Treatment of the Industrial Wastewater by Chemical Coagulation Followed by Biological Process

Sofyan Al-Dulaimi, Gabriel Racoviteanu

Abstract— **In this study the effect of the chemical treatment by Coagulation-Flocculation process followed by biological process by MBBR system on the industrial wastewater, generated from a local meat processing wastewater in Bucharest-Romania was evaluated. Ferric chloride was applied on high and low strength effluents as a chemical coagulant at different doses using a bench-scale device (Jar-test apparatus); after that they were subjected to the biological treatment. Moving bed biofilm reactor (MBBR) with capacity of 13.7-liter was constructed and operated at a different organic load and at different hydraulic retention time (HRT). Results indicate that the chemical coagulation can be useful pre-treatment option for the meat processing effluents, in addition to that results indicted the overall treatment process is an effective treatment process to produce high effluents quality that can be re-used in several application.**

Index Terms— **Meat processing industry, Coagulation-flocculation, Ferric chloride, MBBR.**

I. INTRODUCTION

Production processes and industrial activities are often accompanied by releasing of various types of waste, which are usually harmful to the environment and may pose a threat to human life. After a series of serious environmental events following the Industrial Revolution, industrial waste treatment in most countries has become obligatory to many industrial activities and the disposal or discharges of these wastes has become subject to a range of environmental laws and regulations and with the Industrial progress and with the increase in the pollution rates, the environmental legislation have become stricter with respect to the release of industrial waste into the surrounding environment. Industrial effluents are extremely diverse in their nature, toxicity, and treatability, and usually, require pre-treatment before being discharged to water bodies or to the sewer.

Effluents from industries vary so greatly in both flow and pollution strength. Therefore, it is impossible to assign fixed values to their constituents, and the food industries are not an exemption, which their effluents properties vary according to the production processes and the products type. However, in general, they are characterized by their high organic content and high consumption of water whether for the purpose productions, cooking, cooling, cleaning, sanitizing, and materials transport, among others [1, 2]. The meat industry is one of the vital branch sectors of the food industry, and which the most common in many countries. The effluents of the meat industry are one of the major environmental concerns of such industry, which have a great effect on the environment and often producing high polluted wastewater [3]. Meat industry effluents are heavily contaminated by several organic compounds including carbohydrates, proteins, fats, organic acids. Macromolecules of the protein roll up into compact globules, which have a hydrated coating, and often acquire a negative charge [4].

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There are various treatments that can be applied to treat wastewater produced by such industries. In this study, the effect of chemical treatment by coagulation-flocculation process followed by biological treatment through the MBBR technology was evaluated.

Coagulation-flocculation process is extensively used in water and wastewater treatment and intended to encourages particles contained in the waste/water to join together and forming small aggregates called "Flocs", which are insoluble material and more likely to settle or to be trapped in the filter. Coagulation-flocculation is a complex process, where its mechanism involving destabilization of suspended colloidal and dissolved contaminants in water by the addition of metallic salts which have an electrical charge, the destabilization of the contaminants brings them into contact with one another so that aggregation occurs, so they can easily be removed by subsequent processes. The main source of the stability of the particles is in the presence of an electrically charged layer on the surface of each particle [5, 6].

Inorganic salt such as Aluminum sulfate (Alum) ($Al_2 (SO_4)_3.18H_2O$), ferric chloride ($FeCl_3$ $6H_2O$), ferric sulfate and ferrous sulfate $FeSO_4.7H_2O$, are the most common coagulants used in the chemical treatment [7]. Iron salts usually operate over a broader range of pH than alum and also more effective in removing color from water [8]. The jar test device usually used to determine the optimal values for each coagulant of the dose amount, pH value, and others. Aluminum Sulfate has been used and still is used as the main coagulant for water treatment process. Ferric Chloride showed it is an effective chemical for the destabilization of particles, removal of dissolved organic matter, in many studies The Basic stoichiometric reactions that occurring during the chemical coagulation process for ferric chloride and are giving below:

$$FeCl_3.6H_2O + 3(HCO_3^-) \rightarrow Fe(OH)_{3,am\downarrow} + 3Cl^- + 6H_2O + 3C0_2$$

The aerobic biological treatment is one of the most common treatments used in the treatment of domestic wastewater or the industrial wastewater, which depends on a wide variety of microorganisms, primarily bacteria. These microorganisms (also called aerobes), convert biodegradable organic substance contained in wastewater in the presence of oxygen into simple substances and additional biomass. There are two main categories of the biological process, suspended growth, and attached growth processes, in the second one the microorganisms grow attached to a solid support medium, on the other hand, there are two basic designs of attached growth process fixed film system, or those systems where the media is in motion relative to the wastewater [9, 10].

In recent years, more attention has been given to the applications associated with the attached growth systems in industrial wastewater treatment [11]. The attached growth processes have advantages over the activated sludge process such as lower energy requirements, simpler operation, no sludge bulking problems, requires less maintenance, and better recovery from shock loads [12]. Moving bed biofilm reactor (MBBR) is one of the attached growth processes which were developed by the Norwegian scientists during the late 1980s and early 1990s [13]. The MBBR system is a completely mixed, continuously operated system in which the biomass is grown on small carrier elements that have a little lighter density than water density (0.93-0.95 SG) which provide a large protected surface area for bacteria culture and they are kept in random movement usually by air diffuser system or by the movement of water stream by mixers in an anoxic basin during denitrification process [14, 15].

In many cases, there is a need to combine more than one treatment process to achieve a high level of the removal rates of contaminants and to obtain a high quality of the treated wastewater for reuse or disposal directly to the water bodies. As well, the need to combine treatment processes may be necessary for the highly polluted effluents or which containing concentrations of disinfectants and sanitizers. In general, the cleaning products are widely used in the production process in the food industry. The purpose of cleaning and sanitizing process is to remove nutrients that required for bacteria growth, and to kill those bacteria that are present. In the present study, organic load reduction and reduce the effect of these inhibitors on the biological process as well as obtain reusable effluents was the targeted, thus a physicochemical treatment was added before the biological treatment for that purpose.

II. MATERIALS AND METHODS

The experimental work was divided into two segments. The first consisted of performing coagulation-flocculation laboratory tests using Jar test device in order to select the optimum dose of the coagulant for optimum reduction of the pollutants present in the influent, as well to determine the optimum pH of the chemical coagulant. The second segment was conducted by using a pilot plant represented of MBBR system to study the effect of the combination of the physicochemical and biological treatment process on the meat processing effluents.

A. Jar test

A standardized jar testing procedure [16], using automated jar test apparatus (Flocculator-2000 Kemira kemwater) in six glass cylindrical beakers of 1-Liter capacity was conducted in the coagulation-flocculation experiments. Basically Ferric chloride (FeCl3) was used as coagulant, and they was applied with different doses on the effluents, the pH of the samples was adjusted prior to the addition of coagulants with 1.0 M Hydrogen chloride (HCL), and 1.0 M sulfuric acid (H_2So_4), or 1.0 M Sodium hydroxide (Na OH). The characteristics of the experiments that have been carried out using the jar test device are listed in Table 1.

Table 1 Experimental characteristics of the Jar test

Characteristics	Description
Coagulants	Ferric Chloride
The dose range	60-650 mg/L
Rapid mixing	1 min at 120 (rpm)
Slow mixing	20 min at 45 (rpm)
Settling time	30 min.

B. Pilot plant

Pilot-plant of Moving Bed Biofilm Reactor (MBBR) was fabricated and installed at Water Supply and Sewerage "Colentina" Laboratory - Technical University of Civil Engineering of Bucharest-Romania. The laboratory scale MBBR was a 13.7-liter rectangular basin with a 3 mm perforated baffle, constructed from Perspex glass panels of 6 mm thickness. The baffle was located at the downstream end in order to keep chips media out of the reactor outlet. The carrier elements were kept in motion state by air diffuser system that provides small bubbles which work to carry those chips and make them in continuous movement within the reactor to ensure better contact between the attached microorganisms with nutrient substances contained in the liquid. The schematic diagram of an MBBR-reactor is illustrated in Figure 1.

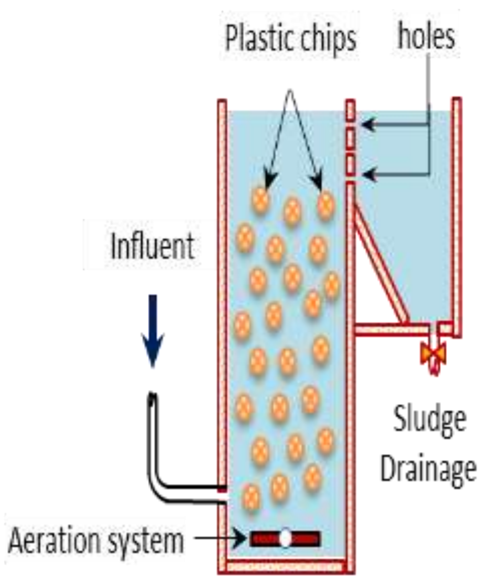

Figure 1 Schematic diagram of MBBR reactor.

C. Methodology

Industrial effluents resulting from a local meat processing plant located in Bucharest capital of Romania, was used as a source of wastewater to evaluate the effect of the physicochemical treatment by coagulation-flocculation process followed by biological treatment by aerobic MBBR process upon those effluents. The characteristics of effluents from this processing plant vary from day to another depending on the type of processes and products, and the sterilization and cleaning procedures approved and the water consumption used in those processes. In the first stage, Jar test was used to assess the efficiency of the used coagulant, by applying different doses of Ferric chloride and then at different pH values. In the second stage of the treatment the pre-treated effluents resulting from the first stage (chemical treatment) was applied to the biological treatment using MBBR system. The reactor was operated at a relatively constant aeration rate and at a different flow rate, as well, at different organic loading rates (OLR). The organic loading rate (OLR) was calculated depending on the COD concentration of the influent and by using the following formula.

$$OLR = \frac{I_{COD} * F}{V_R}$$

Where:

OLR; is organic loading rate (kg/m^3.d), I_{COD}; is the COD concentration in the influent (mg/L), F; is the influent flow rate (mL/min), and V_R; is the volume of reactor (L).

And the hydraulic retention time (HRT) was calculated by the following formula;

$$HRT = \frac{V_R}{F}$$

Where:

HRT; is the hydraulic retention time (min), V_R; is the volume of reactor (mL), and F; is the influent flow rate (mL/min).

The Removal efficiency of pollutant parameters was obtained using the following equation:

$$\text{Removal}\,(\%) = \left[\frac{(ci - cf)}{ci}\right] * 100$$

Where, C*i* and C*f* represent the initial and final concentrations of each parameter.

III. RESULTS AND DISCUSSIONS

A series of laboratory experiments were conducted using Jar test apparatus to evaluate the effect of the coagulant doses on the highly polluted effluents and to determine the optimum dose corresponded to the best removal rate. The effect of the coagulant doses on the pollutant parameters at pH of 6.91 in terms of COD, BOD, TSS, and Turbidity is presented in figure 2.

It is clear there is an increase in removal rates of the pollutant parameters with the increase in the ferric chloride doses until reaching to the optimum removal, at 450 mg/L of the coagulant. The reduction efficiency of the COD, BOD, TSS were 79.5%, 84.8%, and 92% respectively, while 98.8% the reduction rate of the turbidity was achieved using a 500mg/l of the coagulant. The removal rates were decreased when the dosage of $FeCl_3$ was increased beyond 500 mg/L. The addition of larger concentration of the coagulant to the waste/water, metal hydroxides are produced, and the organic substances usually removed either by incorporation into hydroxide flocs" or by adsorption onto those hydroxide flocs that already formed [17]. The reduction in the removal efficiency could be attributed by the re-stabilization of the destabilized colloidal particulates when the coagulant is used with doses greater than the optimal dose [18].

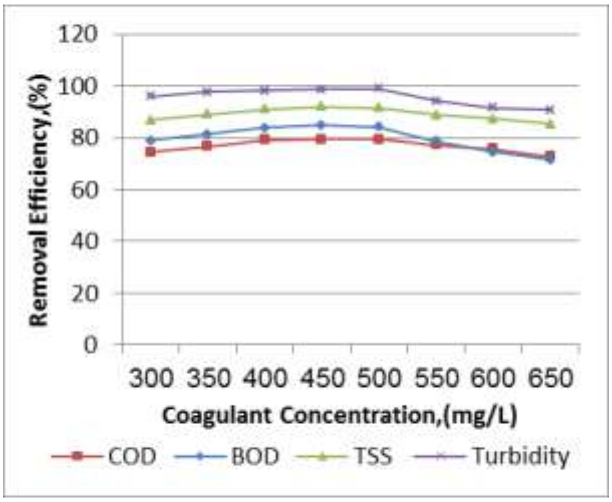

Figure 2 : Effect of ferric chloride dosages on the removal efficiency in terms of COD, BOD, TSS, Turbidity.

The second round of the of jar tests carried out using a fixed dose of ferric chloride 450 mg/L, at different pH values ranged from 3.8 to 10.89, to evaluate the influence of pH on effectiveness removal of the pollutants parameters. Adjustment of the samples was performed by adding solutions HC1 and NaOH regents. The effect of pH on the removal efficiencies of the COD, BOB, TSS, and Turbidity and when $FeCl_3$ was used as a coagulant are presented in Figure 3.

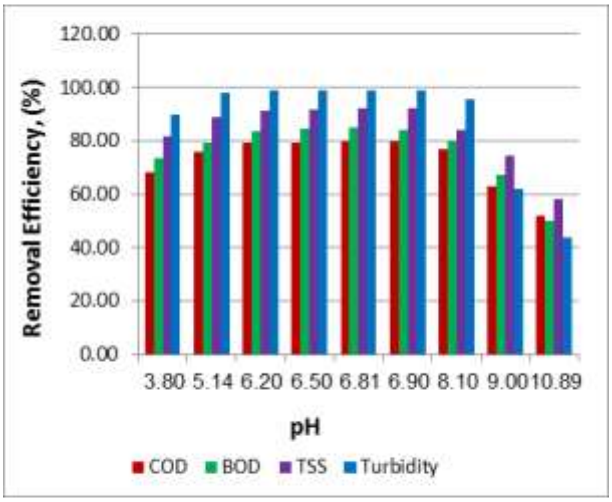

Figure 3 : Effect of pH on the removal efficiency in terms of COD, BOD, TSS, and Turbidity.

The results reveal that best removal efficiencies were obtained at pH of the treated samples within the range 5.14-8.1, and the highest removal rates achieved at pH of 6.8 using 450 mg/L of the ferric chloride. The pH value is a determinant factor in the coagulation-flocculation process since it controls hydrolysis species, and the efficient coagulation occurs within a specific range of pH values for each coagulant [19]. When pH was increased the removal rates increased till reached the highest removal rates at pH of 6.8. At pH higher than 6.9, the removal rates decreased till reached to minimum removal rates at pH of 10.89.

Since the effluents from the meat processing plant varies according to the industrial processes and water demand, ferric chloride has been applied in doses ranging from 40 to 120 mg/L on low-strength effluents. Results showed that the highest removal efficiency for COD, BOD, TSS, and Turbidity was achieved at a dose of 60mg/L, where the reduction rate was 68.4%, 71.8%, 86.1% and 96.1% respectively, is illustrated in Figure 4. The addition coagulant doses higher than the optimal dose for each parameter reflected negatively on the efficiency of the coagulant in removing pollutants, due to re-stabilization of colloidal particles, which resulted in deterioration in the quality of treated water.

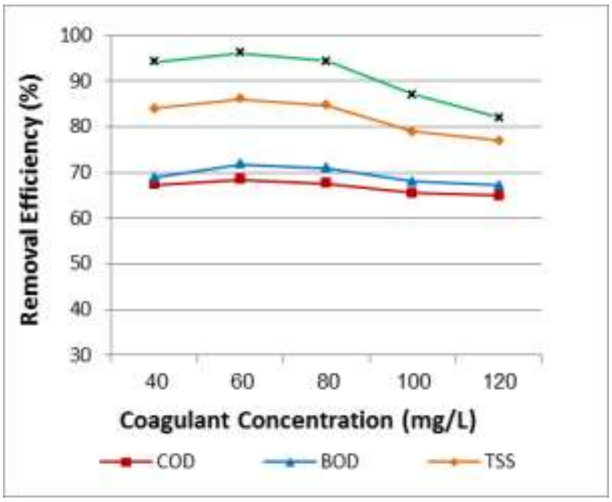

Figure 4 : Effect of ferric chloride on the removal efficiency in trems of COD, BOD, TSS and Turbidity.

In the second segment of this study the influence of biological treatment on the removal of pollutant from the meat processing wastewater in terms of COD and BOD was evaluated. The biological reactor was operated using effluents resulting from the pre-treatment by coagulation-flocculation process. After chemical treatment, the effluents were subjected to further treatment using Biological treatment, to remove the remaining soluble organic compounds from chemical treatment in order to improve effluents quality. The reactor was operated at a under a range of conditions, where the dissolved oxygen in the reactor was maintained within a range from 2 to 2.5 mg O_2/L depending on the influent organic loading rate, as well, the pH of the reactor was maintained at a value of about 7.

In the first stage, the reactor was operated with a hydraulic retention time (HRT) of four hours, and at two different organic loading rates (OLR), then the removal efficiency was measured in terms of the COD parameter. Results indicated a slight increase in the removal ratio when reducing the organic load from to 3.4 to 2.85 kg/m^3.d where the obtained removal rates were 41.31% and 43.6% at HRT of 4 h. The overall removal ratio of the COD which was achieved by the treatment processes is 83.03% and 89.12%, respectively.

In the second stage, the experiments were conducted at a different HRT while the OLR was maintained a constant 2.85 kg/m^3.d. Different hydraulic retention times of 6, 8, 10, and 12 hr., was used to operate the reactor by varying the flow rate to 2.28 l/h, 1.71 l/h, 1.37 l/h, and 1.14 l/h at this stage of the experiment. The removal rates of the COD, and BOD parameters after the biological treatment phase at different hydraulic retention times and the overall removal rates, of the whole treatment process, are shown in figure 5.

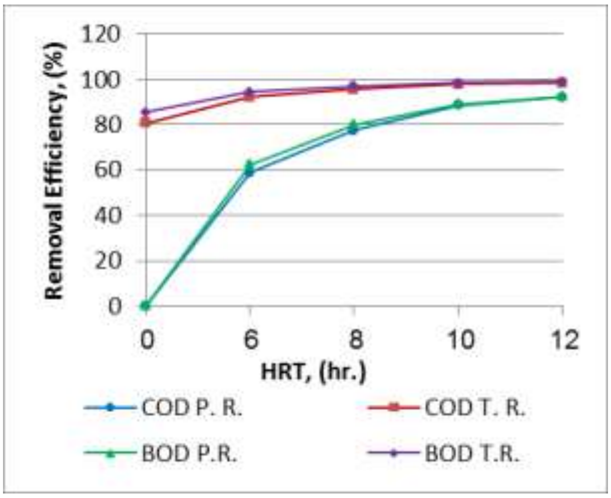

Figure 5 : Performance of MBBR at a different HRT combined with the performance of whole treatment process in terms of COD, and BOD.

As it was shown in figure 5 the removal rates of the COD, and BOD parameters were dramatically increased with the increase of HRT until reached to the highest rates at 92.1%, for COD parameter and 92.5% for BOD parameter. The total removal rates of both parameters are 98.47%, and 98.89% respectively for the overall treatment process.

IV. Conclusion

This paper presents the effect of combined of two treatment processes on the effluents from a local meat processing plant in Bucharest, where the effluents were subjected to pre-treatment by a coagulation-flocculation process after that, they were subjected to the biological treatment using MBBR system. Through the obtained results, we point out the following conclusions.

- The organic content of effluents from the meat processing plant can be effectively greatly reduced by the coagulation-flocculation process.
- Ferric chloride proved a high efficiency in removing pollutants parameters from the effluents from the meat processing plant with high or low organic content with coagulant doses of 450, and 60 mg/L respectively.
- The moving bed biofilm reactor (MBBR), showed high-efficiency as an additional treatment process following the chemical treatment of the effluents from the meat industry, where the removal rates in terms of COD, and BOD were 92.1% and 92.5% respectively at HRT of 12 hours for the biological treatment and the overall removal rates (for the combined treatment processes) were 98.47% for COD and 98.89% for BOD.
- Adding a pre-treatment by the coagulation-flocculation process before the biological treatment process greatly improves the performance of the treatment process and produced high-quality effluents with low pollutant parameters subjected to the local environmental regulation, which can be reused in several areas or can be safely discharged to the natural water bodies.

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