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The Impact of Filtration on Water Modeled by Contact Angle Evaporation (CAE) Distribution

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Abstract. Filtration of water samples with two different transport velocities across a porous medium is examined and change of water properties due to filtration is observed with subsequent conservation of this change in time. As a method to manifest these effects, we use a comparison of the two distributions of wetting angles obtained during the evaporation of sample sessile drops taken before and after the filtration. As a porous medium a folio with small holes of 0.15 micrometer size was used. A clear difference between these two distributions is observed and this difference is conserved 24 and 48 hours after the water filtration.

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1 Introduction

The contact between liquid and solid phases continuously persist as a topic of scientific interest elucidated in a series of reviews, e.g. [1] and references therein. The evaporation phenomena of sessile drops have been studied in a large number of publications, e.g. [2–13].

Here we discuss differences in the sample sessile drops CAE (Contact Angle Evaporation) behavior caused by filtration of the liquid where from the drops are taken. We compare these evaporation processes for sample drops taken before and after the filtration. A part of a sample of deionized water was treated by forcing it to penetrate through a foil with small – 0.15 μm – holes in it, produced by accelerated heavy ions. Drops taken from treated and untreated parts of this water sample are observed to evaporate from a solid substrate. The number of all measured contact angles with values in fixed angular intervals is called here Contact Angle Evaporation (CAE) distribution, cf. Section 2. In the next Sections, we show that drops taken from treated and not treated, (or control) water samples display manifestly different CAE distributions. Moreover after a single filtration, when measurements of the treated and untreated samples are repeated, the difference between corresponding CAE distributions still persist for days.

CAE distribution was used in [14] as an application of theoretical discussions. CAE distribution was applied in [15] to discuss the effect of a magnetic field on a water sample moving in this field. To assess the Hydrogen bond transition rates between free and Hydrogen bounded water molecules in [16] CAE distribution was applied as a tool. CAE distribution was used in [17–19] to investigate natural waters.

A preliminary discussion of the present work was reported on the Seminar of Ecology 2017 [20]. Part of the results presented here were published in [21].

2 The Experiment

As water samples we choose deionized water. As a porous medium we use a polyethylene foil (called nuclear filter) with thickness of 10 μm with wholes in it of 0.15 μm in size produced by bombarding the foil with accelerated heavy ions produced in Joint Institute of Nuclear Research (JINR) at Dubna (Russia). The density of holes was approximately 200 000 holes/mm^2. The water was forced to penetrate trough the foil by means of the piston of a syringe.

We prepared two water samples with the following velocities of non turbulent flow across the nuclear filter: $V = 0.4$ mm/s and $W = 1.4$ mm/s. The non-turbulence was checked by calculating of the corresponding Reynolds numbers.

A Hostaphan® Foil RN 75 (thickness 75 μm) was used as a solid substrate of the sessile drops (Figure 1). We measured simultaneously the wetting angle distributions of 3 drops taken from each of the following three water samples: deionized water sample (the control, untreated sample) and the two samples treated with transport velocities V and W.

The contact angles were measured at 4 minutes intervals with an accuracy of 0.5 degrees. The contact angles at the start of evaporation process were 82.5 degrees

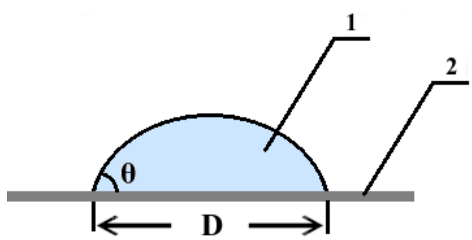

Figure 1. The sessile drop (1), the substrate (2), the wetting (contact) angle θ, and the drop diameter D.

and the starting diameters of the drops contact areas was with the substrate were 4 mm (Figure 1). Since the contact angle measurement is much faster than a measurable change of this angle resulting from evaporation, and in particular due to used accuracy, we can consider the contact angles to be in approximate equilibrium during a single measurement.

After the filtration we measured immediately and simultaneously both the control and treated samples. Then the samples were kept in a refrigerator at a temperature of 4°C. After 24 hours a repeated simultaneous measurement of CAE distributions of sessile drops taken from the samples is performed. The procedure is repeated after a new interval of 24 hours.

The measurement results are displayed in Figures 2 – 4 as graphs on a XY coordinate system. The contact angles measured are plotted on X axis and the whole interval of angle variations is divided into subintervals with a length of 5 angular degrees for each subinterval. The numbers of observations of contact angles with values within each of these subintervals is determined by measurement, for each drop, during the whole evaporation time. These numbers are considered as values on Y axis corresponding to the middle point of the respective X-axis subintervals. In this way one obtains the graphs of CAE distributions of an individual drop.

For the purpose of comparison of different CAE distributions we normalize them by dividing each Y value of a given graph by the total number of measurements corresponding to the same graph. The normalized graphs are CAE probability distributions as shown in figures of Section 3.

3 The Results

This Section contains the graphs of CAE probability distributions of the treated sample, compared to the control. So the treatment effect and its impact after some time intervals are displayed.

In Figure 2 the graph of the control (the graph with circles) is compared with the graphs of the water samples treated with both velocities V and W (the graphs with squares and triangles). This figure shows the result of water treatment measured immediately after the filtration.

The impact of filtration on the distributions is displayed by a shift of the maxima of filtrated samples to smaller angles, having lower values than the maximum of the control sample.

Statistical calculations using three drops representing each single sample during the whole measurement show, that the differences between the control and the filtrated samples are statistically reliable inside the X-intervals of main maxima, i.e. at 70–75 degrees on all figures, 55–65 degrees in Figure 2 and 55–60 degrees in Figure 3.

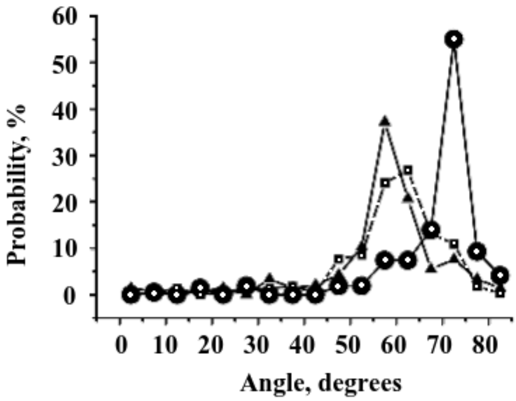

Figure 2. Contact angle probability distributions measured immediately after the filtration: control (circles), samples transported with velocity of 0.4 mm/s (squares), and with velocity of 1.4 mm/s (triangles).

Figures 3 and 4 show the impact of filtration on CAE probability distributions after two time intervals are elapsed from the filtration process. The control sample and the filtered samples are measured simultaneously 24 hours after the treatment (Figure 3). The residual filtration impact and evolution of the forms of the filtrated samples are observed. The graph maxima of the treated samples decreases, with new smaller shifts of these maxima to smaller angles. New local maxima appear at larger angles.

Figure 4 displays the CAE probability distributions of all samples 48 hours after

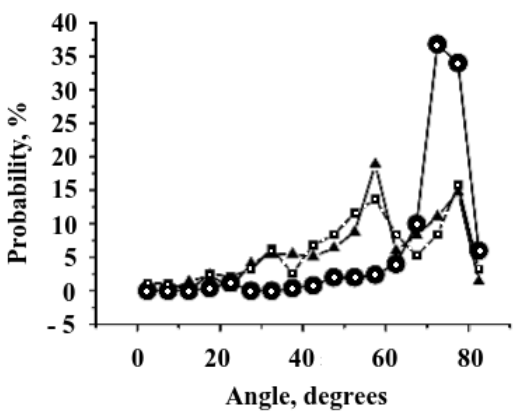

Figure 3. Contact angle probability distributions of the samples from Figure 2 measured 24 hours after the filtration: control (circles), samples transported with velocity of 0.4 mm/s (squares), and with velocity of 1.4 mm/s (triangles).

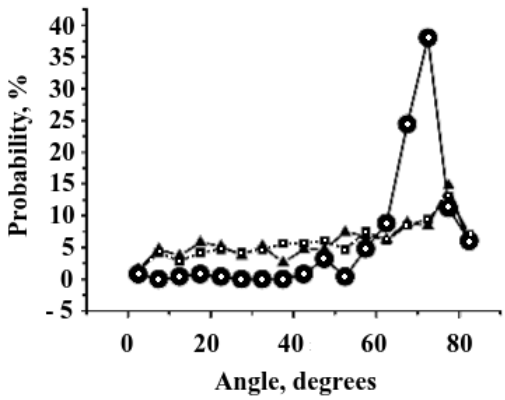

Figure 4. Contact angle probability distributions of the samples from figure 2 measured 48 hours after the filtration: control (circles), samples transported with velocity of 0.4 mm/s (squares), and with velocity of 1.4 mm/s (triangles).

the filtration. A residual impact of filtration reflected by the CAE distribution forms and a time evolution of these forms is evident by a comparison with Figure 3 and Figure 4. The full temporal evolution of the effect of filtration on CAE distributions will be discussed elsewhere.

An way to explain the observed phenomena is to invoke the water clusters (water structure [22]), i.e. domains of water molecules interconnected by Hydrogen bonds. One can suppose that as a result of filtration a difference in water structure appears due to interface interaction between walls of nuclear filter's holes and moving water through the holes.

The experiments performed suggest that the water transport across nuclear filter, results in a change of some sample properties, with a residual impact on them, visualized by the corresponding CAE distributions.

4 Conclusions

To summarize, a non-turbulent transport of water samples with velocities 0.4 mm/s and 1.4 mm/s respectively through the holes of a nuclear filter leads to following results. The CAE distributions of the water samples measured before and after the water transport are manifestly different. A residual impact of the water transport on the CAE distributions is observed if measured 24 and 48 hours after the single transport treatment along with an evolution of the form of the distributions.

The exact mechanism of interface interaction between water and the walls of the filter's holes to produce the results discussed is still not available.

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