Chemical Engineering and Processing xxx (2010) xxx–xxx

Contents lists available at ScienceDirect

Chemical Engineering and Processing: Process Intensification

journal homepage: www.elsevier.com/locate/cep

Effects of static magnetic field on water at kinetic condition

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ARTICLE INFO

Article history:
Received 18 June 2010
Received in revised form 2 November 2010
Accepted 6 December 2010
Available online xxx

Keywords:
Magnetic field
Water
Conductivity
Evaporation

ABSTRACT

Water was exposed for different times to weak static magnetic field (MF) generated from a stack of magnets (B = 15 mT) or from a single permanent magnet (B = 0.27 T) at flow conditions. The water conductivity and the amount of evaporated water were measured as a function of time following the application of MF. It was found that the MF decreases the water conductivity, which is inversely proportional to the flow rate, and increases the amount of evaporated water, even after the water's distillation. The effects are due to the hydrogen bond network strengthening and the perturbation of gas/liquid interface from the air nanobubbles in the water.

1. Introduction

A great number of papers on the effect of magnetic field on the physical and chemical properties of water [1–8], aqueous solutions [9,10] and salt crystallization in MF [11–21] have been published during last years. Besides many conventional theories, the effect of the magnetic field on the physical and chemical properties of water was interpreted on the basis of quantum field theory [19,22,23]. This model establishes amplification of magnetic fluctuations inside the liquid by exchanging energy of external magnetic field with the angular momentum of a single water molecular rotor. An ensemble of individual molecular rotors forced to rotate coherently by the external MF forms water's antisymmetric coherent state. The gain is higher if the MF is in resonance with the rotational frequencies of the molecular rotors and/or low frequencies of the turbulent flow.

Pang and Deng [4,6,7] analyzed the infrared adsorption spectrum and Raman spectrum of magnetized water and they found that static magnetic field causes changes only in the distribution and polarization of the molecules but not in constitution of water. This was deduced from an increase in some of the peaks strength, shift in their frequencies, as well as appearance of some additional peaks. These effects were related to the time of magnetization, the intensity of applied MF and the temperature of water, but no linear relationship between them was found. In this work it was found that magnetic field enhanced the clustering structure of hydrogen-bonded chains and polarization effects of water. Toledo et al. [8] compared the results of experimental measurement of viscosity, enthalpies and surface tension of water after MF treatment with the theoretical calculations and they found that the external MF influences the hydrogen bond networks. They pointed out a competition between intra- and intermolecular hydrogen bonds networks, which weakens the stronger intra-cluster hydrogen bonds, breaking the larger clusters and forming smaller ones, with stronger inter-cluster hydrogen bonds.

Nakagawa et al. [2] examined the effect of MF on water vaporization. They found that the MF enhances the water vaporization in air, but not in nitrogen. Furthermore, the magnitude of these effects depends on the field gradient product $B \cdot dB/dx$ field, and the maximum of the vaporization rate increment is asymmetric to the field axis.

The effect of MF on water's conductivity and simple inorganic electrolytes at static flow conditions, was investigated earlier [5]. In this work, the effect of static MF on the conductivity and the evaporation rate of water under flow conditions is investigated.

2. Experimental

2.1. Materials

Doubly distilled water, deionized with a Millipore Q-Plus 185 system was used for the conductivity experiments.

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doi:10.1016/j.cep.2010.12.005

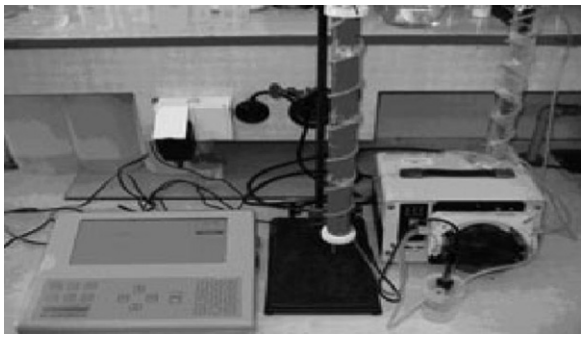

Fig. 1. Photograph of the setup for magnetic stack field treatment (B = 15 mT).

2.2. Magnetic exposure

A magnetic stack (B = 15 mT), of 3.5 cm diameter and 41 cm long, supplied kindly by Feniks, Gliwice, Poland (patent PL 155856) is used (Fig. 1). The stack consisted of 29 magnets and nonmagnetic separating elements arranged convertibly as shown in our previous work [5]. A plastic pipe was twisted around the magnetic stack and the water was circulated with a peristaltic pump. The total length of the pipe, being in contact with the magnet is 95 cm. In a reference system the same size polyethylene hose-pipe was twisted around a glass cylinder of exactly the same diameter as the magnetic stack. In other series of experiments a system with a magnetic field B = 0.27 T was used, which was constructed by attaching a neodymium magnet N–S (Fig. 2) to the reference system. All tested samples of water circulated at the flow rate of 1.4 or 2.8 ml/s for 5, 10 and 20 min in both MF systems. The experiments were repeated three to five times at 23 ± 1 °C.

2.3. Measurements

The conductivity was measured using a multifunction computer meter (ELMETRON CX-731) equipped with probe electrode (the cell constant $K = 0.100 \pm 0.001$ cm^{-1}), PC integrated. The samples of the examined water, 80 ml each, were placed in a polyethylene vessel together with the electrode of the conductivity meter. The conductivity was measured prior to the circulation of water, during the circulation, and 0.5 and 24 h after the circulation, respectively.

The amounts of the evaporated water were also determined. First, 100 ml of the deionized water (Milli-Q Plus System) circulated at flow rate of 1.4 or 2.8 ml/s for 5 min in the same systems as those used in the conductivity experiments. Then, the sample of water, 100 ml, was weighed in a glass beaker of 150 ml volume (the diameter 5 cm and length 9 cm) and then placed for 60 min into a dryer in which the temperature was 95 °C. After that time the sample was taken off and kept for 10 min in an open air at room temperature, then weighed again and the evaporated water amount was calculated. The surface of evaporating water sample was 20 cm^2, i.e. the cross-section of the beaker. Each such experiment was repeated three times.

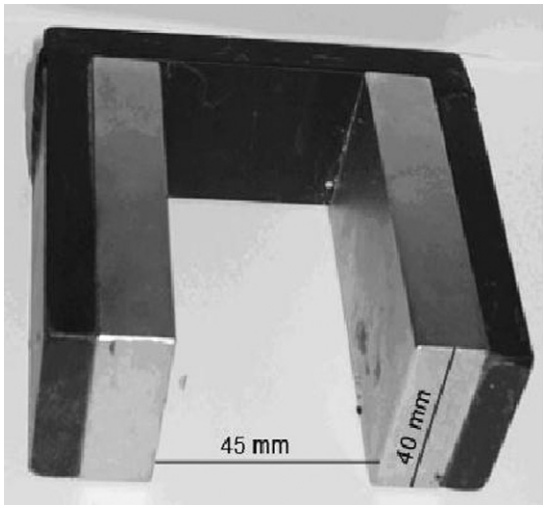

Fig. 2. Setup of single magnet field treatment (B = 0.27 T).

In the next series of experiments the mass loss of doubly distilled water, which had been exposed to the magnetic field before its distillation, was examined. For this purpose the magnetic stack (B = 15 mT) or the neodymium magnet (B = 0.27 T) were attached to the plastic pipe (diameter 1.1 cm, length 70 cm), which was used to supply water to the distillation apparatus. After 90 min of the distillation with the MF on, three samples of the distilled water were taken for the 'evaporation' experiments described above. Similar experiments with samples of doubly distilled water not exposed to MF were also conducted as the reference system. Furthermore, the evaporation rate of tap water (not distilled) was also investigated. The sample of this water flowed through the same plastic tube as those used for the water supply to the distillation apparatus. The flow rate in this case was 100 ml/s.

3. Results and discussion

In Fig. 3, the conductivity changes of distilled water (from Milli-Q Plus System) exposed to MF (15 mT and 0.27 T) for 5, 10 and 20 min, respectively, at the flow rate of 1.4 ml/s are presented. After the application of MF, the flow was stopped and the sample conductivity was measured up to 24 h. In the reference system the same procedure was repeated without MF. It can be seen, that for magnetized samples slight decrease in the conductivity relative to no magnetized sample appears, which is seen both during the application of MF and later on ("memory effect"). With 15 mT of MF applied for 5 min, the conductivity of water is increasing significantly and above the standard error. The enhanced conductivity is maintained for 24 h, a fact that indicates a "memory effect". Moreover, relatively small standard deviations indicate good reproducibility of these experiments. It can be found in the literature that memory of magnetic treatment can last up to 200 h [21]. This effect can be also explained using the quantum field theory [23]. According to Cefalas et al. [23] the amplified magnetic mode will not decay because of the forbidden nature of transition between the antisymmetric and symmetric state and "remains trapped within the coherent state volume of the ensemble of water molecular rotors", which explains the memory effect of water.

To better visualize, in Fig. 4 the difference in conductivity ($\Delta\kappa$) with magnetic field on and off is indicated. The change in $\Delta\kappa$ at B = 0.27 T is proportional to the time duration of the MF. For the magnetic stack at B = 15 mT, the difference in conductivity attains its maximum value after the 5 min exposure. This phenomenon is hard to explain basic on the available theories concerning MF acting on water and aqueous solution. Also according to the quantum field theory, the field of 15 mT is too small to be in resonance with a rotational state of water [19]. However, storage and accumulation of the magnetic field in a coherent anti-symmetric state might take place, and longer water flow time can somehow reduce the MF effect [24]. Moreover, because the MF lines are arranged in different ways for both used magnetic devices, it suggests that magnetic device arrangement might be important for efficient magnetic water treatment. Indeed, more experiments should be conducted to better recognize this unusual behavior.

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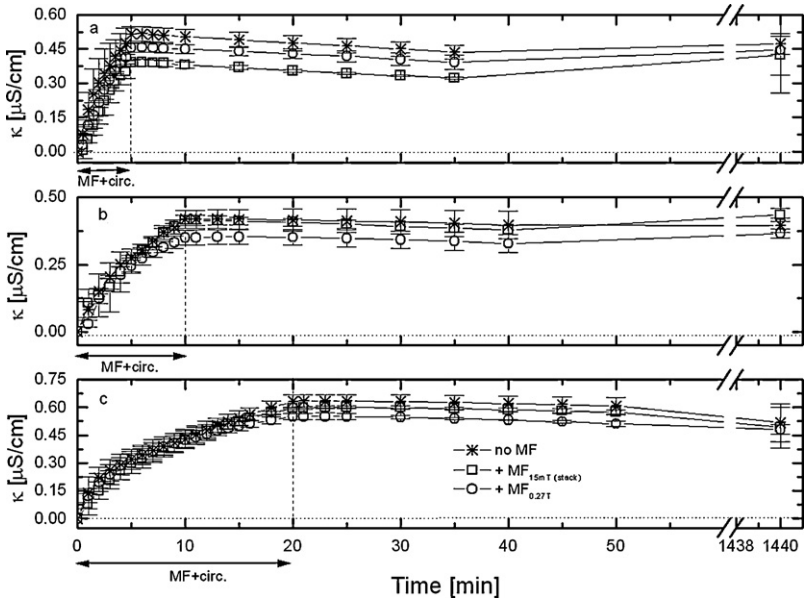

Fig. 3. Changes in conductivity of Milli-Q water caused by exposure to MF for (a) 5 min, (b) 10 min and (c) 20 min vs. time.

Because of the changes in conductivity following the application of magnetic field which decreased with the time of the sample circulation, it seemed interesting to learn how the flow rate influences conductivity of magnetized and no magnetized water samples. In Fig. 5 the difference in conductivity of water ($\Delta\kappa = \kappa_{MF} - \kappa_o$) is shown at different magnetic fields and flow rates, with 5 min circulation. It is verified that $\Delta\kappa$ is inversely proportional to the intensity of MF and the flow rate. On the other hand, Colic and Morse [1] suggested that the electromagnetic field perturbs the gas/liquid interface. Taking into consideration that at higher flow rates the gas solubility is reduced, the experimental results of this work are in agreement with the hypothesis of hydrogen bond strengthening and perturbation of gas phase by the magnetic field. Furthermore, the larger changes are for a weaker MF. This response can be interpreted on the basis that the water is exposed for a shorter period time at 0.27 T than the stack configuration due to geometrical constrains of the arrangement (only 4 cm of the pipe's length is under the MF in the former case, Figs. 1 and 2). The arrangement of magnets in the magnetic devices is a crucial factor [10] because the effects depend on the field gradient $B \cdot dB/dx$[2]. Finally, it is noticeable that the appearance of fluctuation at the conductivity differences cannot be interpreted with the present theory.

In Fig. 6, the changes in evaporated amounts of magnetized and no magnetized water samples (from Milli-Q System) are depicted. The evaporated amount of water is higher under flow (1.4 ml/s) than static conditions at zero MF, and it seems to be flow rate independent regardless of high standard deviation of an individual value from the mean value of the evaporating rate. The evaporating rate is increasing with the intensity of the MF and is still independent on the flow rate at low MF (15 mT). However, at high MF (0.27 T) evaporation is proportional to the flow rate.

To emphasize the effect, the difference between the amount of evaporated magnetized and no magnetized water ($\Delta m = m_{MF} - m_o$) at different MFs is indicated in Fig. 7. The differences of the evaporated amounts are proportional to the flow rate and the strength of the MF. At the same flow rate (1.4 ml/s), Δm is independent on the strength of MF. The increment in the evaporated amount with the strength of MF is higher for tap water, while the distilled water indicates a "magnetic memory effect" as the evaporated amount retains the same value when the MF is turned off. In summary, at higher flow rates the MF has a stronger effect on the water's conductivity and its evaporating rate. The changes in the amount of evaporated water after its exposition to the MF in comparison to the no-magnetized system are not very big in the all investigated

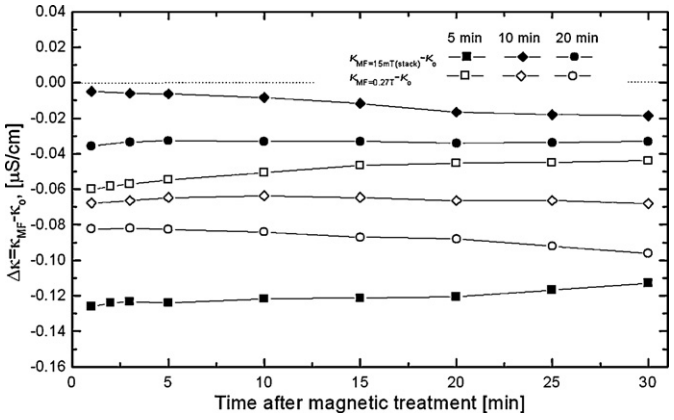

Fig. 4. Differences in conductivity between magnetized and no-magnetized water samples caused by the exposure to MF for 5, 10 and 20 min as a function of time after MF exposure.

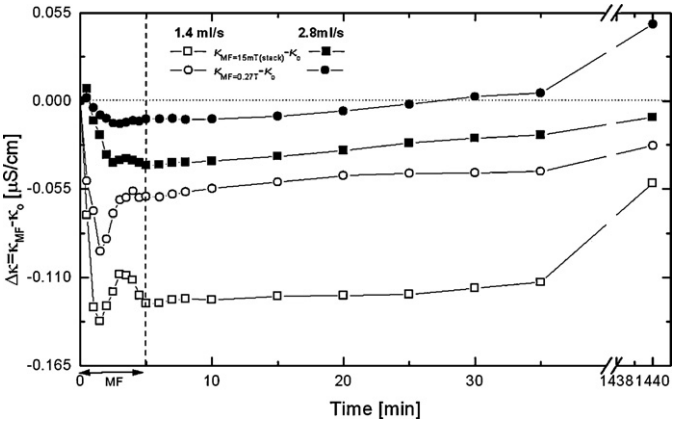

Fig. 5. Differences in conductivity between magnetized and no-magnetized water samples caused by exposure to MF for 5 min at different flow rates a function of time.

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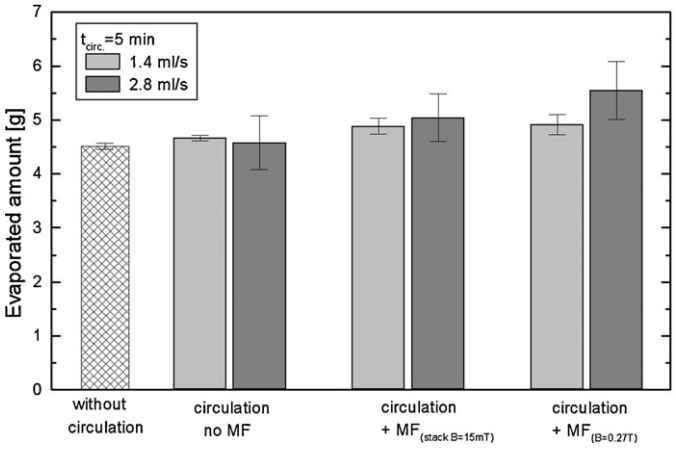

Fig. 6. Changes in the total amount of evaporated water from magnetized and no-magnetized Milli-Q water samples circulated at different flow rates.

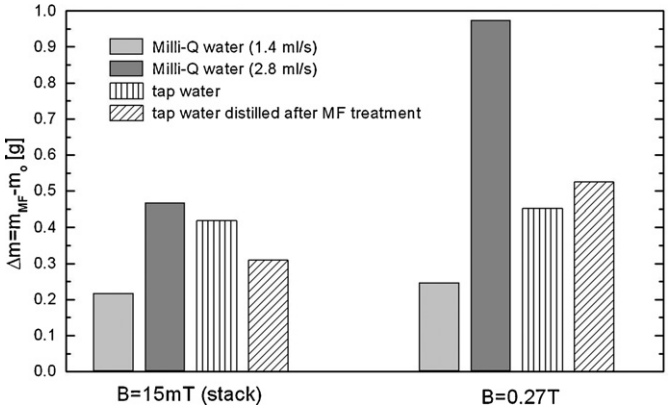

Fig. 7. Differences between the amount of evaporated water from magnetized and no-magnetized Milli-Q and tap water samples.

systems. The biggest difference appeared for water circulated at the flow rate of 2.8 ml/s for 5 min in the presence of 0.27 T MF and for the water sample of 100 g the difference equalled 1 g. Taking into account that the differences of the evaporated amounts are proportional to the flow rate, and that in the industrial processes the water flow rates are much faster, this phenomenon can multiply and hence lower amount of energy would be necessary to evaporate the same mass of water.

4. Conclusions

The magnetic field has an effect on water's conductivity and its evaporation rate. The effect can be interpreted on the basis of stronger hydrogen bonds and from gas/liquid interface perturbation. Magnetic memory effects are demonstrated as well under the above experimental configuration. The MF application during the circulation of water in industrial devices seems to be promising method allowing to save the energy necessary to evaporate water by economically attractive method. However, further verification of the received effects is necessary.

Acknowledgement

We thanks to Mr. Jerzy Ważny for his kind supply of the magnetic device used in these experiments.

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