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Study of Particle Size in Natural and Technological Water Suspensions Using Photon Cross Correlation Spectroscopy with Nanophox

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Abstract Photon cross-correlation spectroscopy (PCCS) has become a novel light-scattering technique allowing for precise measurement of particle sizing and size distribution of suspensions colloids. The size and distribution of particles of suspensions including natural and technological water samples are studied by Photon Cross-Correlation Spectroscopy. The mean diameter, the size distribution range, the specific surface area of the particles in natural spring named Janchivlan are found to be 963±8 nm, 708 nm-1.4 µm and 6.27±0.01 m^2/cm^3, respectively. On the other hand, these values corresponding to the particles in snow samples from the industrial zone of Ulaanbaatar city are determined to be 1.4 µm±70 nm, 947 nm-2.4 µm and 4.16±0.1 m^2/cm^3. It can be assumed that high values in the mean diameter of natural spring and snow samples are related to composition of minerals and PM2.5 and PM10 particles.

Keywords Dynamic light scattering, Gaussian symmetry, Cumulative distribution

1. Introduction

Natural nanoparticles in water occur everywhere. These particle sizes are ranged 1-100nm and very mobile.

Drinking water contains millions of particles, as well as large particles containing 1-100nm nanoparticles. The particles contained in drinking water are inorganic and inorganic materials. Organic particles are plant and animal waste generated by soil, mountain rocks, and human activities [1,2].

The direct effects of these particles on human health are still unknown. However, it has been found that these particles have a definite effect on water quality, as they carry various toxins and bacteria into their own organisms [3].

In addition, nanoparticles play an important role in the environmental system and have a dual role in reducing the concentration of toxic metals and supporting the metal in biochemical reactions.

There are a few studies that have performed in this field.

In this study we have determined the size and distribution of nanoparticles in selected natural and technological water suspension samples.

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2. Experimental Methodology and Techniques

2.1. Photon Cross Correlation Spectroscopy

In this study we have encountered a requirement to measure particles in suspension samples. The Photon Cross Correlation Spectroscopy (PCCS) is a novel technique allowing for the simultaneous measurement of particle size in suspension and emulsion. It is a powerful extension of photon correlation spectroscopy (PCS) also known as dynamic light scattering (DLS).

PCS was first used to measure small particles in dilute systems and poorly scattering materials [4]. In this technique, a laser beam is incident on the solution in which small particles in suspension undergo Brownian motion. The speed of a particle is measured can be converted into a hydrodynamic diameter using the Stokes-Einstein equation [5]. However the PCS is restricted to highly diluted suspension due to limitation of non-interacting spherical particles and single scattered light, while PCCS is allowed to measure particle size in high concentration suspension.

The principle of PCCS is based on the "Brownian motion" of molecules, as described before. It realizes two identical PCS - measurements in the same measurement volume. The two signals correlate only with regard to the single scattered light from the particles in the measurement volume. In this technique a laser beam is split into two partial beams and focused with help of a lens into the sample vial. The crossing region forms the measurement volume. Two photo-detectors receive the scattered light under the scattering angle θ (See Figure 1). The time resolved cross correlated intensities measured by the photo-detectors [6].

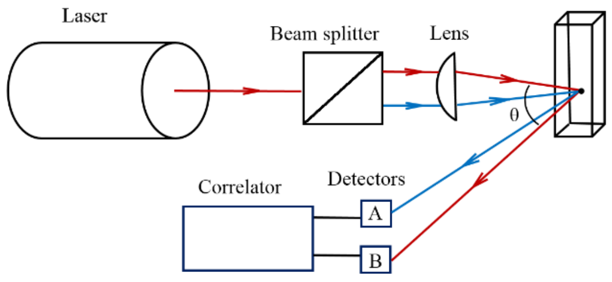

Figure 1. Setup of photon cross correlation spectroscopy

2.2. Sample Preparation

The following 7 natural and technological water samples were selected as the subject of the study. These samples include: 3 mineral water samples from Mongolian springs named Orgil, Zhanchivlan and Unti; water sample from the tap; water samples from clean snow from Terelj National Park area and snow from downtown of Ulaanbaatar city. Last one is a natural petroleum water sample.

To carry out the experiments, a certain volume was extracted from the water sample to methylated alcohol to create a suspension environment. Particles of suspension were filtered by a 39 μm filter to remove large particles. Then 20 ml of suspension was added to 80 ml of distilled water. For the preparation of a homogeneous suspension an Ultrasonic Cell Disruptor KS-900F was used. Samples were sonicated for 15 minutes.

2.3. Particle Size Distribution Analysis

Particle size and size distribution analysis of suspensions have been done on NNLS mode of the PCCS (Sympatec GmbH, Germany). Samples are placed into a transparent cuvette (Eppendorf UvetteR, Sympatec Item No.NZ0020) with dimensions 12.5x12.5x3.6mm, volume of 50-2000μl. Then the cuvette is placed in a thermostat bath with filled clean water filtered by a 0.22μm filter.

This experimental system adopted 632.8nm laser light. The laser passes through the beam splitter and is split into two partial beams to the measured particle suspension through the beam splitter. Two light beams scattered from the suspension as the irradiation of the laser. The scattered intensity was obtained by two photodetectors in different locations but with the same scattering angle as shown in Figure 1. The scattering intensity obtained by correlator is processed by correlator and computer for cross-correlation operation to obtain the particle size information. The measuring temperature is 25℃, and the scattering angle is 90°. The data was calculated by WINDOX 5 software that supports all Photon Cross-correlation data [7].

3. Results and Discussion

Particle size and cumulative distribution of different water suspensions are depicted in Figure 2.

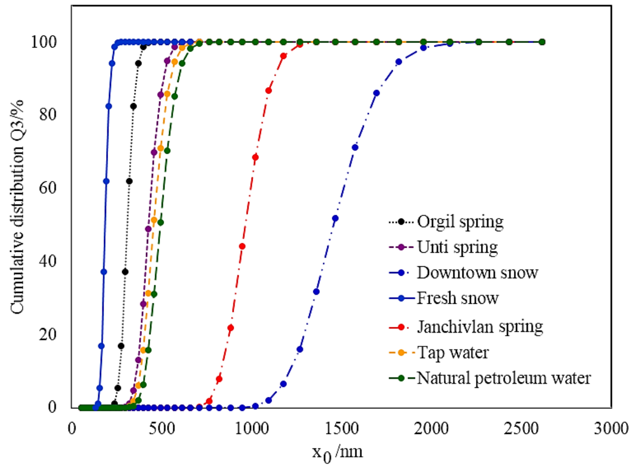

Figure 2. Particle size and cumulative distribution of water suspension samples

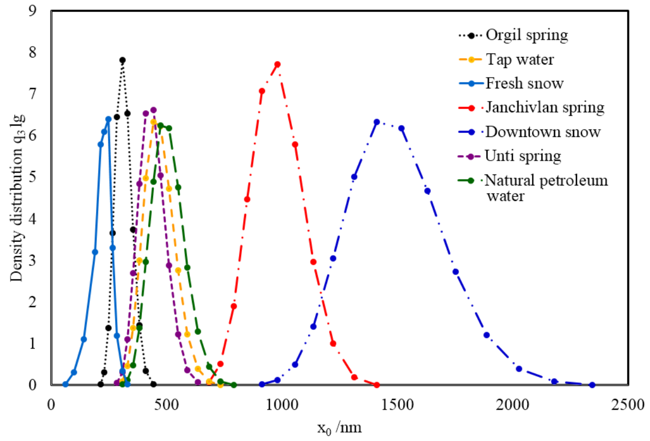

Figure 3. Particle size and density distributions of water suspension samples

Figure 3 shows the dependence of particle size on density distribution for each water suspension sample. As can be noticed, particles distribution is Gaussian with density from 0.02 to 7.72 (q3lg), where the minimum and maximum ranges of the density distributions were in between 69÷343 nm (fresh snow water suspension) and 947÷2343 nm (downtown snow water suspension).

We have calculated the average particle size and specific surface area of the particles using the quantitative values of cumulative and density distributions of the particles in water suspension samples. The particle mean diameter (PMD, x_0), the particle size distribution (PSD) and the specific surface area (Sv) values of suspension samples are listed in Table 1.

From the Table 1, we can see that fresh snow water suspension shows the least particle mean diameter. An opposite result we have observed in snow water suspension samples from the downtown of the Ulaanbaatar city, the most populated place over the country.

Table 1. Values of particle parameters of the suspension samples

Water suspension samples	PMD, x_0	PSD	Sv (m^2/cm^3)
Orgil spring	308±5 nm	222 ÷ 458 nm	19.58±0.07
Janchivlan spring	963±8 nm	708 nm ÷ 1.4 µm	6.27±0.01
Unti spring	428±3 nm	296 ÷ 708 nm	14.13±0.01
Tap water	456±4 nm	296 ÷ 761 nm	13.26±0.06
Fresh snow	242±3 nm	69 ÷ 343 nm	24.86±0.06
Polluted snow	1.4µm±70nm	947nm ÷ 2.4 µm	4.16±0.01
Natural petroleum water	491±4nm	74 ÷ 819 nm	12.33±0.06

The particle size distribution of fresh snow water suspension is determined to be in range 69 ÷ 343 nm. This likely shows that this suspension sample contains ultrafine particles (particle diameter smaller than 100 nm) that are called nanoparticles [8] and fine (less than 2.5 µm) ones. The particle size distribution of polluted snow water suspension is defined to be 947nm ÷ 2.4 µm, that is likely giving us evidence of the presence of fine (PM2.5) and coarse (PM10) particles (particle diameter is between 2.5 and 10 µm).

Particle mean diameter plot of different water suspensions shown in Figure 4. As can be seen, the particle mean diameter of the downtown snow water suspension is almost 6 times higher than other ones. This increase can likely be explained by the existence of urban air pollutants including household heating systems, power plants, car emissions, as well as dust emissions in the capital of Mongolia [9,10].

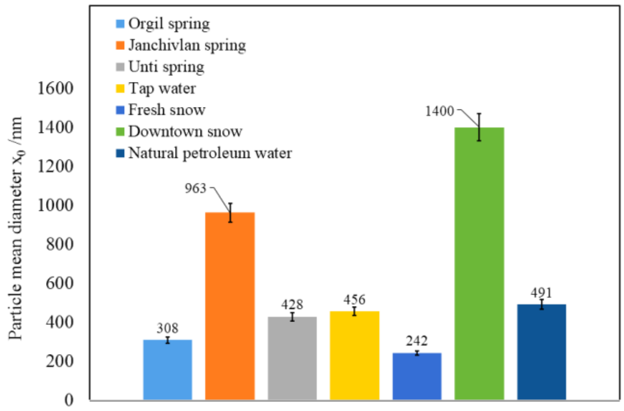

Figure 4. Particle mean diameter plot of different water suspensions

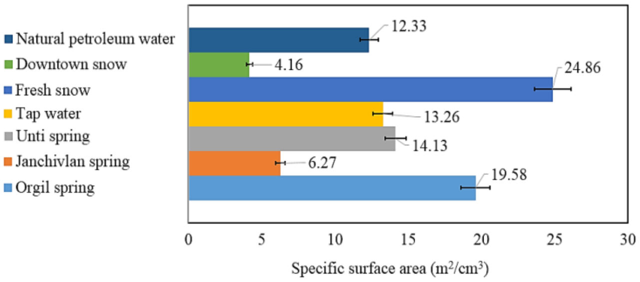

Figure 5. Particle specific surface area of water suspensions

Another higher value in particle mean diameter was observed in water suspension from the Janchivlan cold spring sample. Here, particle mean diameter is determined as 963±8 nm. This can be explained by the comparatively high content of micro and macro elements in the composition of this cold water [11].

As shown in Figure 5, particle specific surface area of different water suspension samples were illustrated. From this figure we can see that decrease in particle mean diameter corresponds to increase of the specific area.

4. Conclusions

Photon Cross-correlation Spectroscopy employed in this work appears to be reliable for particle size and size distribution analysis of suspension samples. Significant differences have been observed in fresh and polluted snow suspensions. The result of fresh snow suspension shows a presence of ultrafine and fine particles. It has been found that the polluted snow suspension contains fine and coarse particles. This is probably accompanied by the existence of urban air pollutants. Also, the higher value in particle mean diameter was observed in water suspension from the Janchivlan spring sample that is significantly larger compared with other spring suspension samples. It can be related to composition of minerals in this sample.

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