



Effect of magnetic field on the physical properties of water

Youkai Wang^a, Huinan Wei^{a,b,*}, Zhuangwen Li^a

^aDepartment of Civil Engineering, Henan Polytechnic University, Jiaozuo 454000, China

^bShenzhen Graduate School, Harbin Institute of Technology, Shenzhen 518055, China



ARTICLE INFO

Article history:

Received 11 September 2017

Received in revised form 6 December 2017

Accepted 9 December 2017

Available online 15 December 2017

Keywords:

Magnetic field

Water

Specific heat

Evaporation

Boiling point

ABSTRACT

In this study, the effect of magnetic field (MF) on the partial physical properties of water are reported, tap water (TW) and 4 types of magnetized water (MW) were measured in the same condition. It was found that the properties of TW were changed following the MF treatment, shown as the increase of evaporation amount, the decrease of specific heat and boiling point after magnetization, the changes depend on the magnetization effect. In addition, magnetic field strength (MFS) has a marked influence on the magnetization effect, the optimal magnetizing condition was determined as the MFS of 300 mT. The findings of this study offered a facile approach to improve cooling and power generation efficiency in industrial.

© 2017 The Authors. Published by Elsevier B.V. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

Introduction

Numerous papers reported that the magnetic field (MF) could change the physicochemical properties of water since several decades [1–9]. When water passing through a MF, it become magnetized water (MW). Han et al. investigated the optical properties of water that between two strong magnets, they found that the infrared absorption property of MW changed [2]. Holysz et al. concluded MF could enhance the conductivity and decrease the surface tension of water [3,4]. Wang et al. has examined the effect of a static MF on liquid water using frictional experiments, the results suggested the friction coefficient was smaller in the MF [5]. Cai et al. studied the effect of MF on the hydrogen bonds of water, and discussed the mechanism of magnetization based on molecular dynamics simulation, experimental and theoretical models [6–8]. Liu et al. described MF could accelerate the degradation of organic substances of pulp and paper wastewater, and the PH values of wastewater first increased to the climax and then decreased when MFS ranges from 0 mT to 900 mT [9].

The effect of MF on water is still a controversial issue, and the mechanism of MF treatment is not unambiguous [1,4–6]. However, MW has been used mainly for agriculture, industry and construc-

tion owing to the changes of physicochemical properties. For instance, it can purify wastewater, promote plant growth, inhibit the scaling of metallic surfaces and improve the performance of concrete [9–12].

Although many properties of water that influenced by MF have been reported from lots of studies, few works focus on specific heat, evaporation amount and boiling point of MW, and these properties are very important in various applications, including condensed systems, thermal power and other fields. The aim of this work is to investigate the effect of MF on these properties of water, we studied the specific heat, evaporation amount (heating from room temperature until sample boils), boiling point of MW and TW. Moreover, influence of MFS on magnetization effect was discussed.

Experimental

Magnetization

The TW used in this study was from the local water supply company (Jiaozuo, China), and the preparation of MW also used TW, Table 1 shows the quality of TW. The changes caused by MF depend on magnetizing conditions, the magnetic field strength (MFS) and water velocity were considered as two influential factors [4,9,15].

The MWD-1 magnetizing equipment was developed to prepare MW, the equipment consisted of 26 magnets, size of each magnet was 40 × 25 × 10 mm (length, width, height) with minimum

Abbreviations: MF, magnetic field; TW, tap water; MW, magnetized water; MFS, magnetic field strength.

* Corresponding author at: Department of Civil Engineering, Henan Polytechnic University, Jiaozuo 454000, China.

E-mail address: huinanw@yeah.net (H. Wei).

Table 1
The quality test of tap water.

Test item	Result	Regulatory standard for tap water
Total dissolved solids (TDS) (mg/L)	423	<1000
pH value	7.36	6.5–8.5
Turbidity (NTU)	0.6	≤1
Residual chlorine (mg/L)	0.33	≥0.3
Fe (mg/L)	0.019	<0.3
Mn (mg/L)	0.0032	<0.1
Al (mg/L)	0.0025	<0.2

strength of 280 mT, and all the magnets were put into 2 U-shape grooves, Fig. 1 shows the details of MWD-1 magnetizing equipment. The MFS is controlled by adjusting the distance between 2 U-shape grooves, 4 types of MFS (100 mT, 200 mT, 300 mT, 400 mT) were selected for MW preparation, and the samples are identified as MW-1 (100 mT), MW-2 (200 mT), MW-3 (300 mT) and MW-4 (400 mT). The PVC pipe is in the middle of 2 U-shape grooves, and the diameter of it is 8 mm. A part of PVC pipe (l = 52 cm) was inserted between the MWD-1 magnetizing equipment, which was the length of the MF. When TW flows through the PVC pipe, it turned into MW. All tested samples except TW circulated at the flow rate of 0.8 m/s for 5 min in MWD-1 magnetizing equipment. The schematic diagram of magnetization is shown in Fig. 2.

Measurement of specific heat

DSC (Differential Scanning Calorimetry) is one of commonly used methods to measure the specific heat of liquid in recent years, it can exhibit different thermal behaviours during the heating process and record the heat flow of samples as a function of time [13–16]. A Synchronous Thermal Analyzer, SDT-Q600 (TA Instruments Inc., America), was used to measure the specific heat of TW and MW, as shown in Fig. 3 and Fig. 4. The operating temperature of the equipment is from room temperature to 1500 °C, the sample capacity of container is 200 mg. The platinum sensor and thermocouple make it possible to detect nearly all the changes (heat flow, temperature and other parameters) in the process of test.

The specific heat of TW and MW samples have been measured between 25 °C and 70 °C at the heating rate (β) of 5 K/min, the gas flow of N₂ (shielding gas) is 50 ml/min. When the temperature reached 25 °C and 70 °C, the samples should keep at the temperature for 4 min. Initial DSC experiments were conducted on 2 empty containers (sample container and reference container) which were made of aluminum. The range of temperature and the heating rate were the same with water samples, the curve of baseline was

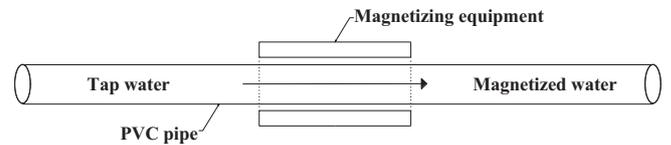


Fig. 2. The schematic diagram of magnetization.



Fig. 3. The SDT-Q600 experimental system.

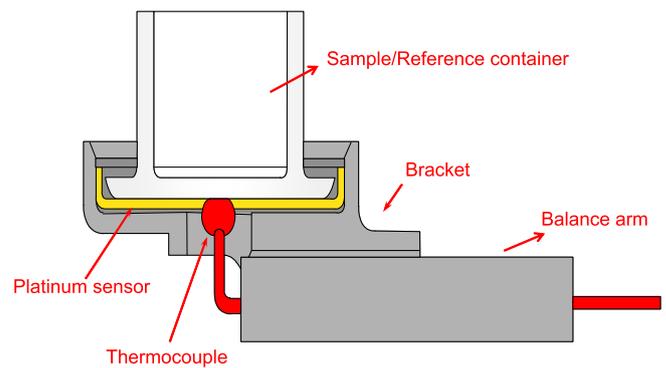


Fig. 4. The schematic diagram of SDT-Q600 working system principle.

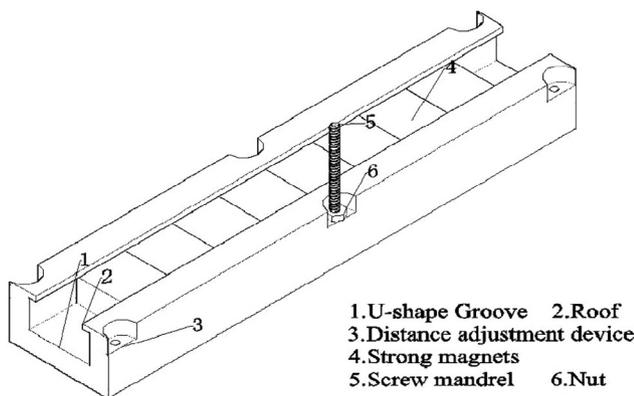


Fig. 1. Details of MWD-1 magnetizing equipment.

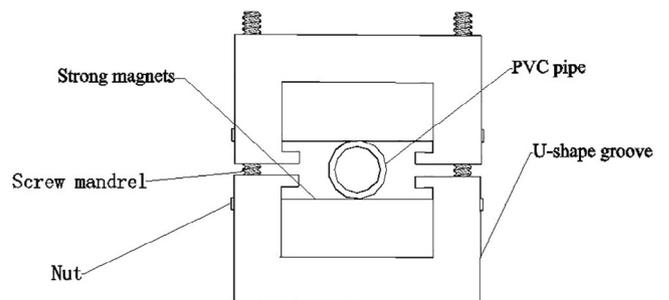


Table 2
The mass of samples.

Groups	TW	MW-1	MW-2	MW-3	MW-4
Mass (mg)	39.33	38.66	33.78	32.67	35.13

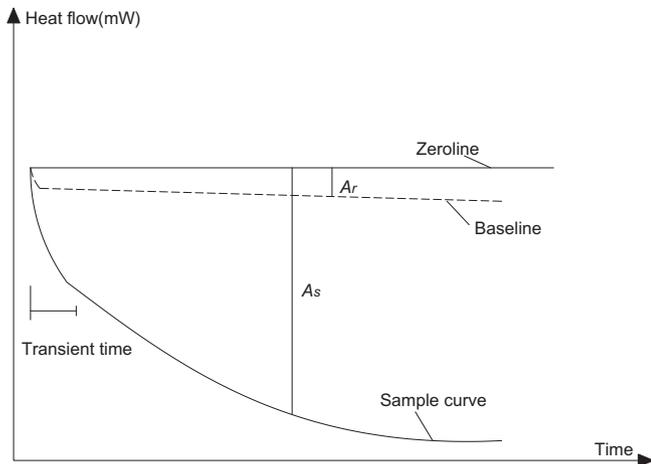


Fig. 5. The calculation of C_s from the DSC curve.

obtained from this experiment. The second conducted with a mass m_s of sample in the sample container, the reference container was kept empty during the DSC experiments, the mass of all samples are given in Table 2. All the data were recorded by software from TA Instruments. The specific heat can be calculated from the DSC curve (Fig. 5). If A_r and A_s are the amplitudes measured from the zero line respectively, the value of specific heat C_s is:

$$C_s = \frac{A_s - A_r}{m_s \beta} \quad (1)$$

where C_s in J/gK; m_s is the mass of samples, (g); A_r and A_s in mW; β in K/s.

Measurement of evaporation amount and boiling point

The FDY-II ebulliometer (Nanjing Sangli Electronic Equipment Factory, China) was used to acquire the evaporation amount and boiling point of TW and MW, which has an operating temperature between -50°C and 150°C . Fig. 6 displays the schematic diagram of it. The steam produced when began to heat samples, but it can not out of device due to condensation. The steam became liquid water after it arrived the condenser pipe under the influence of condensate water, and the liquid water flowed into a pipe that collect evaporated water. As seen in Fig. 6, there is a heating wire in the liquid, and the heating rate is controlled by output voltage. The temperature sensor (SWJ-IC digital thermometer) keep some distance to the heating wire, and the measuring precision of it is 0.01°C . The temperature and voltage are displayed on the LCD.

The samples are accurately weighed by a YC-P electronic balance (Shanghai Guangzheng Medical Equipment Co., Ltd, China) before being placed in the matrass, and the weight of all the samples is 15 g. The heating voltage is 11.50 V in the experiment, the condensate water started to circular flow through the condenser pipe at the beginning of heating, the experiment ended when the sample began to boil and the value of temperature remained stable, then the evaporation amount and boiling point were obtained. The atmosphere varied from 1003.2 hPa to 1008.6 hPa during the experiment, all measurement were performed at $20 \pm 2^\circ\text{C}$. In order to visualize the results from multiple experiments,

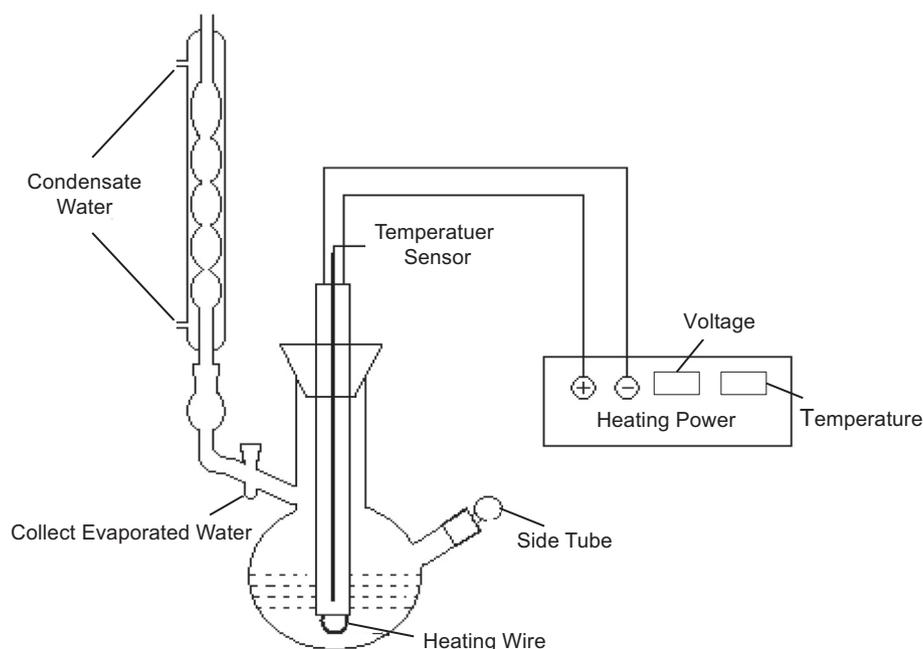


Fig. 6. The FDY-II ebulliometer used in this study.

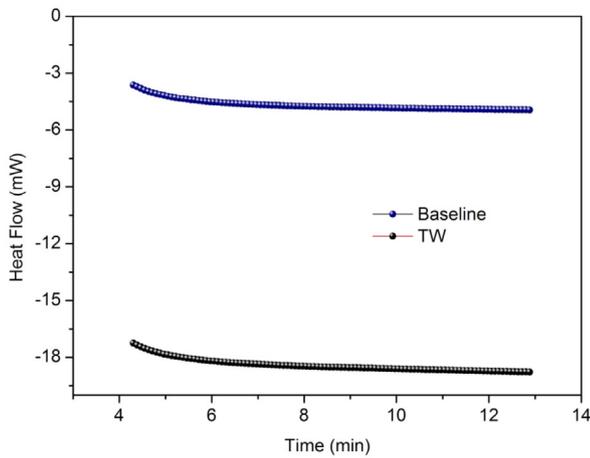
the average values and standard deviations were analyzed on three measurements with different samples.

Results

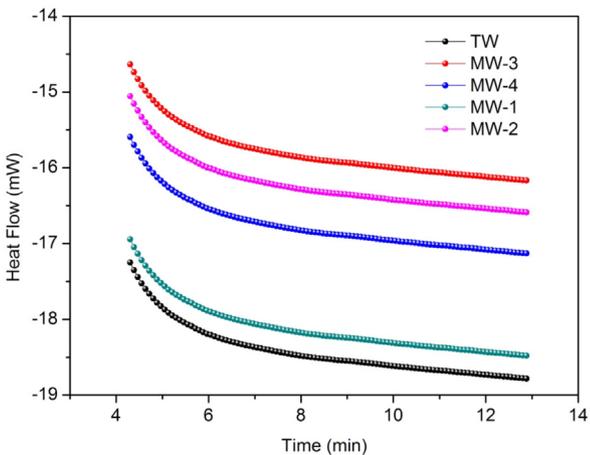
Effect of MF on the specific heat of water

The DSC curve recorded heat flow of samples during heating from 25 °C to 70 °C at 5 K/min, the results are presented in Fig. 7. It is seen that some increase in heat flow for all samples, and the development trend of DCS curves were similar. The change of amplitude (or heat flow) from baseline of each sample owing to specific heat is unstable, as a general rule, the specific heat of water improve slightly with the rise of the temperature. In addition, the heat flow of MW samples were lower than that of TW samples, especially in MW-3, the difference in heat flow between them was obvious. Furthermore, the DSC curve of MW-1 was almost same with TW in heat flow, thus we can concluded that there is not a noticeable change in TW when the MFS is 100mT.

The specific heat of each group can be obtained according to Eq. (1). We summarized the specific heat of TW and MW with 25 °C, 30 °C, 35 °C, 40 °C, 45 °C, 50 °C, 55 °C, 60 °C, 65 °C and 70 °C. As can be seen from Fig. 8, the specific heat of TW varied from 4.1576 J/gK to 4.2205 J/gK when the test temperature between 25 °C and 70 °C, which basically agree with the existing literature



(a) Heat flow of baseline and TW



(b) Heat flow of water samples

Fig. 7. The DSC curve of all samples during heating process from 25 °C to 70 °C.

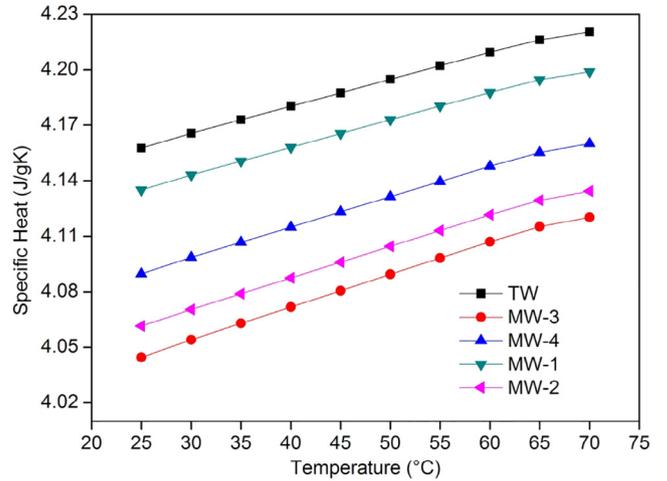


Fig. 8. Measured specific heat of water as a function of temperature.

data, it illustrate that the measuring technique is reliable [13,16]. The specific heat increased very slowly with temperature. However, the specific heat of MW decreased relative to TW, and the downward trend did not continue with increasing MFS, for example, the value of MW-3 (300 mT) were 4.0446 J/gK and 4.1203 J/gK at 25 °C and 70 °C, while that of MW-4 (400 mT) were 4.0897 J/gK and 4.1601 J/gK, respectively. Therefore, it suggested that MF could decrease the specific heat of TW, and the declining trend depend on MFS. In fact, the lowest specific heat was obtained at MFS of 300 mT, which indicate the magnetization effect is satisfactory with 300 mT.

Effect of MF on the evaporation amount of water

No articles have been reported the evaporation amount of MW during the whole heating process. Several authors described the effect of MF on the evaporation of water [3,17,18]. Holysz et al. presented the evaporation amount of water increased when exposed to a static MF, and it concluded that the MF caused changes in the hydration shells of the ions [3]. Guo et al. analysed the evaporation rate of water in a large gradient magnetic field, result shows that the evaporation rate was faster in the MF [17]. In addition, Szcześ et al. also reported the amount of evaporated water improve with a static MF [18].

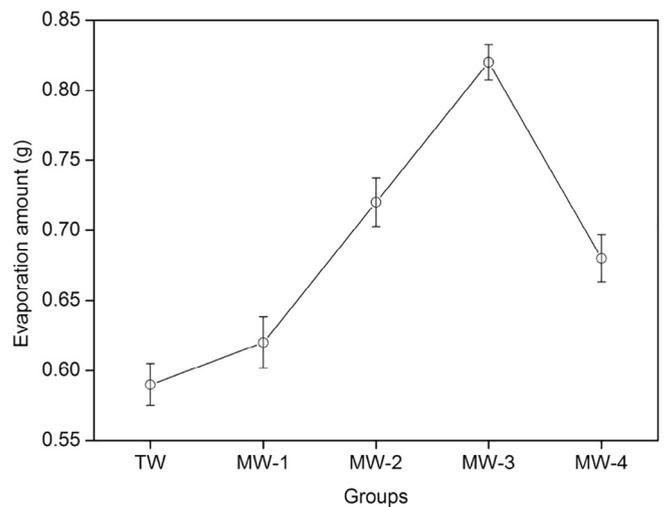


Fig. 9. The evaporation amount of all groups.

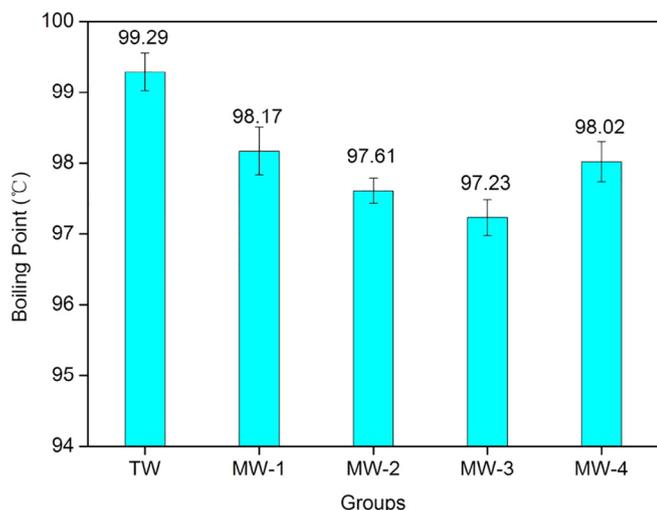


Fig. 10. The boiling point of all groups.

The evaporation amount of TW and MW was measured from room temperature to boiling point. Fig. 9 shows the total evaporation amount when samples reached the boiling point, the evaporation amount of MW were higher than that of TW. Under the same conditions, the evaporation amount of TW was 0.59 g. However, the evaporation amount of MW increased and it got a maximum evaporation 0.82 g in MW-3, rising 38.98% compared with TW. It follows that the evaporation amount of MW improve significantly, the highest increase can be observed in MW-3.

Effect of MF on the boiling point of water

Boiling point is another basic physical parameter of water, the value of it might change under the effect of MF. The results of boiling point are shown in Fig. 10, the boiling point of TW was not up to 100 °C, the behavior could be related to impurities in water and atmosphere in the course of test. As shown in Fig. 10, MW leads to lower boiling point in comparison to TW in the same condition. Nevertheless, the gap between MW-3 and TW was particularly evident, it cut down around 2.06 °C, and the phenomena has not been reported. The changes of boiling point can be related to the magnetization effect of water, and the optimal magnetization effect was determined as the MFS of 300 mT.

Moreover, it was very interesting to find the variation trend of specific heat is in accordance with boiling point with 4 types of MFS, but both of them are opposite to that of evaporation amount. This demonstrated that the change of water properties has the certain regularity, some properties show a similar tendency.

Discussion

Our experimental results suggest that MF have changed some physical properties of water, including specific heat, evaporation amount and boiling point. The evaporation amount results are consistent with reports in literature that the evaporation amount of water increase after MF treatment [3,17,18]. It is worth pointing out that the test condition in our study is from room temperature to boiling point while other studies are room temperature, and the degree of increase is more obvious in our study. This can be explained by the evaporation become faster during the heating process. Moreover, this study explores the effect of MF on specific heat and boiling point of water, and the decrease of specific heat and boiling point have been observed. This is an important result,

which can provides a new way to change the two properties of water, and then apply to the relevant industries to save energy.

In addition, the optimal result in all experiment are achieved in MW-3, which indicate that the magnetization effect reaches a maximum when the MFS is 300 mT, it must be pointed out that the magnetization effect does not enhance with increasing MFS, and the result also reported by other researchers [6,9,12,19]. At the same time, some studies have been carried out to investigate the effect of MF on properties of pure water or high-level purified water [1–4,6]. In general, the changes are similar to that of tap water, such as more evaporation amount, lower surface tension and higher conductivity [5,7,9,12]. Therefore, it can be inferred that dissolved solids and ions have a very limited influence on magnetization effect, and the influence extent should be studied in the future.

But still the principle of MF treatment is obscure, several authors have been done in the attempt to understand it and the hypothesis were proposed that the hydrogen bonds among water molecules were probably effected by MF [5–7]. However, no clear mechanisms of this effect have been reported in the literature.

Conclusions

This article has examined the effect of MF on the part of physical properties of water, the MF treatment changed specific heat, evaporation amount and boiling point of water, and the optimal magnetizing condition was determined as the MFS of 300 mT. The results in this study are helpful in the application of MW to improve cooling and power generation efficiency in industrial.

Acknowledgements

The authors thank the experiment center and department of civil engineering of Henan Polytechnic University for supporting this work.

References

- [1] Pang XF, Deng B. The changes of macroscopic features and microscopic structures of water under influence of magnetic field. *Phys B Condensed Matter* 2008;403(19–20):3571–7. <https://doi.org/10.1016/j.physb.2008.05.032>.
- [2] Han X, Peng Y, Ma Z. Effect of magnetic field on optical features of water and KCl solutions. *Optik-Int J Light Electron Optics* 2016;127(16):6371–6. <https://doi.org/10.1016/j.ijleo.2016.04.096>.
- [3] Holysz L, Szczes A, Chibowski E. Effects of a static magnetic field on water and electrolyte solutions. *J Colloid Interface Sci* 2007;316(2):996. <https://doi.org/10.1016/j.jcis.2007.08.026>.
- [4] Amiri MC, Dadkhah AA. On reduction in the surface tension of water due to magnetic treatment. *Colloids Surf A* 2006;278(1):252–5. <https://doi.org/10.1016/j.colsurfa.2005.12.046>.
- [5] Wang Y, Zhang B, Gong Z, et al. The effect of a static magnetic field on the hydrogen bonding in water using frictional experiments. *J Mol Struct* 2013;1052(11):102–4. <https://doi.org/10.1016/j.molstruc.2013.08.021>.
- [6] Cai R, Yang H, He J, et al. The effects of magnetic fields on water molecular hydrogen bonds. *J Mol Struct* 2009;938(1–3):15–9. <https://doi.org/10.1016/j.molstruc.2009.08.037>.
- [7] Toledo E JL, Ramalho TC, Magriotis ZM. Influence of magnetic field on physical-chemical properties of the liquid water: insights from experimental and theoretical models. *J Mol Struct* 2008;888(1–3):409–15. <https://doi.org/10.1016/j.molstruc.2008.01.010>.
- [8] Chang KT, Weng CI. The effect of an external magnetic field on the structure of liquid water using molecular dynamics simulation. *J Appl Phys* 2006;100:043917. <https://doi.org/10.1063/1.2335971>.
- [9] Liu B, Gao B, Xu X, et al. The combined use of magnetic field and iron-based complex in advanced treatment of pulp and paper wastewater. *Chem Eng J* 2011;178(1):232–8. <https://doi.org/10.1016/j.cej.2011.10.058>.
- [10] Kobe S, Dražič G, McGuinness PJ, et al. The influence of the magnetic field on the crystallisation form of calcium carbonate and the testing of a magnetic water-treatment device. *J Magn Magn Mater* 2001;236(1–2):71–6. [https://doi.org/10.1016/S0304-8853\(01\)00432-2](https://doi.org/10.1016/S0304-8853(01)00432-2).
- [11] Maffei ME. Magnetic field effects on plant growth, development, and evolution. *Front Plant Sci* 2014;5(1):1–15. <http://orcid.org/0000-0001-6814-2353>.

- [12] Wei H, Wang Y, Luo J. Influence of magnetic water on early-age shrinkage cracking of concrete. *Constr Build Mater* 2017;147(1):91–100. <https://doi.org/10.1016/j.conbuildmat.2017.04.140>.
- [13] Hu J, Sari O, Eicher S, et al. Determination of specific heat of milk at different fat content between 1 °C and 59 °C using micro DSC. *J Food Eng* 2009;90(3):395–9. <https://doi.org/10.1016/j.jfoodeng.2008.07.009>.
- [14] Raud R, Hosterman B, Diana A, et al. Experimental study of the interactivity, specific heat, and latent heat of fusion of water based nanofluids. *Appl Thermal Eng* 2017;117:164–8. <https://doi.org/10.1016/j.applthermaleng.2017.02.033>.
- [15] Manyà JJ, Jr MJA, Kinoshita CK, et al. Specific heat capacity of pure water at 4.0 MPa between 298.15 and 465.65 K. *Ind Eng Chem Res* 2011;50(10):6470–84. <https://doi.org/10.1021/ie102462g>.
- [16] Wen-Bo LI, Xue F, Cheng RS. Modification of DSC method for measuring specific heat capacity. *Chem Res Chin Univ* 2005;26(12):2310–3.
- [17] Guo Y-Z, Yin D-C, Cao H-L, Shi J-Y, Zhang C-Y, Liu Y-M, Huang H-H, Liu Y, Wang Y, Guo W-H, Qian A-R, Shang P. Evaporation rate of water as a function of a magnetic field and field gradient. *Int J Mol Sci* 2012;13(12):16916–28. <https://doi.org/10.3390/ijms131216916>.
- [18] Szcześ A, Chibowski E, Hołysz L, et al. Effects of static magnetic field on water at kinetic condition. *Chem Eng Process* 2011;50(1):124–7. <https://doi.org/10.1016/j.cep.2010.12.005>.
- [19] Su Nan, Wu Chea-Fang. Effect of magnetic field treated water on mortar and concrete containing fly ash. *Cem Concr Compos* 2003;25:681–8. [https://doi.org/10.1016/S0958-9465\(02\)00098-7](https://doi.org/10.1016/S0958-9465(02)00098-7).