ICTAM 2016
MONTRÉAL

24th International Congress of Theoretical and Applied Mechanics

Palais des congrès, Montréal, Canada

August 21 – 26, 2016

Book of Papers

IUTAM International Union of Theoretical and Applied Mechanics
Official IUTAM Congress

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www.ictam2016.org

Preface

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ISBN: NR16-127/2016E-EPUB
Catalogue Number: 978-0-660-05459-9

PARTICLES DOUBLE LAYER EVALUATION BY ATOMIC FORCE MICROSCOPY-OPTICAL TWEEZERS

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Summary Atomic force microscopy (AFM) is the most commonly used method of direct force evaluation, but due to its technical limitations this single probe technique is unable to detect forces with femtonewton resolution. We present the development of a combined atomic force microscopy and optical tweezers (AFM/OT) instrument. The optical tweezers system provides us the ability to manipulate small dielectric objects and to use it as a high spatial and temporal resolution displacement and force sensor in the same AFM scanning zone. We demonstrate the possibility to develop a combined instrument with high potential in nanomechanics, molecules manipulation and biological studies.
The presented study is aimed to quantify the interaction forces between two single polystyrene particles in the femtonewton scale by using the developed AFM/OT equipment.

INTRODUCTION

Materials containing suspended microparticles or nanoparticles are used extensively in fields of research and in the industry. In order to understand their behaviour in the liquid, the knowledge of stability and mobility of particles in the liquid is fundamental. In all applications it is vital to maintain single particles well dispersed and to avoid the formation of aggregates. For this reason, it is necessary to know the nanoscale fluid-solid interaction and the hydrodynamic properties of the particles. The equilibrium state and the hydrodynamic properties of many colloid's system in aqueous medium is affected by several environmental parameters. The addition of salt influences the stability of colloids. An explanation for this fact was given by the Derjaguin-Landau-Verwey-Overbeek (DLVO) theory, studying the surface charges at interfaces and the factors that affect the electrostatic double-layer forces [1]. This theory assumed that the interaction between two particles is due to the sum of the electrostatic double-layer repulsion and the van der Waals attraction. At low salt concentration, the double-layer repulsion is strong enough and the single particles are stable, but with increasing ionic strength the electrostatic repulsion is masked. If the saline concentration is high enough the colloid system will be unstable because the van der Waals attraction will be higher than the repulsive electrostatic barrier.
Atomic force microscopy (AFM) was developed for nanoscale imaging purposes, where a topographical reconstruction is obtained by scanning the sample surface using a tip fixed on a flexible cantilever [2]. AFM is not only a useful tool to visualize micro and nanomaterials with high resolution but it can also be used to quantify force in the nanonewtonscale (10^{-9} N). Optical tweezers were first realized by Arthur Ashkin in 1970. He was the first to observe and study light scattering on microparticles and the resulting gradient force. This is a technique with which it is possible to trap and manipulate nanometer and micrometer-sized material using a highly focused laser beam. Optical tweezers is a very sensitive technique used to manipulate objects with nanometer displacements and to measure forces with femtonewton (10^{-15} N) accuracy [3].

EXPERIMENT

The combination of atomic force microscopy and optical tweezers (AFM/OT) in one single piece of equipment (Figure 1) give us the ability to obtain images, to manipulate and quantify the motion and the forces directly in the same sample [4].
This research used an atomic force microscopy combined with optical tweezers system (AFM/OT) to measure the effect of ionic strength on the femtonewton scale interaction force between single polystyrene particles at different separation distances. Here, we describe forces involved in single polystyrene colloid stability according with the DLVO theory. At the beginning, AFM/OT system was used to isolate a 1.0 µm polystyrene particle into a microfluidic well using the dragging force of the trapping laser. Subsequently, a custom-made AFM colloidal probe cantilever in which a single fluorescent 5.5 µm particle was glued to the end of a tip-less AFM. It was used to quantify the interaction force between two polystyrene single particles The experiments were

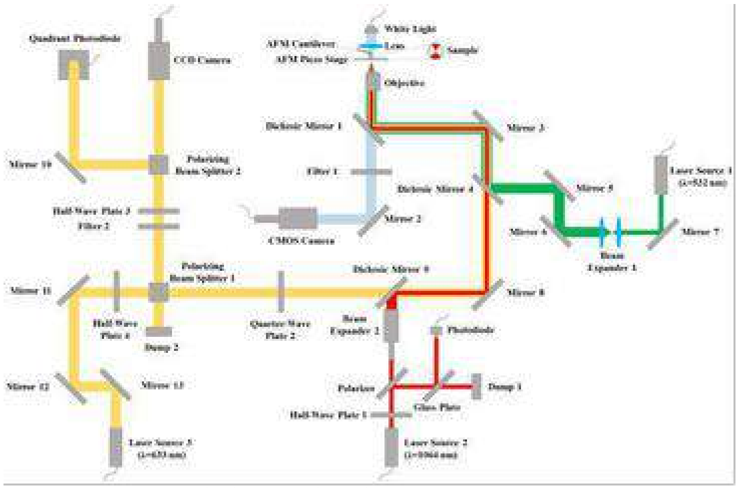

Figure 1. A sketch showing the scheme of atomic force microscopy and optical tweezers (AFM/OT) setup.

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carried out by approaching the trapped particle with the AFM particle probe at a constant velocity (200 nm/s) in pure water and recording the optical tweezers output signals with a resolution of ±100 fN. The same experiment was repeated in 10^{-5} M and 10^{-3} M KCl solutions in that order.

RESULTS

The obtained data (Figure 2) confirm that the behaviour of colloidal systems observed experimentally agrees with the theoretical predictions. In pure water, long range attraction is clearly measured, instead small short range repulsions that are still not strong enough to overcome the attractive component in the analysed range. A completely different behaviour is observed in presence of KCl, where no final attractive forces act in the analysed range, while repulsive forces that grow exponentially with decreasing particle-particle distance are visible. In all the studied systems, no interaction forces between the polystyrene particles could be observed at distances exceeding 450 nm.

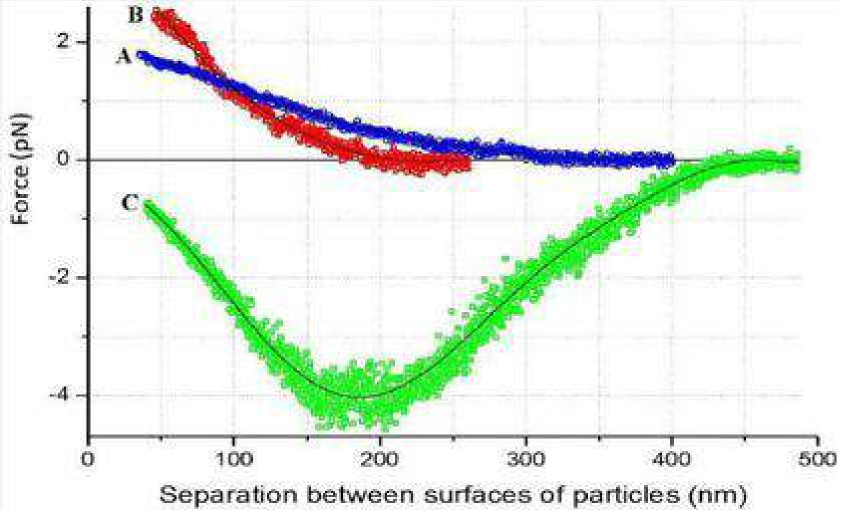

Figure 2. Force as a function of the relative distance between a single pair of polystyrene particles. The interaction force curves measured on approach between the polystyrene sphere attached to the AFM probe and the trapped sphere were collected varying KCl concentration: 10^{-3} M (blue circles; A), 10^{-5} M (red squares; B) and pure water (green triangles; C) at pH 7. The continuous lines correspond to the best fit in the particle-particle interaction range.

CONCLUSIONS

The hybrid AFM/OT allows quantifying the forces involved in the colloid stability with femtonewton resolution tacking in account only forces relative to the two analysed particles. The experiment performed using the developed instrument allows miming the natural colloidal system condition in which the studied single particle is completely bordered by the liquid through the use of the optical trap, giving us a more reliable result than similar experiment performed with AFM only. The used configuration can quantify the forces of interaction between single particles with good reproducibility.

The obtained experimental results confirm the applicability of our combined system to study single particle interaction forces. It is shown that the polystyrene particle colloid systems are more stable in a 10^{-3} M KCl solution, than a 10^{-5} M KCl solution and that is, in turn, more stable than the same system in water. The change of attractive and repulsive forces at various ionic strengths due to the modification of double layer structure affect the stability and the hydrodynamic properties of colloid systems.

ACKNOWLEDGEMENT

The support of NCN grant no. 2011/03/B/ST8/05481 is acknowledged.

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