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Comparison of coagulants and coagulation aids for treatment of meat processing wastewater by column flotation

Rênnio F. de Sena *, Regina F.P.M. Moreira, Humberto J. José

Laboratory of Energy and the Environment (LEMA), Department of Chemical Engineering and Food Engineering (EQA), Federal University of Santa Catarina (UFSC), Florianópolis, SC 88040-900, Brazil

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ABSTRACT

The physicochemical treatment of the wastewater from a meat processing industry was studied using three ferric salts as coagulants in conjunction with four different polymers as coagulation aids by batch column flotation. The effluent was characterized in terms of pH (6.5–6.7), turbidity (1000–12000 NTU), total solids (TS) (2300–7000 mg l^{-1}), oils and greases (OG) (820–1050 mg l^{-1}), and biochemical and chemical oxygen demands (BOD_5 and COD) (1200–1760 and 2800–3230 mg l^{-1}), respectively. The treatments achieved typical organic load reductions of oils and greases, and total solids (up to 85%), as well as biochemical and chemical oxygen demands (between 62.0–78.8% and 74.6–79.5%, respectively). The research also found that the utilization of a column flotation achieved high efficiency of organic matter removal and its operation as a primary treatment showed no significant dependence of pollutant removal and air flow rate.

1. Introduction

As long as the world population continues to grow and demand for food products increase, the environment will continue to be associated with important international health issues (Sofos, 2008). The treatment of both the solid wastes and wastewater from the meat processing industry has been one of the greatest concerns of the worldwide agro-industrial sector, mainly due to the restrictions that international trade agreements have imposed regarding their use and their environmental issues.

Meat processing plants use approximately 62 Mm^3/y of water. Only a small amount of this quantity becomes a component of the final product; the remaining part is wastewater of high biological and chemical oxygen demand, high fat content and high concentrations of dry residue, sedimentary and total suspended matter as well as nitrogen and chlorides (Sroka et al., 2004).

The physical nature of these wastewaters has been studied by Sayed et al. (1987), who have shown that of the COD of screened (1 mm mesh) effluent, 40–50% was present as coarse, suspended matter, which was insoluble and slowly biodegradable, and the remainder is present as colloidal and soluble matter. This varies considerably from domestic wastewater, in which the COD is present mainly in the colloidal form (Jonhs, 1995). It also generates high amounts of biodegradable organic matter, usually varying from 1100 to 2400 mg O_2 l^{-1} in terms of BOD_5, with the soluble fraction varying from 40% to 60% (Caixeta et al., 2002).

However, for meat processing and slaughterhouse effluents, blood is considered the most problematic component, because of its capacity of inhibit floc formation (Bohdziewicz et al., 2002). In fact, even with correct handling during the meat processing, 2.0 and 0.5 l of blood are present in the effluent from each cow and pig, respectively (Tritt and Schuchardt, 1992).

Column flotation generates bubbles between 50 and 1000 μm of diameter, while DAF systems may generate smaller bubbles, between 30 and 100 μm, which increase significantly the organic load removal. However, many authors have reported that the costs with electricity, equipments and maintenance are higher than other processes (Schofield, 2001; Meyssami and Kasaeian, 2005; Mittal, 2006). De Nardi et al. (2008) concluded that chemical-DAF process (coagulation/flocculation/DAF) using coagulant and coagulation aids can be too costly while achieving high removal efficiencies, excluding the DAF unit operational costs.

A popular method of primary treatment is the dissolved air flotation (DAF) system that is used to reduce the effluent load of fat, suspended solids and BOD_5. However, other methods can achieve similar results at low-cost (Mittal, 2006). To increase flotation efficiency, coagulants and polymers (coagulation aids) can be added to the system (Meyssami and Kasaeian, 2005). Due to the high costs with chemicals and operational maintenance, cheaper separation techniques like column flotation can be efficiently used to reduce the organic load of the wastewater of meat processing plants.

The aim of this paper is to present a case of study of a meat processing industry in Santa Catarina State, Brazil, where the physicochemical treatment of the wastewater plant was evaluated regarding to the coagulation/flocculation process, using different

* Corresponding author. Tel.: +55 48 3334 9448x240; fax: +55 48 3331 9687.
E-mail address: rennio@enq.ufsc.br (R.F. de Sena).

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combinations of coagulants and coagulation aids in a column flotation process.

2. Methods

2.1. Materials

The wastewater was sampled from a meat processing plant in Santa Catarina State (southern Brazil) whose activities include the slaughter and processing of poultry and swine. It was characterized as having a high pollutant load, substantial amounts of total solids (TS), turbidity, oils and greases (OG), and high biochemical and chemical oxygen demands (BOD_5 and COD). The wastewater was dark brown in color, with a strong and putrefied smell. The wastewater treatment plant has a hydraulic capacity of $350\ m^3\ h^{-1}$ of wastewater, and the daily physicochemical parameters of the untreated effluent during the experiments were: initial pH 6.5–6.7, turbidity 1000–1200 NTU, total solids (TS) 2300–7000 $mg\ l^{-1}$, oils and greases (OG) 820–1050 $mg\ l^{-1}$, and biochemical and chemical oxygen demands (BOD_5 and COD) of 1200–1760 and 2800–3230 $mgO_2\ l^{-1}$, respectively.

2.2. Apparatus

The physicochemical treatment of the wastewater was carried out using a batch integrated column flotation system containing a 1.0-l volume flotation cell, a rotameter with air flow rate in the range of 0.1–1.0 $l\ min^{-1}$, and a 9.6 m^3 gas cylinder containing synthetic air. Previously, jar test procedures were also accomplished for the optimal coagulation dosages determination, for both coagulants and coagulation aids (results not reported herein).

2.3. Methods and reagents

The reagents used as coagulants were commercial ferric chloride (FC-Pix), commercial ferric sulfate (FS-Pix) and ferric aluminum sulfate (FS-Lema). Kemwater Brasil S.A. provided the FC-Pix and FS-Pix. The FS-Lema is a coagulant developed by the Laboratory of Energy and the Environment (LEMA) at UFSC (Brazil). The four coagulation aids (polymers of anionic polyacrylamide) used were Flonex 9073 (F1), Polyfloc ANP1099 (P1), Optifloc A1210 (O1) and Optifloc A1220 (O2), which were provided by their respective suppliers in Brazil.

The tests were carried out after the optimum reagent solution concentrations were determined, (concentrations of 10 $g\ l^{-1}$ Fe^{3+} for the coagulants and 1 $g\ l^{-1}$ for the coagulation aids). Samples (1.0-l) were then placed in the flotation cell prior to the ascendant air flow for equalization of the raw wastewater. Subsequently, the pre-determinate coagulant dose was added into the liquid to initiate the coagulation process. The same procedure was used for the coagulation aids (anionic polymers) to provide an increase in floc size and, therefore, their flotation by the release of air bubbles. The treated wastewater samples were then collected for analysis.

2.4. Analytical procedures

Turbidity, COD and BOD_5 were determined according to the Standard Methods for the Examination of Water and Wastewater (APHA-AWWA-WPCF, 1995). The OG and TS contents were determined by gravimetric methods. The turbidity and COD were determined using a Hach D/R 2000 spectrophotometer. All results for comparison between combinations of coagulants and coagulation aids are reported as residual percent, while preliminary tests are reported as pollutant removal (%).

3. Results and discussion

3.1. Primary assays and the column flotation technique

The optimal conditions established for air flow using ferric sulfate (FS-Pix) in conjunction with the polymer Flonex 9073 (F1) are shown in Table 1.

The data confirmed a direct association between the air flow rate and the coagulation time, with a decrease in coagulation time as the flow rate increased. According to Rubio et al. (2002), the flotation system efficiency is affected by particle size, especially in relation to bubble diameter, which is responsible for the particle adhesion. Column flotation processes usually generate bubbles between 30 and 1000 μm of diameter, with microbubbles (30–100 μm) responsible for most of the organic matter removal. Although an excessive air flow rate, particularly a high ascendant velocity, entering the fluid leads to the decreasing and destruction of the flocs, and the flotation time decreased as the air flow rate increased (Fig. 1). However, the flotation phenomenon did not occur when too much air was injected, independent of the air flow, leading to floc destruction or incapacity to capture bubbles.

The flotation assays were carried out after the determination of the optimal reagent dosages, and preliminary determinations of COD, TS and turbidity. They were carried out for each air flow rate assayed to determine whether there was a correlation between the flotation time for the different air flow rates and pollutant removal.

The air flow rate of 0.6 $l\ min^{-1}$ was previously evaluated as the optimum rate, primarily in relation to the efficiency of solids separation, turbidity and COD removal, and minimum flotation time. However, the other air flow rates also had satisfactory results for organic matter removal. According to Fig. 1, there is no correlation between air flow rate and pollutant removal, because the differences between results were not significant.

3.2. Wastewater treatment

Before the flotation assays were performed, the chemical analysis of the raw wastewater was carried out. The characterization of the raw wastewater collected at the inlet of the physicochemical treatment plant, after the screening process, showed that the raw wastewater has a high organic load constituted, basically, of blood and organic materials that cause the red color and most of the turbidity. These components inhibit the coagulation process due their complex removal from the liquid. The wastewater also has a high concentration of total solids, oils and greases, BOD_5 and COD.

The aim of the utilization of coagulants is to transform the soluble matter into small particles that can be removed by settling or flotation. The particle removal occurs, according to Gregor et al. (1997), through the formation of insoluble complexes favored at lower pH values.

In the coagulation process, the size and the geometry of the particles vary considerably, which aids the floc formation. However, the utilization of coagulation aids after the floc formation, such as anionic polyacrylamide, increases the overall removal of organic matter due the greater amount of particles aggregated by van der Waals forces (Biggs et al., 2000; Al-Mutairi et al., 2004). In fact, in many coagulation processes, for sedimentation or flotation purposes, the utilization of coagulation aids has been widely applied by industry to enhance process efficiencies.

Fig. 2 shows the correlation between coagulants/polymers and BOD_5 abatement, where the results achieved for residual BOD_5 was below 35%, and the samples treated with the polymer Optifloc A1210 (O1) achieved the lowest results (25% on average).

Fig. 3 shows the residual COD of the treated samples that reached values of 25% using O1 as coagulant aid, and an average

Table 1
Operational conditions for different air flow rates used during the primary flotation assays

Air flow rate ($L min^{-1}$)	Flotation time (s)	Coagulant dose (mg $Fe^{3+} l^{-1}$)	Polymer dose ($mg l^{-1}$)	pH
0.2	90	30.0	3.0	5.1
0.3	70	30.0	3.0	5.1
0.4	60	30.0	3.0	5.1
0.5	50	30.0	3.0	5.1
0.6	30	30.0	3.0	5.1

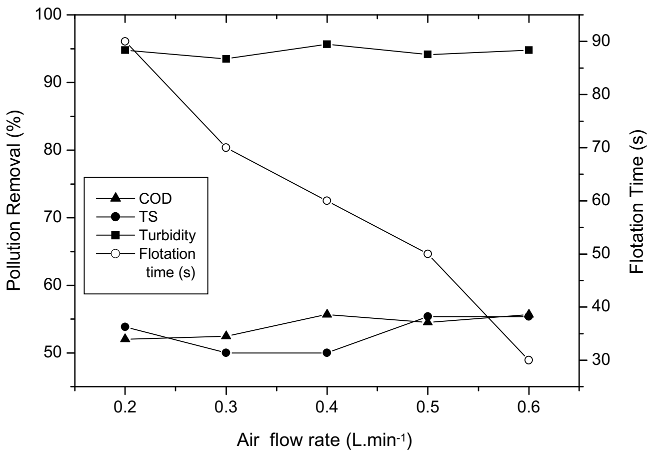

Fig. 1. Evaluation of the wastewater treatment by column flotation in terms of COD, TS and turbidity removals, for different air flow rates and flotation times.

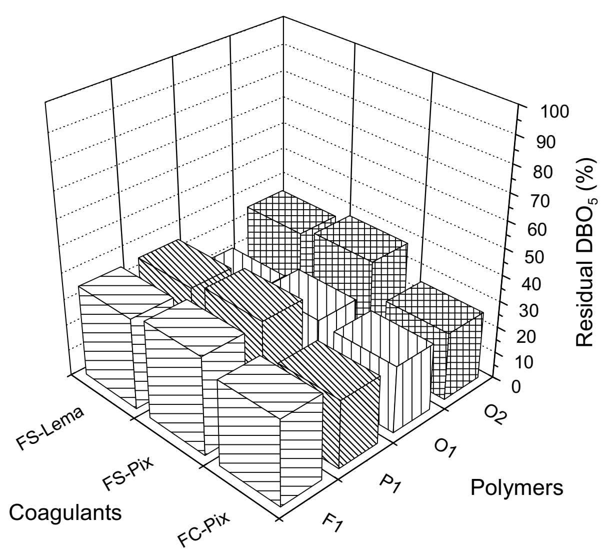

Fig. 2. Comparison of residual BOD_5 results using different coagulants in conjunction with different polymers by column flotation process.

of 21% for other samples. COD reduction is one of the most important parameters used to evaluate treatment efficiencies, especially in conjunction with a BOD_5 reduction. Nunez et al. (1999) reported the use of the coagulation process for the treatment of a slaughterhouse wastewater using ferric salts and anionic polyacrylamide, attaining a maximum of 75% of COD removal (25% residual). They also reported that the use of coagulation aids, such as anionic polyacrylamide, increased substantially the removal of COD and BOD_5, as well as organic matter in general, since when coagulants were used isolated the organic matter present in these wastewaters did not flocculate completely.

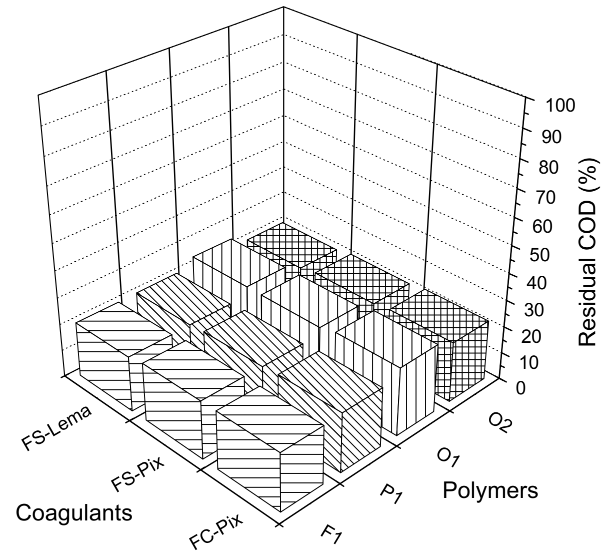

Fig. 3. Comparison of residual COD results using different coagulants in conjunction with different polymers by column flotation process.

Fig. 4 shows the results for the residual OG of the treated samples that reached values lower than 7% for samples using FC-Pix and FS-Pix as coagulants, and those which used FS-Lema had average values of 10%. However, all the results reported herein are satisfactory for a primary treatment, especially when the treated liquids proceed to biological treatments, where high OG contents can cause inefficiency and operational instability.

According to Jonhs (1995), meat industry wastewater is rich in oils and greases, sanitizers and blood, substances that need to be removed by physicochemical treatment to decrease the organic load to be treated in the biological systems. These substances, particularly oils and greases, are formed of long-chain organic compounds, which need longer retention times for their oxidation by microorganisms. In the development of wastewater plants for the meat industry, several authors have reported the requirement for high efficiency primary treatment before biological treatment (Sayed et al., 1987; Bohdziewicz et al., 2002; Sroka et al., 2004).

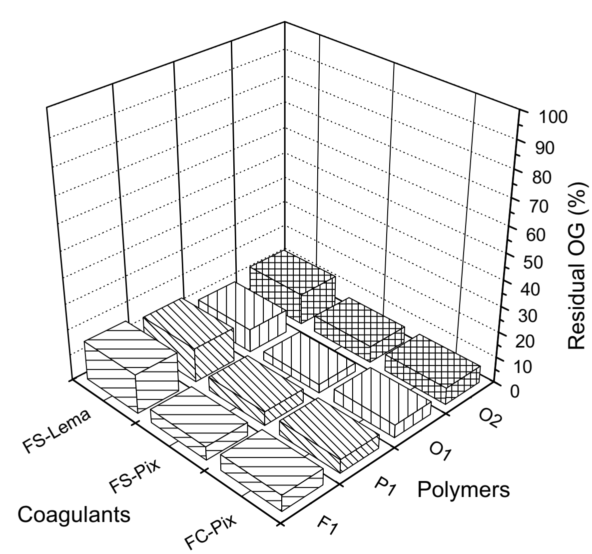

Fig. 4. Comparison of residual OG results using different coagulants in conjunction with different polymers by column flotation process.

Figs. 5 and 6 show the residual TS and turbidity, respectively, where results were lower than 10% for both parameters. It also shows a direct correlation between TS removal and turbidity of the wastewater, as previously observed by several authors (Tritt and Schuchardt, 1992; Nunez et al., 1999; Aguilar et al., 2002, 2003). According to Delgado et al. (2003) the utilization of ferric salts as coagulants in concentrations between 5 and 30 mg l^{-1} in jar test assays, the turbidity removal was 75% (25% residual) for the best assays, while the tests undertaken in this study attained removal efficiencies of up to 95% when coagulation aids were used. This demonstrates that the use of these polymers can increase significantly the efficiency of these processes.

In this regard, Aguilar et al. (2003) investigated the use of ferric sulfate and anionic polyacrylamide for the treatment of slaughterhouse wastewaters, reaching 99% of solids reduction, while tests carried out without coagulation aids achieved 87% for the best results, probably due to the formation of smaller flocs during the coagulation.

De Nardi et al. (2008) reported lower COD, OG and TS removals (52–77%, 60–99% and 44–91%, respectively) using chemical-DAF in an industrial wastewater treatment plant at 40% recycle rate. However, since the results reported herein had higher removal percentage in average, column flotation can be as efficient as DAF if the physicochemical parameters and chemical dosages were well-controlled, presenting substantial low operational costs.

3.3. Treatment and reagents assessment

The results reported in this paper revealed that the column flotation process used for the treatment of meat industry wastewater has high efficiency rates in relation to the pollutant reduction, especially solids and oils and greases. The use of different air flow rates did not significantly affect the treatment in terms of the physicochemical parameters, but had a direct influence on the flotation time.

All three ferric salts gave high overall effectiveness. However, FS-Lema gave the lowest OG and TS removal rates, but the highest BOD_5 and COD removal rates, which are essentially related to the organic load of these wastewaters. This behavior may be related to the purity of the product, classified as ferric aluminum sulfate, containing Al^{3+} atoms (2.6 mg l^{-1}) in the coagulant solution, which probably compete with the Fe^{3+} atoms during the coagulation phenomenon.

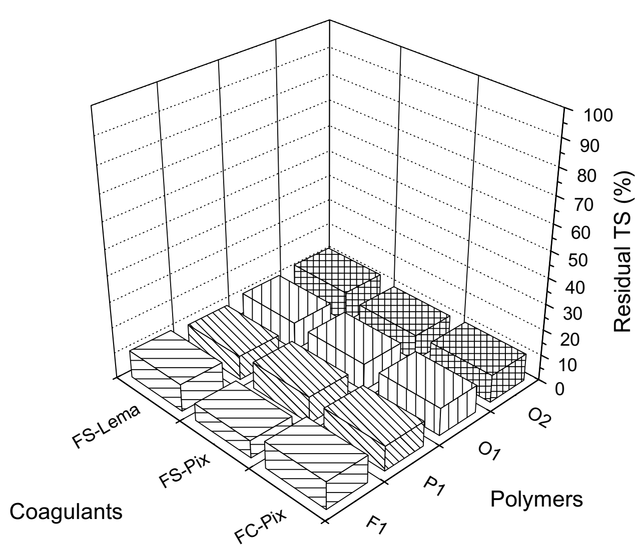

Fig. 5. Comparison of residual TS results using different coagulants in conjunction with different polymers by column flotation process.

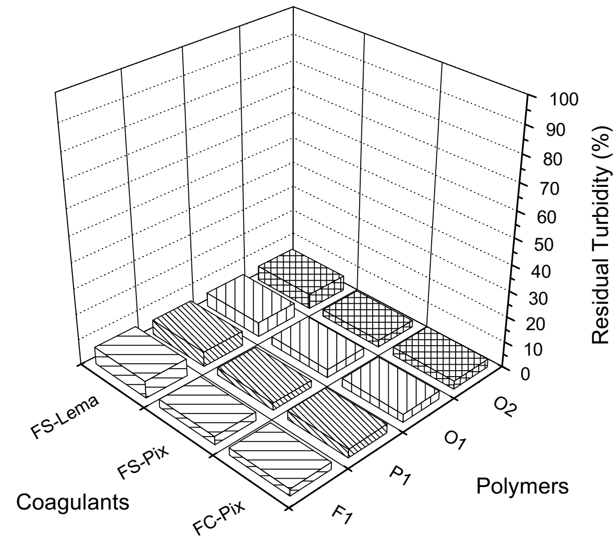

Fig. 6. Comparison of residual turbidity results using different coagulants in conjunction with different polymers by column flotation process.

FC-Pix is a coagulant used worldwide, which has a high efficiency of organic matter removal in wastewater treatment, and was used as a comparative parameter. FS-Pix gave the best overall results, especially in relation to the TS removal in conjunction with the polymer Flonex 9073 (F1).

Among the coagulation aids used in the flotation assays, Flonex 9073 (F1) and Polyfloc ANP1099 (P1) had good results for organic matter reduction and also increased the biodegradability of the treated wastewater. According to Biggs et al. (2000), each polymer acts differently depending on the wastewater and coagulant used, because the influence of the polymer on the floc increase depends, mainly, on the chemical structure of the polymer. For this reason, it is necessary to assay each polymer with different coagulants or wastewaters, to determine the treatment of the best efficiency.

Even after the physicochemical treatment, the organic load is still high, and an efficient biological treatment or an advanced oxidation process (AOP) is necessary to guarantee that these effluents achieve lower BOD_5 and COD values before discharge and/or reuse.

Sroka et al. (2004) have reported that, in Poland, the permissible standard for the discharge of wastewater treated by the meat industries is lower than 1% of organic load, on average, and that an efficient treatment begins with physicochemical treatment followed by a biological treatment, in order to achieve pollutant levels in accordance with the legislation. They investigated the application of a combined system using chemical coagulation before the biological treatment by activated sludge, and had final results for organic matter in accordance to the standards.

Although DAF systems are widely reported as a higher solid separation technique compared to other types of process, column flotation can achieve also high removal efficiencies compared to DAF with lower costs and effortless maintenance. Nevertheless, the increase in efficiency by this technique is intrinsically related to a successful and well-controlled coagulation/flocculation process, including the choice of effective coagulants and coagulation aids, as well as the efficient management on the dosages of the reagents used in the treatment.

4. Conclusions

The aim of the physicochemical treatment is to increase the efficiency of organic load removal from wastewaters. In this case study, the results for a column flotation system showed a high efficiency for this treatment, using coagulants together with coagulation aids during the injection of an air flow rate of 0.6 l min^{-1} into the liquid. However, the results showed that the use of different air flow rates had no direct interference on the organic matter removal, but influenced the flotation time.

In this study, high organic load removal rates from a meat industry wastewater were obtained, confirmed through the analysis of raw and treated wastewater. Results were shown to be in accordance to previous investigations. The physicochemical results for BOD_5 and COD reduction varied between 62–78% and 75–79%, respectively. For OG and TS, reductions of up to 89% were achieved

Based on this investigation, it can be concluded that the efficiency of column flotation can be increased through careful selection of coagulant – polymer combinations, and optimization of their dosages. Also, the use of ferric salts as coagulants gave high overall efficiencies, which has previously been investigated in detail.

As a concluding remark, the results herein show the importance of primary treatment to decrease substantially the organic load to be treated in combined systems, and the role of flotation in the treatment of meat industry wastewater in achieving low discharge parameters established by legislation in Brazil and in other countries.

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