universal Serial Bus
WD	Working Distance

APPENDIX LIST

CHAPTER 1

INTRODUCTION

1.1 Introduction

The chapter gives a brief introduction to the research carried out. The chapter starts with the background of the research. This leads to the problem that will be discussed in the problem statement. In order to tackle the challenge that has been highlighted in the problem statement, several objectives have been identified to give this research a guideline to follow. Next, the significance, scope and limitation of the research will be discussed. This chapter ends with the summary of the thesis.

1.2 Research Background

Optical tweezers (OT) are a powerful tool that can be used to manipulate or trap microscopic particles. In 1970, Arthur Ashkin demonstrated that the motion of micro-sized dielectric particles in water can be manipulated by using optical force (Ashkin, 1970). Continuation of this experiment was done by using two light sources shone directly towards each other. Particle located between the trap was held by the force from radiation pressure exerted by the light sources. In 1986, Ashkin realised that usage of a single-beam laser that was tightly focused was sufficient to trap the particles. The setup for this particular experiment was called as OT (Ashkin, Dziedzic, Bjorkholm, & Chu, 1986).

It is well known that light exerts an apparent mechanical effect on a particle, so called radiation pressure. This radiation pressure pushes away microparticles. In OT, this push is known as scattering force, F_s. To balance the force, laser beam is made to be highly focused. OT is established due to the conservation of light momentum. Figure 1.1 illustrates the path of the light beam entering a transparent microparticle. Suppose a light beam passes through a high-power convex lens and being focused at a certain point inside a microparticle. R_1 and R_2 represent rays at the outermost end of the light beam. An optical gradient force, F_g is resulted due to the conservation of the light momentum. The resultant of gradient forces, F_r pulls the particle towards the centre of the trap which is near the laser focal spot. The motion of the microparticle is constrained by the balance of F_s and F_r. Details on this trapping mechanism will be discussed in Chapter 2.

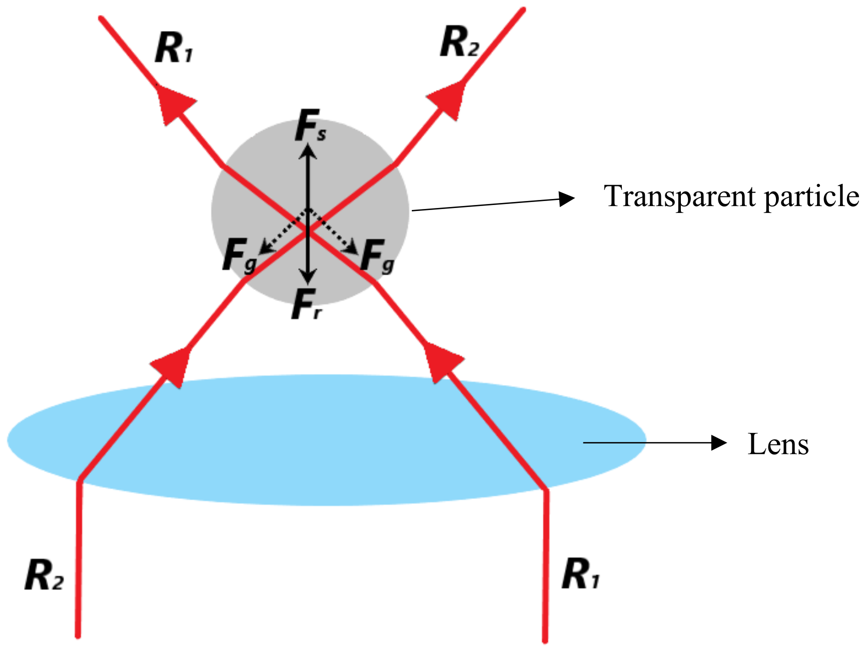

Figure 1.1. Ray diagram for a beam of light entering a transparent particle.

OT has been widely used in many fields of science and engineering. In biological context, OT has been used to sort out viability of *E. coli* bacteria (Ericsson, Hanstorp, Hagberg, & Enger, 2000), micro-manipulate *E. coli* bacteria (Ferrari, Emiliani, Cojoc, Garbin, & Zahid, 2005) and in the study of interaction between red blood cells and viruses (Crick et al., 2014). Since OT does not exert any mechanical contact, damage on the sample due to mechanical force can be minimised. Although heat absorption might cause a problem for delicate and sensitive sample, it can be reduced by changing certain parameters in the OT such as the laser intensity, the wavelength of the laser and the trapping duration (Pan, 2012).

Aside from biological samples, another promising application of OT is in the manipulation of liquid droplets. Manipulation of charged and neutral liquid drop in air was first demonstrated by Ashkin in 1975 (Ashkin & Dziedzic, 1975). Since then, OT had been used to control and manipulate droplets of protein (Reiner et al., , 2006), liposomes (Kulin, Kishore, Helmerson, & Locascio, 2003), liquid crystals (Juodkazis, Shikata, Takahashi, Matsuo, & Misawa, 1999) and aqueous droplets (Power et al., 2012) to name a few. These droplets can act as a small container or nanovials for a chemical reaction to occur. As living creatures carry out biochemical reaction within their cellular compartments, these droplets could mimic the compartments by setting up boundaries separating it from suspensions, similar to phospholipid layer boundaries in cells.

1.3 Problem Statement

Organic solvents are carbon-based solvent that were capable of dissolving other substances. Most of the organic solvents had higher refractive indices than water. In optical trapping context, the relative difference in refractive indices between the trapped particle and its surrounding is an important parameter for a stable trapping force. The refractive index of the particle to be trapped must be higher compared to its surrounding medium to increase the magnitude of gradient forces. Since most organic solvents had a higher refractive index than water, they were a suitable candidate for potential applications requiring an optical trapping technique. In addition, the solvent can potentially act as a container or nanovials containing nanosized particle that can be used in a chemical reaction which can be investigated using OT. For example, calixarene had been proven to be able to detect the presence of heavy ions in water since it formed a layer of thin film on water due to its amphiphilic properties (Supian, Richardson, Nabok, Deasy, & Azmi, 2014). Since calixarenes were insoluble in water but soluble in organic solvents, there are possibilities to employ the organic solvents droplets as a probe to carry the calixarene inside water as illustrated in Figure 1.2. The resulting organic solvents droplets containing calixarene can be optically manipulated to detect any reactions particularly in liquid. Therefore, the solvent should be made into the size of the laser spot of OT or smaller so that it can be trapped using OT. This tiny volume of the solvent was called microdroplet.

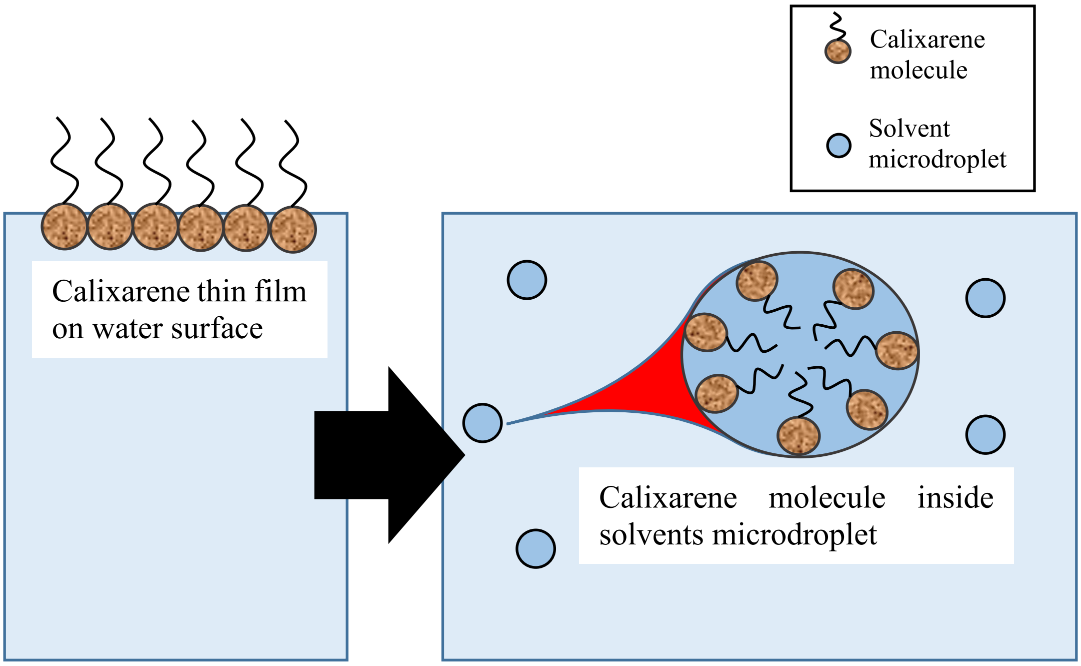

Figure 1.2. Organic solvents microdroplets as container for calixarene molecule.

However, problem arises as there were no established procedure on preparing the solvents for optical trapping purpose. By literature search to-date, there were no guidelines on choosing the proper solvent for use with OT. In addition to variation in their refractive indices, organic solvents show a range in solubility in water. Some of the solvents were completely soluble in water, while some did not mix at all. To the best of our knowledge, there were no information on steps to produce specific number of microdroplets with size less than 10 μm. This could be problematic in optical trapping investigation as the investigation required only one microdroplet inside the trapping spot with its diameter being comparable to the trapping spot size. In addition, the refractive indices of the solvents vary which could lead to a distinctive characterization between each solvent upon investigation using an OT.

This research was carried out to investigate the possibility of producing microdroplets using six different organic solvents. The characteristics of the microdroplets were then determined using OT. This could bridge towards production of microdroplets that can be used as a probe for sensing mechanism such as calixarene. The difference in optical trapping characteristics of each solvent can be used to determine the suitable solvent for a specific purpose and differentiate between physically and/or chemically different microdroplets.

1.4 Research Objectives

The objectives of the research are:

i. To develop a procedure for optical trapping of organic solvents microdroplets.

ii. To evaluate the optical stiffness of the microdroplet trapping based on solvent type, microdroplet size and laser power density.

1.5 Research Significance

Organic solvents were capable of dissolving a wide range of material. Although a lot of research were done on optical trapping, organic solvents were rarely used as the trapping target as they were usually used in preparing other materials for optical trapping purpose. This research aimed to develop a procedure for preparing organic solvents microdroplets which can be optically trapped and can possibly act as a container for calixarene for heavy ion detection in water.

This research also provided the basic recipe that could be used by other researchers to produce organic solvents microdroplets. In addition, the properties of organic solvents that were capable of producing microdroplets were investigated in this research. This could help other researchers in term of selecting the suitable organic solvent according to their own specific applications.

1.6 Scope of Research

The OT used in this research was Modular Optical Tweezers, OTKB (/M) model. The wavelength of the laser used was 915 nm. If a different wavelength were used, the result obtained could be different. The laser power densities were limited to three different values; 6.3, 7.4 and 8.4 MW/cm^2. There were six organic solvents used which were 1,2-dichlorobenzene, acetonitrile, chloroform, ethanol, ethyl acetate and toluene. The trapping process were performed only on droplets within size of 2 to 3 μm in diameter as smaller microdroplets were difficult to visualised by camera using current setup and larger microdroplets were not able to be trapped. There were no additional surfactant or modifier added other than the solvents and water.

1.7 Thesis Summary

This thesis consists of five chapters. Chapter 1 explained the background of the research, problem statement, objectives of the research, significance of the research and scope of the research. The second chapter explained briefly on the principle behind optical trapping, its applications, PSD calibration method, k_T and f_c of a trapped particle. Chapter 3 described the methodology for preparing the organic solvents microdroplets, setup of OT, data analysis procedure system performance test. The next chapter, Chapter 4 presented the results obtained from this research. The microdroplets were produced and trapped by using the OT. f_c and k_T of the microdroplets were determined using steps mentioned in the previous chapter. The final chapter concludes the research and provides recommendation for further studies that could be improved based on this research.