

## EXPOSURE EFFECT OF MAGNETIC FIELD ON WATER PROPERTIES IN RECIRCULATION AQUACULTURE SYSTEMS(RAS)

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### ABSTRACT

The objective of this study to investigate the effect of magnetic field on water properties recirculating aquaculture systems. This study is based on previous works reporting the positive effects of exposure to magnetic field on water properties, plant growth, plant germination, livestock-drinking water, and fish fertilisation. It was conducted against the backdrop of serious issues pertaining to water quality in recirculating aquaculture systems, which negatively impact aquaculture species growth. First, this work evaluates the effect of exposed to magnetic field intensities of 0.10, 0.15, 0.20, 0.10+0.15, 0.10+0.20, 0.15+0.20, and 0.10+0.15+0.20 T on water quality. The results showed significant ( $p < 0.05$ ) increases of the dissolved oxygen (DO), pH, and conductivity(CD) by 17.3, 1.6, 3.0%, respectively, and significant decreases of the ammonium level( $\text{NH}_4\text{-N}$ ), specific conductivity(SPC), total dissolved solids(TDS), oxygen reduction potential(ORP), and chlorides by 25.3, 1.1, 1.4, 1.0, 16.9, 3.4%, respectively, throughout the experiment in recirculation aquaculture systems. Therefore, the installation of the device in recirculation aquaculture systems is simple, low cost, and can be retro-fitted into existing systems, which helps simplify fish rearing for fish farmers.

**Keywords:** magnetic field, recirculation aquaculture systems, water properties, water quality.

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مجلة العلوم الزراعية العراقية -2018: 49(6):1018-1031

تأثير التعرض للمجال المغناطيسي على خصائص الماء لنظام تربية الأحياء المائية في الدوائر المغلقة  
صدام محمد حسن ريدزوان عبد الرحمن نجلاء صلاح مدلول نور أفده عمرالدين  
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المستخلص

تهدف الدراسة لمعرفة تأثير المجال المغناطيسي على خصائص المياه في تربية الأحياء المائية . تستند هذه الدراسة إلى النتائج السابقة التي بينت بعض التأثيرات الإيجابية للتعرض للمجال المغناطيسي على خواص الماء، الإنبات، نمو النباتات، المياه المستعملة لشرب الحيوانات، وفقس الأسماك. وقد أجريت على خلفية المشاكل الخطيرة المتعلقة التي تتمثل بتدهور نوعية المياه مثل ارتفاع نسبة الأمونيا، العكورة، الأملاح الكلية الذائبة وانخفاض الأوكسجين الذائب والإس الهيدروجيني في نظم إعادة الاستزراع المائي والتي تؤثر سلباً على نمو الأنواع المختلفة من الأحياء المائية. أولاً، يقوم هذا العمل بتقييم تأثير كثافة المجال المغناطيسي للشدد 0.10، 0.20، 0.15 + 0.10، 0.20 + 0.15، 0.20 + 0.10 + 0.15 و 0.20 + 0.15 + 0.10 تسلاً على نوعية المياه المستخدمة في تربية الأحياء المائية، أظهرت النتائج زيادة معنوية في الأوكسجين الذائب، الأس الهيدروجيني والموصلية بنسبة 17.3، 1.6 و 3.0% على التوالي، ونقص ملحوظ في مستوى الأمونيوم، الموصلية النوعية، المواد الصلبة الذائبة الكلية، والكلوريدات بنسبة 25.3، 1.1، 1.4، 1.0 و 3.4%، على التوالي، وعلى مدى فترة التجربة في أنظمة إعادة تدوير المياه. ولذلك، فإن تنصيب أجهزة توليد المجال المغناطيسي في أنظمة تربية الأحياء المائية هو بسيط، ومنخفض التكلفة، وسهل التركيب في أنظمة التربية مما يساعد على حل مشكلة تدهور نوعية المياه المستخدمة بسبب النواتج العرضية للعمليات الأيضية والعلف غير المتناول في أنظمة تربية الأحياء المائية المغلقة التي تهدف إلى الإقتصاد في كمية المياه المستعملة.

كلمات مفتاحية: المجال المغناطيسي، نظام تربية الأحياء المائية في الدوائر المغلقة، خصائص الماء، نوعية الماء.

## INTRODUCTION

Water quality is paramount in aquaculture. Excellent water quality is necessary for the optimal growth of fish, as it reduces the stress the fishes experience and prevent the proliferation of diseases. Important water quality parameters in aquaculture include temperature, dissolved oxygen, pH, ammonia, and nitrate and nitrite content (14, 33). Recirculation aquaculture systems (RAS) are systems where water is partially reused post-treatment (42). In RAS, fish are cultured at high densities in indoor tanks or raceways under a controlled environment. In this system, water continuously flows from the culture tank, and is treated by mechanical and biological filtration to remove solid wastes and carbon dioxide, oxidise ammonia and nitrites. If the culture species is particularly sensitive or high production intensity is required, then the water needs to be further disinfected and treated to remove fine solids and dissolved organics, Water is then recirculated into the culture tank to maintain its water volume (18, 46). Only 2 - 10% of water needs to be exchanged/daily (46), which decreases water usage and maintain its quality (31). Magnetised water is used extensively in industry, agriculture, and medicine. Some of its uses include removing dirt from industrial boilers and aiding digestion in humans (39). The proposed study is based on earlier discoveries by (26), (27), (28), (30) and (40) among others, on the effects of exposure to magnetic field on water properties, which influence water surface tension, density, viscosity, hardness, conductivity, and solubility of solid matter. The changes in the physico-chemical properties of magnetised water could also affect its biological properties. Recently, (36) summarised the major effects of exposure to magnetic field on water: Structurally change the hydrogen ions, the physico-chemical properties, and the behaviour of dissolved inorganic salts. It has been shown that magnetic water can positively impact several water quality parameters. An application of magnetic field intensity of 0.4 - 0.6 T has been proven to reduce pollutants in the water (26). Other significant effects include a change in organic compounds such as ammonium, orthophosphates, and chlorides.

The efficiency of the process depends on the chemical content of treated water, exposure time, and type of magnetiser (28). Good water quality refers to the quality of water that ensures successful culturing organisms, including fish, shellfish, crustacean and others. The maintenance of good water quality is compulsory for the survival and maximum growth performance of cultured species. Water quality can be measured using several indicators. Good or bad signals from indicators reflect the fluctuation in the quality of water. Temperature, dissolved oxygen, pH value, ammonia concentration, salinity, carbon dioxide, organic materials, and total hardness of the water are some of these parameters. Good water quality depends on the ability to control the aforementioned parameters (14). Water conditioning in intensive fish breeding should be concentrated on proper oxygen concentration replenishment in the system and the removal of harmful fish metabolic products, such as ammonium, urea, and dissolved and suspended organic matter (11). Fish growth and health is heavily influenced by its environment i.e. the water quality. A sufficiently good water quality is important for the optimal growth and superior general health of the fishes (14). This study is focused on improving the water properties in RAS. Water quality in RAS is paramount. The system typically removes solid waste, carbon dioxide, oxidises ammonia and nitrites, and provides aeration before it is returned to the rearing tanks. If the fish species are extremely sensitive to environmental conditions, the water must undergo further treatment involving the removal of solids and dissolved organic matter alongside disinfection (1). Adequate filtration is critical to maintaining a healthy environment for the product being produced. If water quality is poor, the fish will suffer from stress, causing reduced growth, mortality and decreased feed efficiency. Filtration removes excess nutrients, metabolic wastes, and solids from the water. It is important to consider all factors when designing and investing in aquaculture systems. The use of magnets has been proposed as a potential way to improve certain aspects of water quality, such as softening water, thus decreasing mineral solubility,

which have important industrial implications (1, 16). Meanwhile, there are reports of decreasing surface tension, which could be attributed to enhanced hydrogen bonding with other water molecules (13). These findings are not without some controversy; as indicated by (13), this is sometimes due to inconsistent results, as well as unclear exact mechanics in certain areas. Research showed that more hydrogen bonds are formed with increasing strength of the magnetic field. Thus, this phenomenon can be exploited to control the size of the water cluster to achieve a more stable structure (15). On the other hand, experiments have shown that the size of the contact angles between the hydrogen atoms of magnetised water is lower compared to that in unmagnetised water. This causes the magnetised water to have a lower surface tension. The clustering structure of hydrogen-bonded chains and polarisation effects of water molecules are enhanced after magnetisation (39). According to Maheshwari (34) and Rasoolian (41), exposing water to a magnetic field causes the molecules to rearrange in one direction. This is due to the relaxation of bonds, with the bond angle decreasing to less than  $105^\circ$  (22), leading to a decrease in the consolidation of water molecules. Applying a magnetic field causes the hydrogen-oxygen-hydrogen bonding angle to be reduced from  $104^\circ$  to  $103^\circ$ . This in turn causes the water molecule to cluster together in groups of 6 or 7 rather than 10 to 12 or higher (49). The intensity of magnetisation of water depends on several factors, such as the amount of fluid prepared for the magnetisation, magnetic field strength, and magnet type, the duration of contact between the liquid and the magnet (37). However, it strongly depends on the physico-chemical properties of the water. If the pipe material is similar, then the surface roughness has an important effect on the magnetic treatment of  $\text{CaCO}_3$  crystallisation (5). Alabdura (4) and Lo (44) studied the effect of magnetic field on water turbidity, and reported a decrease in water turbidity post-exposure to magnetic field. Laboratory studies have confirmed that a magnetic field can accelerate the degradation of organic waste. A magnetic field intensity of 0.005-0.14 T intensifies the biological degradation of the

majority of organic pollutants commonly present in wastewater (26). Some researchers reported that organic pollutant degradation continues for ~12 hours, even after removing of the magnetic field (30). Conductivity is an index of the total ionic content of water, and therefore indicates freshness or otherwise of the water (38). Conductivity can be used as indicator of primary production (chemical richness) and thus fish production. Conductivity of water depends on its ionic concentration ( $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ,  $\text{HCO}_3^-$ ,  $\text{CO}_3^-$ ,  $\text{NO}_3^-$  and  $\text{PO}_4^-$ ), temperature and on variations of dissolved solids. Distilled water has a conductivity of about  $1 \mu\text{ mhos/cm}$  and natural waters have conductivity of 20-1500  $\mu\text{ mhos/cm}$  (3). Specific electrical conductivity is used as a measure of the total amounts of dissolved ions in the water. This is because electrical conductivity can be regarded as the only contributed by the ions present in the water and not the water itself. Water can exist as hydroxide ( $\text{OH}^-$ ) and hydronium ( $\text{H}_3\text{O}^+$ ) ions, but is insufficient to carry an electric charge (25). Constant magnetic field was found to influence the formation of hydroxyl radicals ( $\text{OH}^\cdot$ ) via the Fenton reaction (29). A high magnetic field induces free radical generation, due to the breaking of hemolytic bonds or electron transport between molecules. This phenomenon is also found in thermal, ultraviolet, visible, or ionising radiation of molecules (35). It seems possible that since magnetised water has been shown to reduce chloride levels in waste water, possibly by precipitation or complexing with other molecules (27, 28), this could have occurred in aquaculture, and warrants further investigations. Magnetic treatment can be used to soften water by flowing hard water through a magnetic field. The magnetic field will cause a change in the CD, total dissolved salts (TDS), and pH. Hard water is treated by decreasing the TDS in the water. (1) demonstrated the importance of water flow rates via a magnetic field in salt removal. The objective of this study to investigate the effect of magnetic field on water properties in RAS.

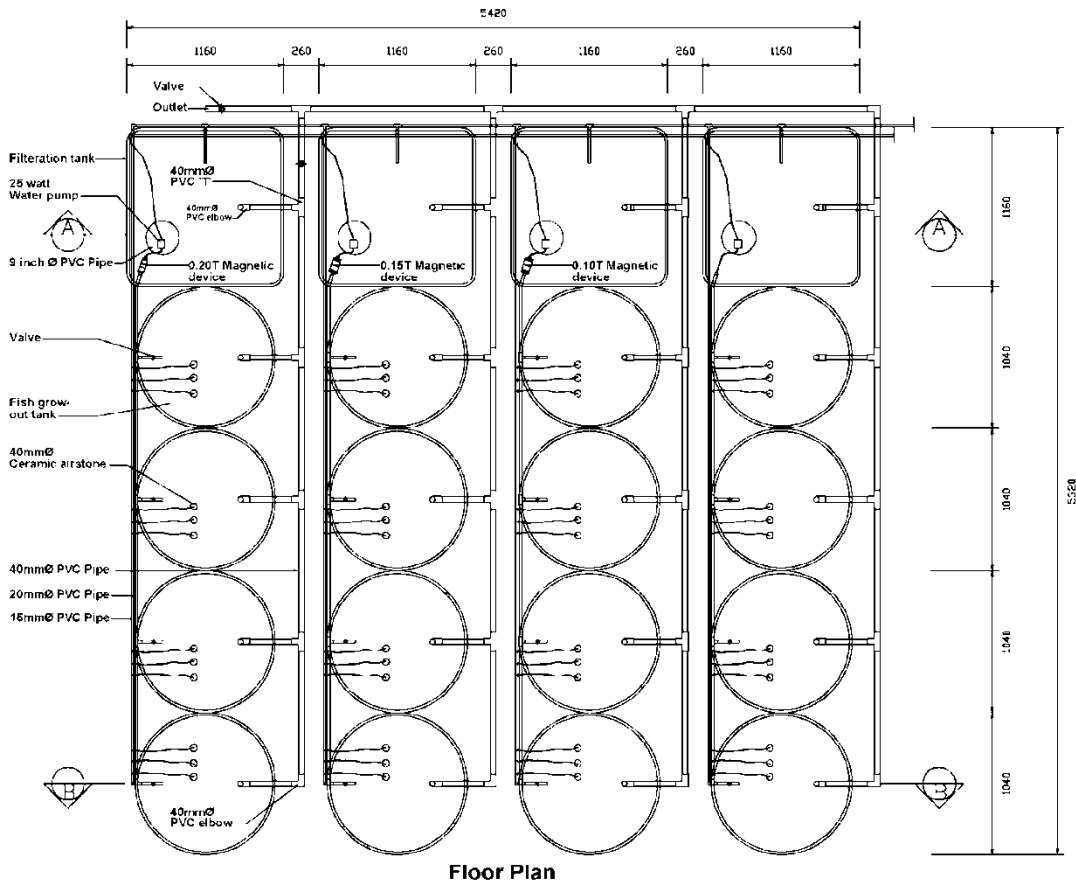
## MATERIALS AND METHODS

**Magnetic devices:** Each device consists of a polyvinyl chloride (PVC) pipe (half inch) and magnetic plates attached to each side. The strength density of the magnet was measured inside the PVC pipes of magnetic devices using a Gauss meter (FW Bell: 5170 Gauss/Tesla meter, USA), the value of which are expressed in Gauss or Tesla, where 1 Gauss is equal to  $10^{-4}$  Tesla, or 100 microT ( $\mu\text{T}$ ). The device is fabricated by attaching magnet pieces to the sides of a PVC water pipe. The intensity of the magnetic fields is dependent on the magnets' intensity. To obtain a magnetic field with intensities of 0.10, 0.15 and 0.20 T, two pieces of different magnet intensities were used. Each magnet piece measured 5 cm in length, and 1 cm in width. The effects of magnetic fields with intensities of 0.10, 0.15, and 0.20 T on water properties and linking these magnetic devices together to obtain the intensities of 0.10+0.15, 0.10+0.20, 0.15+0.20, and 0.10+0.15+0.20 T were analysed. Syarikat Air Perlis tapped water was used throughout the experiments. The Professional plus multiparameter (YSI; Pro Plus 4/ USA) water quality was used to measure water temperature, DO ( $\text{mgL}^{-1}$ ), pH, SPC ( $\text{uscm}^{-1}$ ), SAL (ppt), CD ( $\text{uscm}^{-1}$ ), TDS ( $\text{mgL}^{-1}$ ), and  $\text{NH}_4\text{-N}$  ( $\text{mgL}^{-1}$ ) content, Hydrolab (DS5 HACH Environmental) was used to measure Oxidation reduction potential and chlorides ( $\text{mgL}^{-1}$ ) content, UV/VIS Spectrometer (Lambda 35/ Perkin Elmer) was used to measure the absorbance, (2100N,

HACH) was used to measure turbidity of the untreated/treated water.

### Experimental Design

The configuration of the recirculating system was designed to integrate the water treatment devices, mechanical, biological, and physical filters, and grow-out units. The flow rate of water was 540 L/h, provided by a centrifugal pump, which was sufficient to recirculate water once every 2.22 hours, or recirculate the whole system 10.8 times/day. Four separate closed-cycle grow-out systems were used. Sixteen Polyethylene (PE) tanks served as the fish tanks and polyvinyl chloride (PVC) pipes were used to transport water. The overall design of each RAS system consisted of water flowing from these tanks to a 500 L tank containing green sponge, coral rubble, and gravels, acting as a mechanical filter. Below the green sponge were gravels, which served as the biological filter. Each device was designed to allow water to flow past the magnets in a pipe and the length of the pipes that delivered the water to each of the tanks after going through the magnets was 70 cm between the magnetic device and first tank, 100 cm between the first and second tank, 100 cm between second and third tank, and 100 cm between third and fourth tank. Fish excrement and leftover feed were discharged into the filtration tank, which filtered the water and returned it to the culture tanks, the magnetic devices were continuously installed throughout the RAS, as shown in Figures 1.

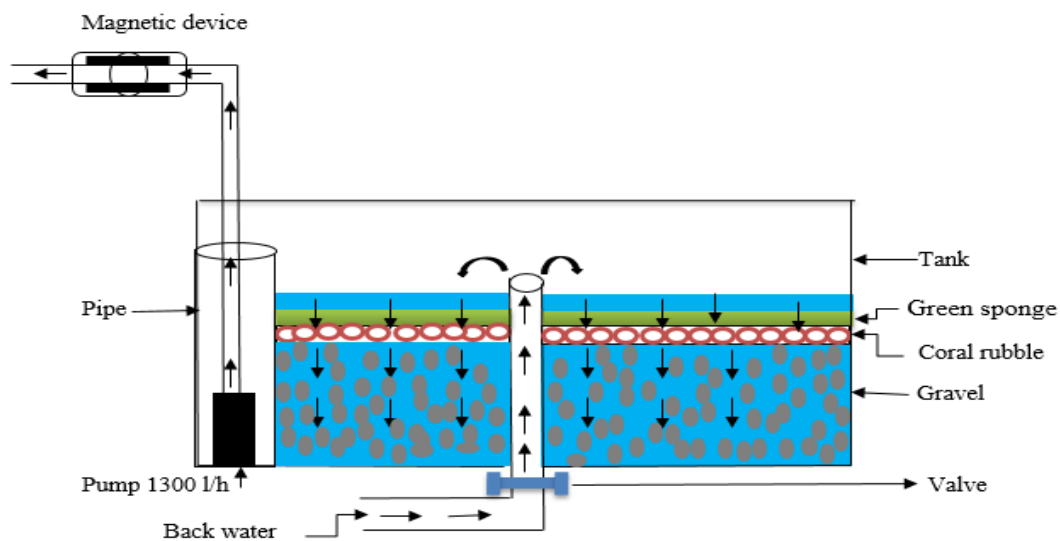


**Figure 1. Floor plan of the grow-out, filtration tanks and magnetic devices of recirculating aquaculture system**

**Filtration tanks**

Filter units were prepared by filling a variety of media that served as a filter and also for development of nitrifying bacteria. The filter media used in this case comprised of green sponge, coral rubble, and gravel. The volume ratio of green sponge: coral rubbles: gravels were 4.8: 4.8: 90.3. The filtration tank is

bigger than the culture tank (500 L), as shown in Figures 2, 3 and 4. Excess feed and fecal matter were back-washed from the filtration tank. To maintain water quality, every two weeks a partial water exchange was performed ( $\approx 40\%$ ), where each treatment was maintained at a fixed level of water.



**Figure 2. Longitudinal of the mechanical, biological and physical filtration tank in RAS**

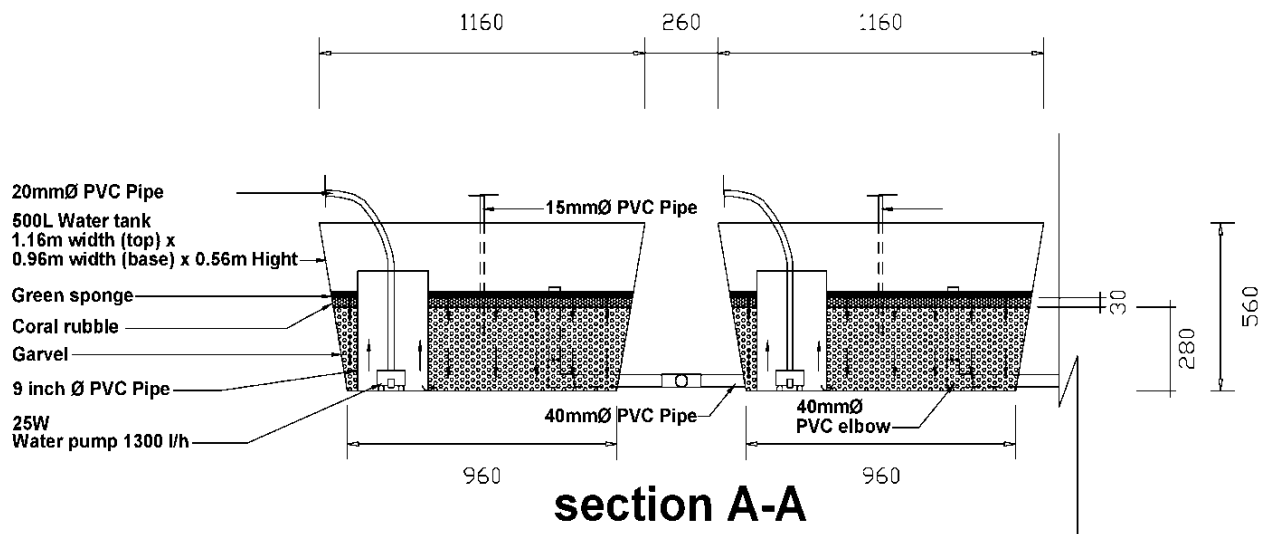


Figure 3. Section A-A of the filtration tanks.

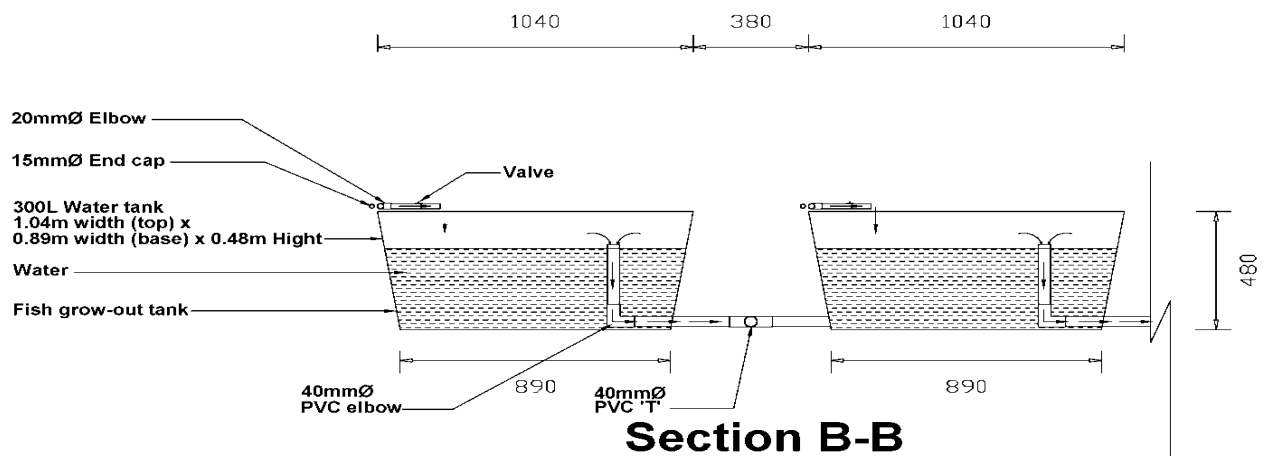


Figure 4. Section B-B of the grow-out tanks.

## RESULTS AND DESCUSION

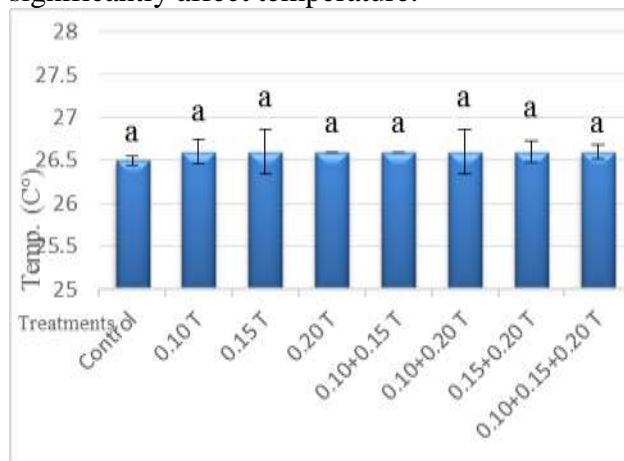
Excellent water quality guarantees the successful culture of aquatic organisms, encompassing fish, shellfish, crustaceans, and others. Water quality is essential towards the survival rate and growth performance of the cultured species. Water quality is defined by specific indicators. As is commonly known, water is important to fishes, thus its quality should agree with the fish. The success of an adequate water quality assessment mainly depends on the capacity of recognizing those water quality parameters that are more critical in the ecosystem, which can be harmful if they

are not monitored and controlled efficiently. There are many factors influencing fish growth; e.g., temperature, pH, salinity, concentrations of DO, nitrogen, nitrates, nitrites and NH<sub>3</sub>-N, where any fluctuations in these aforementioned parameters could significantly influence fish growth (14, 33). Main technological equipment's used in this experiment for water treatment are mechanical filters, biological filters, aeration/oxygenation devices, and UV filters. To create proper environmental conditions for fish breeding, it is necessary to assure an adequate quality of the recirculated water (12). Temperature, DO,

pH value,  $\text{NH}_3\text{-N}$  concentration, and salinity of water are some of the more common parameters of water quality. Control of these parameters are crucial towards aquaculture production (14). The effects of magnetic field on water properties, namely temperature, DO, pH level,  $\text{NH}_4\text{-N}$ , SC, SpCond, TDS, CD, salinity, ORP, CL, turbidity, and absorbent are reported hereafter:

#### Effect of the exposure to magnetic field on water parameters

**Effect of the exposure to magnetic field on temperature ( $^{\circ}\text{C}$ ):** The variation of temperature duration throughout the experiment is shown in Figure 5. The data represents the temperature before magnetisation (control) and after magnetisation at magnetic field intensities of 0.10, 0.15, 0.20, 0.10+0.15, 0.10+0.20, 0.15+0.20, and 0.10+0.15+0.20 T. The magnetic field intensities does not significantly affect temperature.

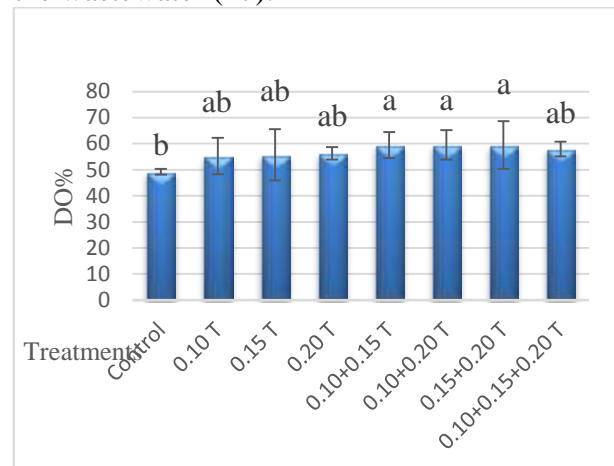


**Figure 5. Effect of exposure to magnetic field on temperature**

#### Effect of the Exposure to Magnetic Field on Dissolved Oxygen Concentration (%)

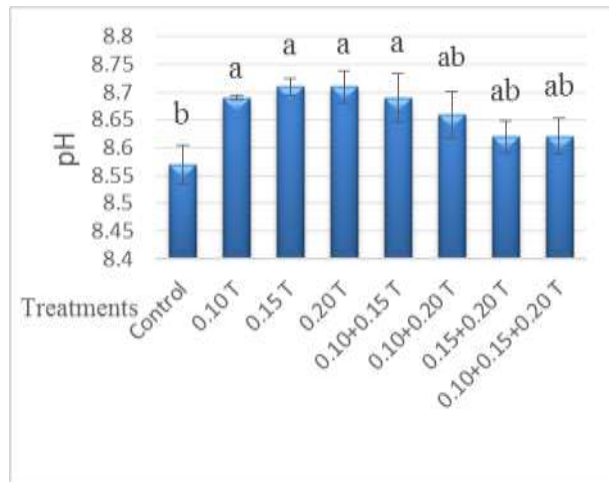
The dissolved oxygen significantly increased with increasing water magnetisation intensities, Figure 6. An increase from 49.2 to 59.5 was recorded after the water was magnetised with magnetic field strengths of 0.10+0.15, 0.10+0.20, and 0.15+0.20 T. The results agree with the results of Al-Ibady (4), who pointed out that increased magnetic intensity led to an increase in the DO concentration. The external magnetic field works to reduce the angle between the two atoms of hydrogen and oxygen within the water molecule from  $104^{\circ}$  to  $103^{\circ}$  (48). Exposure to a magnetic field of 0.10 T for 30

minutes increased the oxygen production in the wastewater (47).



**Figure 6. Effect of exposure to magnetic field on DO**

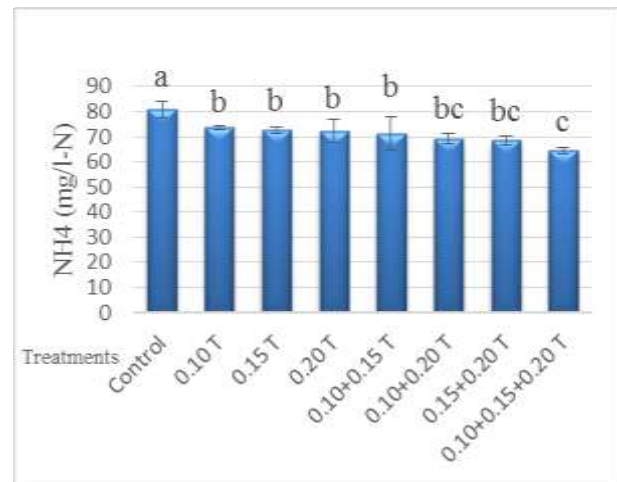
**Effect of the exposure to magnetic field on pH level:** The results showed the highest increase of 1.61% pH units after the water was magnetised with magnetic field strengths of 0.15 and 0.20 T, as per Figure 7. Generally, the pH increases slightly with increased magnetisation intensity due to the increase in free carbonate content in water (5). The normal water contains temporary hardness salts Calcium bicarbonate  $\text{Ca}(\text{HCO}_3)_2$  and magnesium bicarbonate  $\text{Mg}(\text{HCO}_3)_2$ , so the salts dissociate due to the magnetic field to  $\text{Ca}^{+2}$  and  $(-\text{HCO}_3)$ , while water decomposes to  $(^+\text{H} \ \& \ ^-\text{OH})$ , which goes on to form calcium hydroxide  $\text{Ca}(\text{OH})_2$ , which is a strong base, and  $\text{H}_2\text{CO}_3$ , which is a weak acid, leading to increased pH due to the effect calcium hydroxide being than the weak acid. The effect was found to be dependent on the intensities of the magnetic field exposure and magnetisation intervals, which changes the composition of the water molecule and the permeability pressure (1). Magnetic field affects the hydrogen bonds between water molecules, resulting in altered pH. On the other researchers, (7, 35), observed that the exposure of water to magnetic field softens the water and increases its pH due to the rearrangement of the water molecules into one direction. This was supported by Hasson and Bramson (23), who reported an increase of 12% in water pH post-magnetisation. pH affects the metabolism and other physiological processes (43).



**Figure 7. Effect of exposure to magnetic field on pH level**

#### Effect of the exposure to magnetic field on ammonium concentration

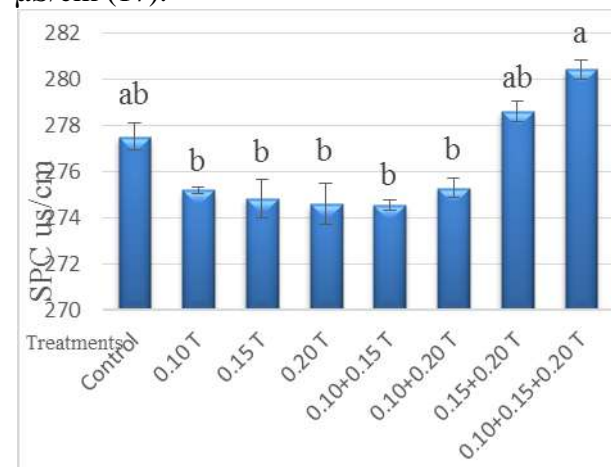
The difference in ammonium concentrations between control and magnetic field treatments are shown in Figure 8. It can be clearly seen that increasing the exposure to magnetic field significantly decreased the ammonium-nitrogen concentration, from 80.73 in the control treatment, to 64.45 mgL<sup>-1</sup> in the 0.10+0.15+0.20 T treatment. The NH<sub>4</sub>-N content exhibited a general decreasing trend with increasing magnetisation intensities. According to Sunitha (43), high levels of NH<sub>3</sub>-N is detrimental to the fishes, which means that low levels of NH<sub>3</sub>-N in treatments is preferred to encourage fish growth. High reactivity and high oxidation potential of the aforementioned compounds could effectively reduce the concentration of organic matter, which means that the magnetic field increased the oxidation rate ten-fold. The disintegration of a water molecule due to the formation of free radicals taking place when a sufficient amount of energy is available. This can be induced by magnetic fields (29).



**Figure 8. Effect of exposure to magnetic field on NH<sub>4</sub>-N (mgL<sup>-1</sup>).**

#### Effect of the exposure to magnetic field on specific conductance (SPC)

Result of specific conductance showed a significant ( $P \leq 0.05$ ) decreasing trend for the 0.10, 0.15, 0.20 T treatments, but it increased when combining the magnetic devices to affect treatments of 0.10+0.15, 0.1+0.20, 0.15+0.20 and 0.10+0.15+0.20 T, as shown in Figure 9. Post-magnetisation, the polarisation features of molecules and their corresponding distribution in magnetised water are changed. These changes to the water molecules results in variations of the transition character of the electrons in these molecules. The effect depends on the intensity of exposure to the magnetic field. The specific conductance is an important measure of water quality conditions, because it is positively correlated with nitrate ions, ammonia, ranging between 26 - 263  $\mu\text{S}/\text{cm}$  (17).

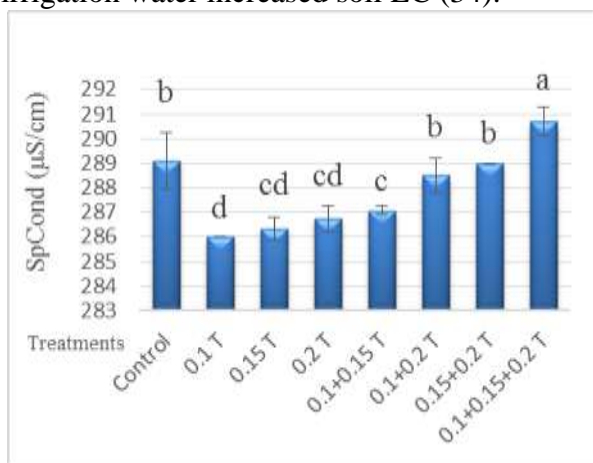


**Figure 9. Effect of exposure to magnetic field on SPC ( $\mu\text{S}/\text{cm}$ ).**



### Effect of the exposure to magnetic field on specific conductivity (SpCond)

The SpCond reported a significant ( $P \leq 0.05$ ) decreasing trend with exposure to magnetic field at intensities of 0.10, 0.15, and 0.20 T. It began increasing again when the magnetic devices were coupled to produce treatments at intensities of 0.10+0.15, 0.10+0.20, 0.15+0.20, and 0.10+0.15+0.20 T, as per Figure 10. Post-magnetisation, the polarisation features the molecules and their corresponding distribution in magnetised water are subsequently altered. Such changes to water molecules resulted in variation to the transition character of the electrons within these molecules (40). The effect depends on the intensity of the exposure to the magnetic field, which agrees with Barseghyan results (9), who pointed out that the electromagnetic field decreased in response to specific EC, and that one-hour treatment of extremely low frequency electromagnetic field brings about a specific decrease to the electrical conductivity. A magnetic field in the range of 3.5–136 mT for irrigation water increased soil EC (34).

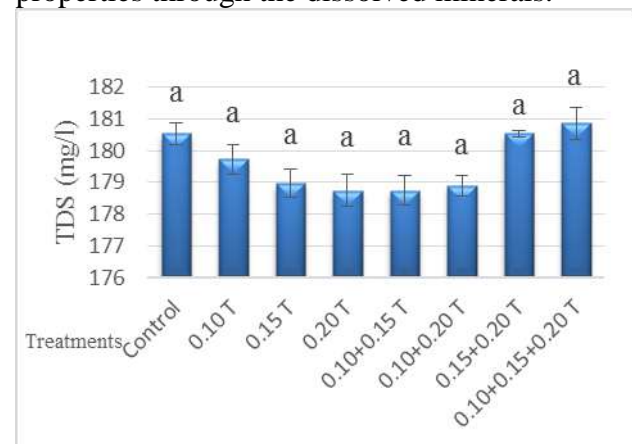


**Figure 10. Effect of exposure to magnetic field on SpCond (µS/cm).**

### Effect of the exposure to magnetic field on total dissolved solids

Result shows decrease of TDS, from 180.54 to 178.75 ( $\text{mgL}^{-1}$ ), after the water was magnetised with a field strength of 0.20 T. Magnetisation was found to decrease the TDS with increasing magnetisation intensities, but caused an increase in dissolved solids again when combining the magnetic devices to produce treatments of 0.10+0.15, 0.10+0.20, 0.15+0.20, and 0.10+0.15+0.20 T, because of the deterioration of magnetic intensity after coupling the magnetic devices with each other,

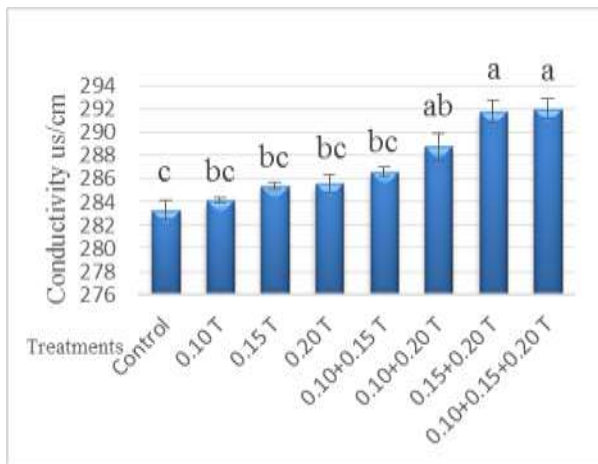
as shown in Figure 11. The use of a magnetic field of intensity of 1.12 T decreased the TDS by ~14 % (2). Results of this study agree with those reported by (21; 23). Researchers demonstrated that exposure to magnetic field affects the molecular and physico-chemical properties of water by altering the water's nucleus (20; 16; 13). The reason for the increased solubility of the salts is when it's exposed to the dipole magnetic fields, some of the physico-chemical properties of water are modified, while retaining the dipole magnetic properties through the dissolved minerals.



**Figure 11. Effect of exposure to magnetic field on TDS (mgL-1).**

### Effect of the exposure to magnetic field on conductivity

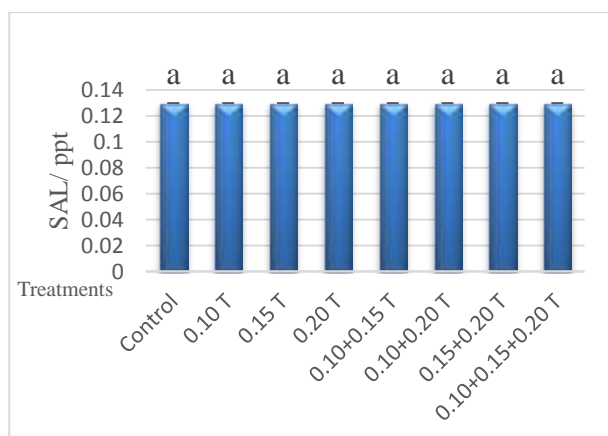
Exposure to magnetic fields significantly increase water CD from 283.3 for the control sample, up to 292.05 for magnetised water to 0.10+0.15+0.20 T, as shown in Figure 12. Abdel Hady (1) believes that this is due to the change in the electric dipole of water molecules, which is related to the change in the overall CD. This disagrees with (23), who found that a 16% decrease, and agrees with Alkhazan and Saddiq (7), who noted an increasing CD post-exposure to a magnetic field. EC increase is attributed to the magnetised field transforming the molecular structure of water, from larger to smaller molecules. This magnetised force transforms ordinary water quintet installation to an effective water installation hexagon, resulting in a high permeability to cells and tissue in the body and increased EC, which ultimately results in increased electrical conductivity (4).



**Figure 12. Effect of exposure to magnetic field on CD**

### Effect of the exposure to magnetic field on salinity

Exposure to magnetic field has no significant ( $P \leq 0.05$ ) effect on water salinity, as shown in Figure 13. This disagrees with El-Yazied (19), who demonstrated that exposure to magnetic fields can influence water salinity. The results showed that even low magnetic fields (0.3-0.7) can decrease the total dissolved solids, which are suitable for the removal of salinity from irrigated land using magnetised water for irrigation (7). Applying a strong magnetic field to water can increase the removal of soluble salts compared to normal water. The removal of soluble soil salts by leaching is an improvement and reclamation for salt-affected soils (24).

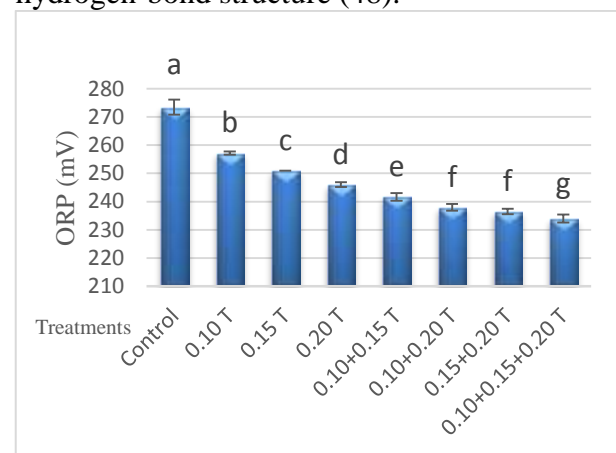


**Figure 13. Effect of exposure to magnetic field on SAL (ppt)**

### Effect of the exposure to magnetic field on oxidation reduction potential

Exposure to magnetic field significantly decreases the Orp, as shown in Figure 14. The results show that magnetic treatment increases both the reducing and oxidation abilities of

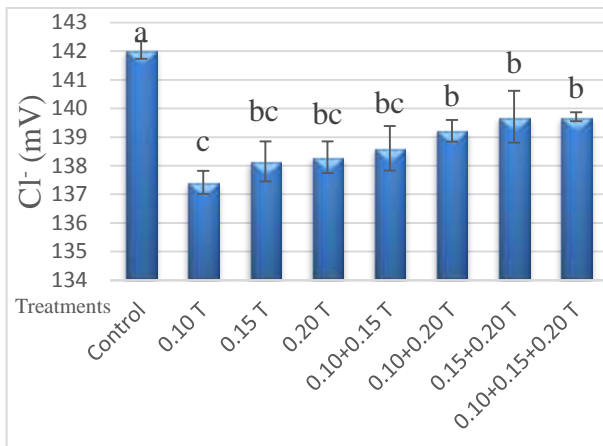
hydrogen peroxide and sodium hypochlorite. In terms of the mechanism of the magnetic field effect, it could be explained by H-bond distortion. The reduction of oxidation potential could be due to the magnetically increased deproteinisation of the agents, but this can only be confirmed with theoretical and experimental researches (10). The Orp of distilled and deionised water were measured after the exposure of the samples to varied magnetic fields. The result represents the presence of appreciable activation barriers for process kinetics that is somehow related to the magnetic field. This behavior could be related to the morphological nature of the water's hydrogen-bond structure (48).



**Figure 14. Effect of exposure to magnetic field on ORP (mV).**

### Effect of the exposure to magnetic field on chlorides

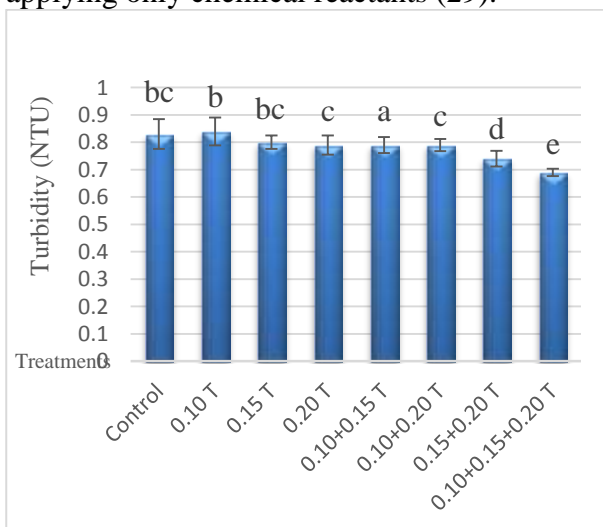
The result shows a significant ( $P \leq 0.05$ ) decrease of chlorides, from 142.04 to 137.42 (mv), after the water was magnetised at an intensity of 0.10 T. The Cl content initially decreased, but increased when combining the magnetic devices to produce treatments at intensities of 0.10+0.15, 0.10+0.20, 0.15+0.20, and 0.10+0.15+0.20 T, as shown in Figure 15. This agrees with (27), who found that water exposed to magnetic fields of 0.40 and 0.60 T decreased the Cl by 6.5%, and the exposure to the magnetic field to the technological system allowed for chlorine reduction of wastewater (45). A magnetic field intensity of 0.005-0.14 T intensifies the biological degradation of the majority of organic pollutants commonly present in wastewater (26).



**Figure 15. Effect of exposure to magnetic field on chlorides (mV).**

### Effect of the exposure to magnetic field on turbidity

Effect of exposure to magnetic fields significantly decreases water turbidity, from 0.83 for the control, to 0.69 for magnetised water, to 0.10+0.15+0.20 T, as shown in Figure 16. Alabdraba (5) confirmed that magnetic fields of 1.38, 2.76, 4.14, 5.52, 6.9, 8.28 T increased the efficiency of removing impurities from water (turbidity reduced from 662 to 0.36 NTU, and from 45.25 to 0 NTU). The method of magnetic aggregation and separation can reduce the turbidity of raw water of different initial turbidity and from different areas at different pH values (32). The results showed that a magnetic field significantly affect the number of generated hydroxyl radicals. It was observed that the application of the magnetic field increased the oxidation rate ten-fold compared to the system applying only chemical reactants (29).



**Figure 16. Effect of exposure to magnetic field on turbidity (NTU)**

The conclusions and achievements of this dissertation are detailed below. Results and observations from this study led to the conclusion that magnetic forces affected certain physico-chemical properties of water in RAS. However, pH, DO and CD values increased as the magnetic strength increased. On the other hand, parameters such as NH<sup>4</sup>-N (mgL<sup>-1</sup>), Sc (uscm<sup>-1</sup>), SpCond (uscm<sup>-1</sup>), TDS (mgL<sup>-1</sup>), ORP (Mv), Cl (mgL<sup>-1</sup>) and viscosity (mPa) were inversely related to magnetic field intensities as compared to untreated water. It was therefore concluded that electromagnetic fields of different intensities affect water quality parameters in RAS.

### ACKNOWLEDGMENTS

This study was partially funded by a grant from Universiti Malaysia Perlis (UniMAP); project no. 2016/6129-00001.

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