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Enhancement Effects of Water Magnetization and/or Disinfection by Sodium Hypochlorite on Secondary Slaughterhouse Wastewater Effluent Quality and Disinfection By-Products

Nagham R. Elsaidy [1], Nooran S. Elleboudy [2], Adel Alkhedaide [3], Fatma A. Abouelenien [1], Mona H. Abdelrahman [4], Mohamed Mohamed Soliman [3] and Mustafa Shukry [5,*]

1 Department of Hygiene and Preventive Medicine, Faculty of Veterinary Medicine, Kafrelsheikh University, Kafrelsheikh 33516, Egypt
2 Department of Microbiology and Immunology, Faculty of Pharmacy, Ain Shams University, Cairo 11566, Egypt
3 Clinical Laboratory Sciences Department, Turabah University College, Taif University, Taif 21995, Saudi Arabia
4 Pharmaceutical Analytical Chemistry Department, Faculty of Pharmacy, Ain Shams University, Cairo 11566, Egypt
5 Department of Physiology, Faculty of Veterinary Medicine, Kafrelsheikh University, Kafrelsheikh 33516, Egypt
* Correspondence: mostafa.ataa@vet.kfs.edu.eg

Abstract: Wastewater disinfection is one of the most critical issues in protecting human health against exposure to waterborne pathogenies. Chlorine is among the most commonly used disinfectants in many wastewaters' treatment plants. Nevertheless, disquiets regarding chlorine's disinfection by-products (DBPs) have grown recently. One of the most effective ways to reduce DBPs generation is to reduce chlorine dosage by increasing disinfectant efficiency. Using magnetic field (MF) in wastewater treatment is one of the promising research topics with significant progression. This study aimed to evaluate the efficiency of using a magnetic field and/or sodium hypochlorite (NaClO) disinfection on secondary slaughterhouse wastewater effluent quality and by-products. Three groups of secondary slaughterhouse wastewater effluents were used: G1 was treated with NaClO only at 0, 2, 4, and 6 mg/L; G2 was treated with exposure to MF at 14,500 gausses, and G3 was pretreated with MF, then NaClO at the exact chlorine dosages and MF strength. The results showed an augmented effect when using a magnetic field as a pre-treatment step before NaClO treatment in the remediation of slaughterhouse wastewater over the use of any of them solely. The removal rate of COD and BOD increased by up to 26 and 20%, respectively, when pre-treatment with MF was employed as a mean percentage at all chlorine dosages, while TSS, TDS, and EC increased by 23.5 and 5.5%, respectively. Over and above, the removal rate for each TN and TP increased by 12 and 6.5% as a mean percentage at all chlorine dosages when using a combination of the two. In addition, pre-treatment by MF reduced the required concentration of NaClO from 6 to 4 mg/L, resulting in an 11% increase in the reduction rate of total coliform count, 8% increase in the reduction rate of fecal coliforms, and 10% increase in the reduction rate of *E. coli* and 5% in *Salmonella* via increasing the disinfection efficiency of NaClO. Finally, it decreased the concentration of Chloroform produced by more than 77.2% by using the higher concentration of NaClO (6 mg/L). The issue that approved the promising approach of using MF as a pre-treatment step in the treatment of slaughterhouse wastewater provides the advantage of using smaller dosages of disinfection, lowering the cost of the procedure process, and reducing the harmful concentration of DBPs.

Keywords: wastewater; magnetic field; NaClO; indicator microorganisms; DBPs

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1. Introduction

Environmental pollution is considered one of the most significant problems that the world faces nowadays. One of the primary sources of polluting the environment is the wastewater produced by human activities [1]. Slaughterhouses and Meat Processing Plants (MPPs) are part of a large industry worldwide that uses approximately 62.0 million cubic meters of water annually. A small volume of this amount is a component of the final meat products, while wastewater's most significant volume [2].

Throughout the slaughtering process, significant amounts of wastewater are generated with blood, rumen contents, and contaminants from equipment and hall washing, which seriously pollute surface water, groundwater, and agricultural lands by discharging into the environment [3]. Many human pathogens can be transmitted by water contaminated with wastewater runoffs. Slaughterhouse wastewater effluents enclose many pathogens that could harm humans [4], such as *Salmonella, Shigella,* and *Brucella* [5]. At the same time, the presence of coliform bacteria in the digestive tract of livestock and poultry is harmless; their presence in water contaminates it and causes the possible presence of other pathogens [6]. Disinfection is critical for wastewater treatment before discharge into receiving waters, preventing pathogenic microorganisms and waterborne disease transmission [7]. Chlorine, ozone (O_3), and ultraviolet (UV) from the most common disinfectants used for wastewater disinfection. Chlorination is the most widely used disinfection method [8]. Well-established application practices, low cost, high disinfection efficiency, and long-lasting disinfection effect from the most common advantages of chlorine disinfectant [7]. However, the reaction of chlorine with organic/inorganic matter leads to the formation of mutagenic/carcinogenic and toxic by-products (DBPs) that are potentially harmful to human and aquatic organisms [9,10]. Secondary wastewater effluents are composed of a mixture of natural organic matters, synthetic organic compounds, and bromide at substantially high concentrations [11]. Upon reaction with chlorine form more species of DBPs in higher concentrations. The most effective approach in the reduction of disinfection by-products is reducing the applied dosage of disinfectant, were at the same time assures the disinfection efficiency; thus, pre-treatment or combined disinfection with physical disinfectant is a promising way to achieve this goal. In recent decades, MF has shown great potential in medical, industrial, and environmental applications. Using MF in wastewater treatment is one of the promising research topics with significant progression, particularly after using magnetic fields in ecological engineering to improve processing systems or processes [12]. MF has been employed in wastewater treatment to remove colors, heavy metals, suspended solids and turbidity, organic compounds, and hazardous substances [13]. Previous studies have established the remarkable efficacy of MFs at enhancing the physical features of solid-liquid separation by encouraging colloidal particle aggregation and the physical qualities of wastewater treatment by increasing bacterial activity [14]. Much research on the effects of MFs on microorganisms, their viability, and metabolism has already been published in the literature [15]. Magnetic fields affect Gram-positive and gram-negative bacteria's cell wall transport mechanisms differently [16]. Johan-Sohaili et al. [17] explained the great potential of magnetic technology in sewage treatment by enhancing the separation of suspended particles. MFs usage showed significant advantages over conventional wastewater treatment, including safety, compatibility, simplicity, environmentally friendliness, and low operating cost [18]. To the best of the authors' knowledge using magnetic field as a disinfection pretreatment step as an environmentally friendly, and low-cost approach has not been investigated previously. Therefore, this study aimed to assess the efficacy of using MF and/ or NaClO disinfectant on the physicochemical quality of secondary effluents of slaughterhouse wastewater pretreated with zeolite and rice straw. This is in addition to their efficacy on the microbiological quality of wastewater effluents and inactivation of the key waste water indicator microorganisms *Escherichia coli* and *Sallmonella*. Furthermore, their impact on the formation of the critical disinfection by-products, THMs.

2. Materials and Methods

2.1. Material

2.1.1. Wastewater Characterization

Wastewater samples were obtained from Kafrelshiekh slaughterhouse located in the Kafrelshiekh governorate (31_6022.7520 0 N, and longitude of 30_56031.110 0 E), Egypt, and treated by sedimentation to remove suspended solids; then coagulation using 1000 mg/L natural zeolite [19] for removal of suspended and dissolved solids and decreasing COD and BOD. Finally, it was filtrated using a physically activated rice straw [19]. The character of the obtained treated slaughterhouse wastewater (SHWW) used in this study is illustrated in Table 1.

Table 1. Characteristics of the SHWW under examination in the experiment.

Parameters	Treated SHWW (Mean Values)
pH	7.59
BOD (mg/L)	480
COD (mg/L)	1600
TSS (mg/L)	661
TP (mg/L)	10.6
TN (mg/L)	441
EC (ds/m)	2.72
TDS (mg/L)	1350
TCC (cfu/100 mL)	16875
FCC (cfu /100 mL)	8675
E coli (cfu /100 mL)	4850
Salmonella (cfu/100 mL)	10,500

2.1.2. Magnetic Field

Delta Magnetic water device of 14,500 Gauss magnet (Delta water company/80/8000, Egypt) was used (Figure 1). Device specifications: Diameter size:1 inch; Flow rate 12 m^3/h, Connection: Thread connection; Material: Stainless steel; Packing Box Dimension: 11 × 11 × 85 cm; Device weight: 6 kg; Temperature (up to):80 °C; Pressure (Up to): 7 bar.

Figure 1. Delta water magnetic device.

2.1.3. Sodium Hypochlorite

A commercial stock solution of NaClO was used with available chlorine 12% *w*/*v* and pH of 11.5–13 (Advent, CHEMBIO PVT.LTD, India) and prepared at different chlorine dosages (2, 4, and 6 mg/L). Where all the mentioned NaClO dosages are denoted, the mean available chlorine contents.

2.2. Methods

Study Design for SHWW Disinfection

The experiment was conducted at three aligned scenarios on slaughterhouse wastewater effluent to investigate the efficiency of using either (1) NaClO disinfectant alone, (2) MF using Delta Magnetic water device alone, or (3) MF using Delta Magnetic water device as a pre-treatment step and immediately after pre-treatment, NaClO was added as summarized in Figure 2.

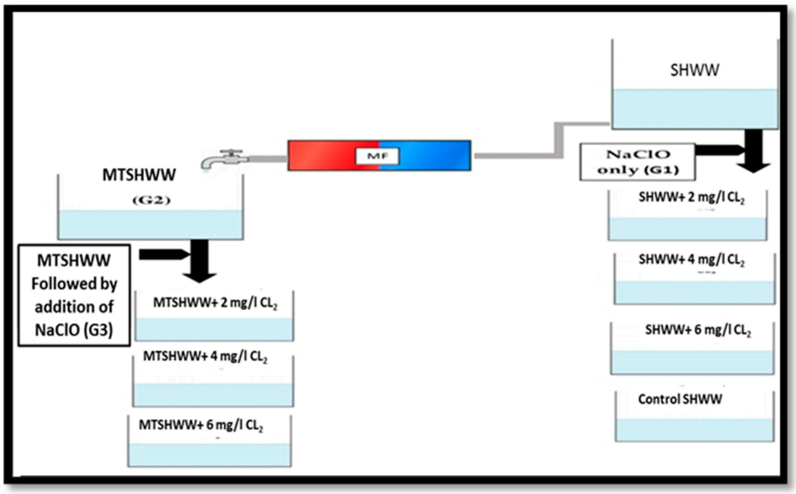

Figure 2. Study design: SHWW; slaughterhouse wastewater treated previously by sedimentation followed by coagulation using natural zeolite (1000 mg), then filtration through physically treated rice straw [19]. Different disinfection methods achieved treatment; G_I) 0, 2, 4, and 6 mg/L active chlorine; disinfection with 12% (*w*/*v*) commercial NaClO; G_2) MF: disinfection with magnetic field producing magnetically treated slaughterhouse wastewater (MTSHWW) and G_3) was pretreated with MF then NaClO at the exact chlorine dosages and MF strength.

Firstly, four containers of 10-L capacity were used with three replicates filled with SHWW effluent and treated with a commercial stock solution of NaClO 12% (*w*/*v*) available chlorine to reach a final concentration of 0, 2, 4, and 6 mg/L available chlorine [20], where the first one kept as control. With continuous stirring for 1 h contact time (Figure 1). To test the efficacy of the magnetic field as a pre-treatment step in the treatment of SHWW, a water container made from plastic fiber with a capacity of 20 L was used and filled with 15 L of SHWW. The influent of SHWW was directed through the magnetic device by installing the water container containing SHWW at a higher level than the magnetic device, which permits water flow by gravity, giving a flow rate of 66 mL/s that achieved 4 min exposure period between the influent and magnetic field (nonstandard). This model is constructed to project a perpendicular magnetic field into the SHWW flow. The magnetically effluent was collected at the end of the device and managed on a storage tank, repeated three times for sampling collection (Figure 1).

Finally, to test the efficacy of the magnetic field as a pre-treatment step of SHWW, four wastewater samples with three replicates were allowed to pass through the magnetic field under the exact circumstances of the previous step (Figure 1) and then immediately treated with NaClO as mentioned in the first step. Wastewater samples were taken before and after each step.

All of the disinfection studies above were stirred for three minutes to ensure the even distribution of disinfectants. The experimental set-up was left alone for 1 h as a contact time.

2.3. Analytical Methods

All these treatments were investigated for their impacts on the quality of secondary effluent of slaughterhouse wastewater by studying its influence on (1) Organics degradation

(COD, BOD); (2) Solids removal (TSS, TDS, and EC); (3) Nutrients contents (TN and TP); (4) Microbial load for detection of the critical indicator microorganisms, (TCC, FCC, *Salmonella*, and *E.Coli).* Finally, (5) DBPs, mainly Chloroform. The methods used to measure pH, COD, BOD, TSS, EC, TDS, TP, TN, TCC, FCC, Salmonella, E. Coli, and detection of DBPs are illustrated in Table 2.

Table 2. Analytical methods.

Parameter	Method
pH	Standard method 4500-H+ pH value
COD	Standard method 5220
BOD	Standard method 5210
TSS	Standard Method 2540D
TP	Standard method 4500-P
TN	Standard method 4500-N
EC	Standard method 2510
TDS	Standard method 2540A
TCC	Standard method 9222 A
FC	Standard method 9222 A
E coli	Standard method 9222A
Salmonella	Standard method 9260
DBPs (Chloroform, $CHCl_3$)	Standard method 5710

2.4. Statistical Analyses

The treated (SWW) were subjected to a comprehensive analysis, as described in the previous section, to establish the treatment removal efficiency for organics, solids, nutrients, and microbial load via the following equation:

Removal efficiency Ci% = [$\underline{Ci - Cf}$] × 100

Ci and Cf are the initial and final concentrations of the measured parameters, respectively.

3. Result

3.1. Effect of MF and/or NaClO Disinfectant on Organic Degradation and Solids Removal of Secondary Effluent of Slaughterhouse Wastewater

3.1.1. Effect of NaClO Only as a Disinfectant

Figures 3 and 4 show that adding NaClO could reduce COD, BOD, TSS, TDS, and EC concentrations at secondary slaughterhouse wastewater pretreated by zeolite and rice straw. Where NaClO dosage of 2 mg/L CL_2 recorded removal % of COD, BOD, TSS, TDS, and EC by 19.4, 20, 36.46, 16.1, and 16.9, respectively. On the other hand, 4 mg/L CL_2 dosages recorded removal % of COD, BOD, TSS, TDS, and EC by 35.4, 36, 51.59, 20.7, and 21.3. respectively. While the removal % recorded for 6 mg/L CL_2 of COD, BOD, TSS, TDS, and EC were 48.3, 48.8, 62.2, 21, and 21.7, respectively.

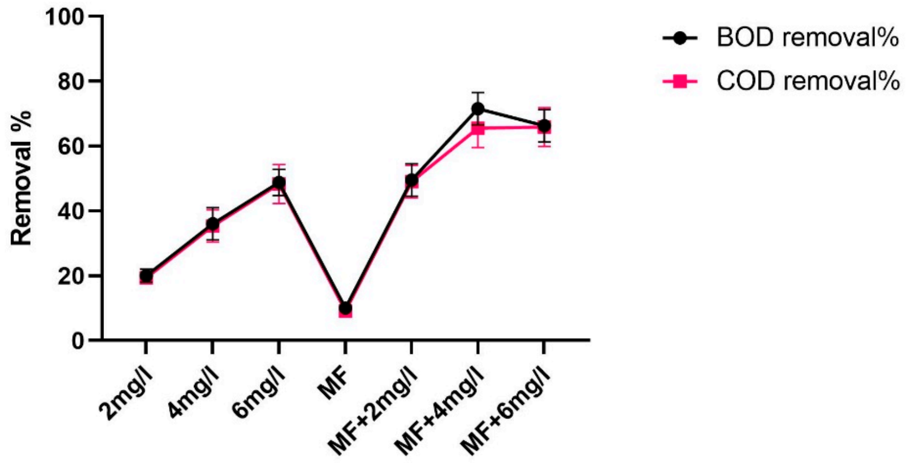

Figure 3. Organics removal % of secondary effluents of SHWW treated by different disinfection methods; (l) 2, 4, and 6 mg/L active chlorine; Disinfection with 12% (w/v) commercial NaClO (2) disinfection with magnetic field; and (3) MF+ 2 mg/L, MF+ 4 mg/L, and MF+ 6 mg/L; pretreatment with magnetic field then disinfection with NaClO.

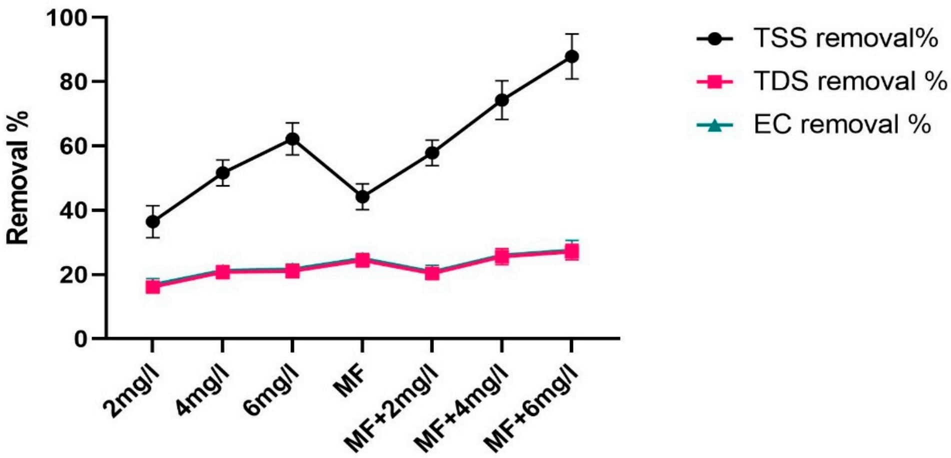

Figure 4. Solids removal % of secondary effluents of SHWW treated by different disinfection methods; (l) 2, 4, and 6 mg/L active chlorine; Disinfection with 12% (w/v) commercial NaClO (2) MF: disinfection with magnetic field; and (3) MF + 2 mg/L, MF + 4 mg/L, and MF + 6 mg/L; pretreatment with magnetic field then disinfection with NaClO.

3.1.2. Effect of MF

Figures 3 and 4 showed that secondary effluent slaughterhouse wastewater exposed to MF showed removal % of COD, BOD, TSS, TDS, and EC concentrations 10, 9.12, 44.2, 24.4, and 25, respectively.

3.1.3. Effect of Pre-Treatment with MF Followed by NaClO Addition

Figures 3 and 4 presented that secondary slaughterhouse wastewater pretreated with a magnetic field followed by NaClO addition showed amplified removal % of COD, BOD, TSS, TDS, and EC concentrations. At NaClO dosage of 2 mg/L CL_2 the removal % of the previous parameters increased to 30, 29.5, 21.5, 4.2, and 4%, respectively. This is in addition to the increased removal rate was 30.1, 13.5, 22.5, 5.2, and 5%, respectively, at CL_2 dosage of 4 mg/L. Finally, CL_2 dosage of 6 mg/L recorded increased removal % of 17.6, 17.5, 25.7, 6, and 6%, respectively.

3.2. Effect of MF and/or NaClO Disinfectant on Nutrients Load (TP, TN) of Secondary Effluents of Slaughterhouse Wastewater

3.2.1. Effect of NaClO Only as a Disinfectant

Figure 5 shows that adding NaClO could reduce TP and TN concentrations at secondary slaughterhouse wastewater pretreated by zeolite and rice straw. NaClO dosage of 2 mg/L CL_2 recorded removal % of TP and TN by 32.6 and 63.5, respectively. On the other hand, 4 mg/L CL_2 dosages recorded removal % of TP and TN at 40.6 and 85.1, respectively. While the removal % recorded for 6 mg/L CL_2 of TP and TN were 44.2 and 85.7, respectively.

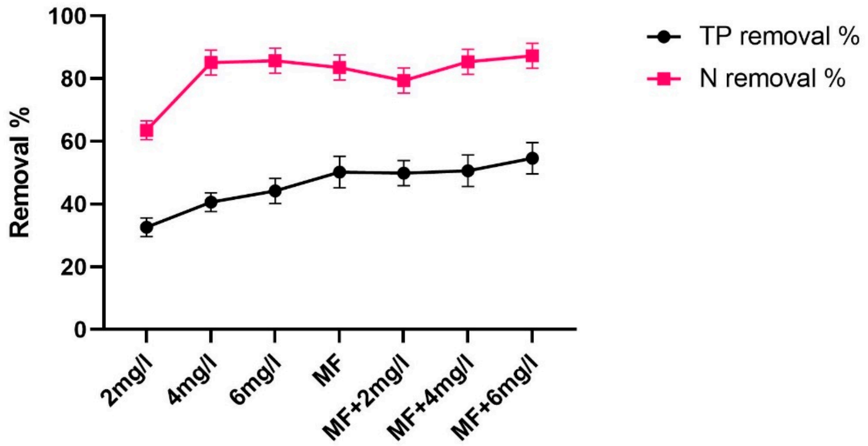

Figure 5. Nutrients removal % of secondary effluents of SHWW treated by different disinfection methods; (l) 2, 4, and 6 mg/L active chlorine; Disinfection with 12% (*w*/*v*) commercial NaClO (2) MF: disinfection with magnetic field; and (3) MF + 2 mg/L, MF + 4 mg/L, and MF + 6 mg/L; pretreatment with magnetic field then disinfection with NaClO.

3.2.2. Effect of MF

Figure 5 shows that secondary effluent of slaughterhouse wastewater exposed to the MF showed removal % of TP and TN concentrations of 50.2 and 83.5, respectively.

3.2.3. Effect of Pre-Treatment with MF Followed by NaClO Addition

Figure 5 shows that secondary slaughterhouse wastewater pretreated with magnetic field observed by NaClO addition showed removal % of TP and TN concentrations at NaClO dosage of 2 mg/ L CL_2 49.9 and 79.4, respectively. On the other hand, four mg/L CL_2 dosages recorded removal % of TP and TN at 50.6 and 85.4, respectively. At the same time, the removal % recorded at 6mg/L CL_2 for TP and TN was 54.6 and 87.3, respectively.

The findings declared increased TP and TN removal rates by 16.3 and 16%, respectively, at two mg/L CL_2 dosages. In addition, increased removal rate of TP and TN by 10 and 0.5%, respectively, at four mg/L CL_2 dosages. Finally, TP and TN increased the removal rate by 10 and 3% at six mg/L CL_2 dosages. The highest verified removal % was recorded for a CL_2 dosage of 6 mg/L. The results declare the same trend of a magnified effect of using a magnetic field as a pre-treatment step before NaClO application in the remediation of slaughterhouse wastewater over the single use of each of them.

3.3. Effect of MF and/or NaClO Disinfectant on Microbial Load of Secondary Effluents of Slaughterhouse Wastewater

3.3.1. Effect of NaClO Only as a Disinfectant

Results in Figure 6 explain that secondary effluents of slaughterhouse wastewater showed removal % for TCC, FC, *E-coli*, and *Salmonella* at a two mg/L NaClO were 38.1, 32.2, 31.7, and 53.8, respectively. Additionally, 35.5, 33.7, 32.9 and 54.8 % at 4 mg/L NaClO for TCC, FC, *E-coli* and *Salmonella* respectively. Finally, were 40, 35, 35.6 and 57.14 % at 6 mg/L NaClO for TCC, FC, *E-coli* and *Salmonella*, respectively.

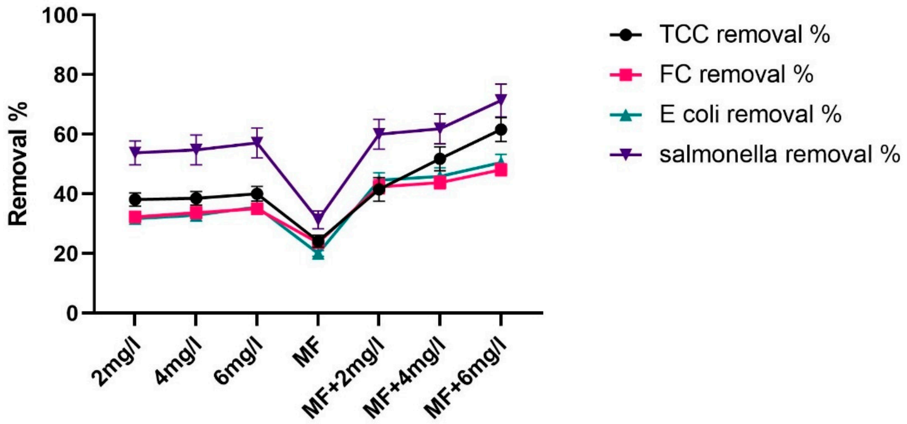

Figure 6. Microbial removal efficiencies of secondary effluents of SHWW treated by different disinfection methods; (l) 2, 4, and 6 mg/L active chlorine; Disinfection with 12% (*w*/*v*) commercial NaClO (2) MF: disinfection with magnetic field; and (3) MF + 2 mg/L, MF + 4 mg/L, and MF + 6 mg/L; pretreatment with magnetic field then disinfection with NaClO.

3.3.2. Effect of MF

Figure 6 shows the effect of MF treatment for secondary effluents of slaughterhouse wastewater on the removal % of TCC, FC, *E-coli*, and *Salmonella,* which recorded 24.1, 23.6, 20 and 31.3%, respectively.

3.3.3. Effect of Pre-Treatment with MF Followed by NaClO Addition

Figure 6 showed that pre-treatment with MF followed by NaClO addition could remove TCC, FC, *E-coli*, and *Salmonella* by 41.5, 42.4, 44.6, and 60%, respectively, at a NaClO dosage of 2 mg/L. Furthermore, 51.8, 43.8, 45.9, and 61.9%, respectively, were removed at a NaClO dosage of 4 mg/L. In addition, 61.6, 48.1, 50.5 and 71.4 were removed, respectively at 6 mg/L NaClO dosage.

The presented results declared increased disinfection performance at all used dosages based on TCC, FC, *E-coli* and *Salmonella* removal percentages.

3.4. Effect of MF and/or NaClO Disinfectant on the Formation of the Key Disinfection by-Products THMs

3.4.1. Effect of NaClO Only as a Disinfectant

Figure 7 shows that the values of DBPs, mainly Chloroform, were 6.7, 5.6, and 26.8 at a dosage of 2, 4, and 6 mg/L NaClO.

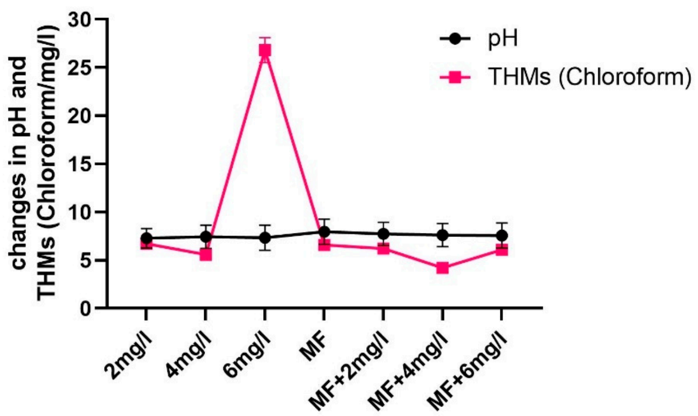

Figure 7. The level of disinfection by-products THMS (Chloroform) mg/L by different disinfection methods; (l) 2, 4, and 6 mg/L active chlorine; Disinfection with 12% (*w*/*v*) commercial NaClO (2) MF: disinfection with magnetic field; and (3) MF + 2 mg/L, MF + 4 mg/L, and MF + 6 mg/L; pretreatment with magnetic field then disinfection with NaClO.

3.4.2. Effect of Pre-Treatment with MF Followed by NaClO Addition

Figure 7 recorded DBPs, particularly Chloroform of secondary slaughterhouse wastewater exposed to MF as a pre-treatment step, were 6.2, 4.2, and 6.1 mg/L at 2, 4, and 6 mg/L NaClO dosage, respectively.

4. Discussion

We found that adding NaClO could reduce COD, BOD, TSS, TDS, and EC concentrations at secondary slaughterhouse wastewater pretreated by zeolite and rice straw. Those findings are possible due to the organic compound oxidation process, which takes place quickly with the addition of Cl_2 compound in the wastewater [21]. The expressed results in Figures 3 and 4 explained that the organic compound degradation of slaughterhouse wastewater negatively correlated with the applied Cl_2 dosage. The results are in harmony with a previous study [22], which reported a decrease in COD concentrations in industrial wastewater effluent from 356 mg/L to 247 mg/L by increasing the hypochlorite Cl_2 dosage from 60 mg/L Cl_2 to 300 mg/L Cl_2. The dosage of 6 mg/L Cl_2 gave the best record for declining the most examined physicochemical parameters of slaughterhouse wastewater. The results were consistent with Mulyani et al. [23], who recorded a decrease in COD concentration from 7933.333 mg/L at Cl_2 dose 2 mg/L to 3483.333 mg/L at Cl_2 dose 6 mg/L.

In addition, the removal of the organic achieved by NaClO TSS (often specified as turbidity) reduction is also reported by using a different dosage of hypochlorite where it behaved in the same manner of decreasing values with increasing hypochlorite concentration. The results are in the same line as those [24]. Zerva et al. [25] showed that the full-scale wastewater treatment plant's BOD and COD removal efficiencies exceeded 89%. As well as, the TSS showed a sharp decrease in the effluent, reaching 93.8 %, an issue that indicates biosolids removal.

The ability of a solution to conduct electric current is defined as electrical conductivity (EC), which is highly reliant on the availability of ionic species (Julian et al., 2016). A high EC in wastewater indicates a high concentration of total dissolved solids. The total dissolved solids (TDS) concentration is directly proportional to the EC.

The TDS and EC removal percent at secondary slaughterhouse wastewater effluent employing NaClO decreased as the dosage of NaClO was used as an oxidizing agent. The results that in harmony with those results given by Vasanth et al. [26]. The results could be explained based on the previous findings of removing the organic achieved by NaClO and TSS (often specified as turbidity). TDS is a measure of inorganic salts, organic matter, and other dissolved components in water [27].

The findings are consistent with those of the initial research that revealed the remarkable efficiency of MFs as adjunctive or alternative to traditional wastewater treatment [18]. The results declared that MF treatment achieved the highest removal rate for TSS. Basavaiah [28] demonstrated that an appropriate MF could strengthen coagulation and the biodegradation of organic compounds of the activated sludge. Under specific circumstances, it considers one factor determining pollutant removal's efficacy. Wahid et al. [29] demonstrated that a magnetic field could increase the removal of suspended solids by 41 to 49% at 670 Gauss compared to untreated raw sewage. The removal rate of suspended solids could improve as magnetic field strength and exposure time increased, and flow rate decreased. Wahid et al. [29] explained the issue based on extra energy produced due to the exposure to a magnetic field where the charged particles will vibrate excessively due to this energy. As a result, more particles collide with one another. This reaction produces more ions (positive and negative charge), resulting in a natural magnetic attraction between the oppositely charged particles. This situation exaggerates the coagulation that facilitates the flocculation and perception of collides when they become denser. However, the recorded removal rate of suspended solids may be lower than those demonstrated in those results due to differences in the type and characteristics of wastewater and the strength of the magnetic field.

The enhancement effect of using a magnetic field as a pre-treatment step before adding NaClO in the remediation of slaughterhouse wastewater over the single use of each of them at each Cl_2 concentration. The finding in the same line of [18] demonstrated that the magnetic-based wastewater treated (WWT) system treated sewage containing 0.2 g/L COD, removing 72–94% COD with a retention time of 8 h. As well as intensifying organic compound (COD) removal from domestic wastes [30]. In addition, the issue that may be attributed to the PH effect is MF exposed wastewater showed a higher PH value which has proven that high PH contributes to increasing (SBR) Sequencing Batch Reactor ability, especially in COD removal [31]. The biodegradability of wastewater is usually shown by increasing the BOD/COD ratio and the increasing pH [23]. NaClO reduces TP and TN in slaughterhouse effluent cleaned with zeolite and rice. The results are in harmony with those obtained by Collivignarelli et al. [20], who reported removal% of urban wastewater TN and TP via disinfection at (65 and 77%, respectively).

Krzemieniewski et al. [30] demonstrated the possibility of an MF influencing phosphorus removal from domestic wastes intensifying. Tomska and Wolny [32] also showed that exposing activated sludge systems to MFs improved the nitrogen compounds transformations in the system compared with the system without MF treatment. The same trend was observed by Geng et al. [12], who demonstrated that magnetic fields improved the ability of the activated sludge to remove TN, and TP by 15.2 and 4.3%, respectively, at 70 mT compared with that of the reactor with no magnetic field. Nevertheless, those recorded results are lower than the removal % recorded in this study. The issue may be attributed to the different wastewater characteristics and higher magnetic field strength (1450 mT).

At two mg/L Cl_2, TP and TN removal rates increased by 16.3 and 16%. At 4 mg/L Cl_2, TP and TN removal rates rose by 10% and 0.5%. TP and TN elimination rates rose 10% and 3% at 6 mg/L Cl_2. The results declare the same trend of a magnified effect of using a magnetic field as a pre-treatment step before NaClO application in the remediation of slaughterhouse wastewater over the single-use of each of them. The highest verified removal % was recorded for a Cl_2 dosage of 6 mg/L. The outcomes may be attributed to the magnetic field's intensifying effect in removing TP and TN. The results in the same harmony with those given by Liu et al. [33], who demonstrated that an anaerobic TN elimination in synthetic sewage with a lab-cultivated anammox microbial population increased up to 50% at 75 mT. Similarly, synthetic sewage with municipal sludge was raised at 48 mT, with higher proliferation and activity of nitrite-oxidizing bacteria [34].

Disinfection is among the essential steps in wastewater treatment before discharge into receiving waters. Disinfection reduces the number of pathogens to a manageable level, preventing the spread of waterborne disease [7].

The explained results approved that chlorination of wastewater effluents is a well-established technology and effective against a wide range of pathogenic microorganisms [35] where the significant oxidizing capability of NaClO affects bacterial cell membrane structure, protein functionality, and DNA [36]. The obtained results demonstrated increasing the bactericidal effect of NaClO by increasing the applied dose. The results are in harmony with those given by Johansson [37], who showed that NaClO has different disinfection effects on different types of indicator organisms depending on the dose of the disinfectant. Du et al. [38] also approved that chlorinated effluents of MBR in municipal wastewater treated with NaClO at a dosage of 3 mg/L showed a higher inhibition rate (48%) for indicator organisms than the control. The NaClO disinfectant products irreversibly kill bacterial cells by denaturing proteins in the biofilm matrix and inhibiting primary enzymatic functions in bacterial cells [39].

Concerning previous results, it could elucidate the promising abilities of MF for enhancing water and wastewater quality. The issue explained in the literature about the apparent impacts of MF on microorganisms, their viability and metabolism depending on strength and type of MF (static, pulsating), and length of exposure [15]. For example, exposure to a pulsing (50 Hz) MF with a strength of 10 mT reduced the growth of Escherichia coli, Leclercia adecarboxylata, and Staphylococcus aureus [40]. As well as, Filipic et al. [41]

demonstrated the growth of *E. coli* and *Pseudomonas putida*, during exposure to static MF (17 mT) at their ideal development temperature (28 and 37) °C was suppressed in municipal wastewater treatment facilities.

The results showed that the pre-treatment magnetic field could have a synergistic disinfection effect. MF could produce multiple products, firstly antimicrobial and antibacterial properties of different frequency bands of MF spectrum, which resemble ultraviolet (UV) radiation [42], which helps kill microorganisms. Secondly, the role of MFs in removing suspended solids from sewage. Accelerating sludge settling and rising sludge density and sedimentation rate are the fundamental mechanisms of MF action for enhancing broken solids removal [18]. Accordingly, more particles associated with bacteria were exposed to NaClO. The results that in harmony with those given by Burgess et al. [43], who found that magnetically treated swimming pool water showed increasing in the *E. coli* killing rate for a given disinfectant dose by 25% as a result of improved chlorine solubility. Furthermore, the findings showed that MF pre-treatment could reduce the necessary amount of NaClO from 6 to 4 mg/L, resulting in a 12% increase in the reduction rate in total coliform count, 9% increase in the reduction rate of fecal coliforms, and 10% reduction in *E. coli* and 5% in *Salmonella* via increasing the disinfection efficiency of NaClO.

DBPs values (trichloromethane)(THMs) mainly, Chloroform was 6.7, 5.6, and 26.8 at a 2, 4, 6 mg/L NaClO dosage. However, the high disinfecting power of chlorine, its reaction with organic/inorganic matter forms toxic disinfection by-products (DBPs) [44]. The main THM created by HOCl is Chloroform ($CHCl_3$). Chloroform is among the most studied DBPs due to its dominance [45]. The reaction of chlorine with humic compounds [46], triclosan [47], citric acid [48], and resorcinol [49] has been studied for the formation of Chloroform. When they contact chlorine species, aldehydes and ketones are converted to Chloroform by a base-catalyzed reaction pattern [50].

The results demonstrated an increase in Chloroform concentration with increasing NaClO formation. The results may be explained based on the pH change at different NaClO doses. Özbelge [49] indicated that as pH decreases, chloroform formation reduces.

A higher concentration of NaClO (6 mg/L) was found to reduce the concentration of Chloroform produced by more than 77.2%, which provides the advantage of using the most efficient dose of NaClO in the degradation of various chemical compounds and microbial contaminates without increasing the formation of DBPs.

The results are inconsistent with Sun et al. [51]. They reported using combination methods of disinfection such as using oxidants such as H_2O_2, O_3, Cl_2, ClO_2, and metal oxides along with UV light have been used for various disinfection.

Decontamination applications, as well as Burgess et al. [43] found that swimming pool water that was magnetically treated showed to some extent, reduced chloroform generation.

5. Conclusions

This study proves that using MF as a pre-treatment approach before the addition of NaClO in the treatment of secondary effluents of slaughterhouse wastewater is a promising technique in treating wastewater. Where represented a high efficiency in treating secondary effluents of slaughterhouse wastewater achieving high potency of COD, BOD, TSS, TDS and EC removal rate. As well as a decline of nutrient-rich effluents TP and TN. In addition, high efficiency at microbial inactivation was achieved firstly due to antimicrobial and antibacterial properties of different frequency bands of MF spectrum, which resemble ultraviolet (UV) radiation. Secondly, the role of MF in removing suspended solids from wastewater is most likely owing to the suspended particles' shielding effect, which protects bacteria from the effects of the disinfectant agents. The findings approved that this approach could reduce the necessary dose of NaClO from 6 to 4 mg/L, resulting in an 11% increase in the reduction rate of total coliform count, 8% increase in the reduction rate of fecal coliforms, and a 10% increase the reduction rate of E. coli and 5% in Salmonella via increasing the disinfection. Finally, decreasing the concentration of Chloroform produced by more than 77.2% by using the higher concentration of NaClO (6 mg/L) give the advantage of using the most efficient dose of NaClO in the degradation of various chemical compounds and microbial contaminates without increasing of DBPs. The synergetic effect of MF and NaClO, wastewater treatment technique is a critical attitude that should be examined further because it has the potential to ensure a higher level of global disinfection efficiency, even when using smaller dosages of disinfection, potentially lowering the cost of the procedure process and reducing the harmful concentration of DBPs.

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Nomenclature

BOD	Biological oxygen demand
COD	Chemical oxygen demand
DBPs	Disinfection by-products
EC	Electrical conductivity
FC	Fecal coliform
MF	Magnetic field
MPPs	Meat Processing Plants
NaClO	Sodium hypochlorite
SHWW	Slaughterhouse wastewater
TCC	Total coliform
TDS	Total dissolved solids
THMs	Trihalomethane
TN	Total nitrogen
TP	Total phosphorus
TSS	Total suspended solids

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