*Desalination and Water Treatment*
www.deswater.com

12 (2009) 270–275


doi: 10.5004/dwt.2009.952

# Coagulation/adsorption combined treatment of slaughterhouse wastewater

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Received 23 January 2009; Accepted in revised form 20 September 2009

**ABSTRACT**

This study focused on the treatment of slaughterhouse wastewater characterized as having exceptionally high BOD, COD and TSS contents. A combined treatment system of coagulation and adsorption onto activated carbon was applied for the effluent treatment. Different coagulants, including alum, lime, ferrous sulfate, and ferric chloride were used individually and in combination. A jar test method was applied to determine the optimal dose of these coagulants. The sludge formation and COD measurements were made in each treatment type. Increasing dosages of coagulants increased the sludge formation and COD removal. Volume of sludge was found to be an indicator of maximum removal of COD. Alum was proved to be the best coagulant in removing COD up to 92%. Maximum sludge volume (400 ml/L) was also observed with alum. More than 90% removal efficiency in pollution load was observed at the set optimal conditions with coagulation process. A combination of coagulation and adsorption processes made negligible improvement in the removal efficiency of the system and removed pollution load up to 96%.

*Keywords:* Slaughterhouse wastewater; Coagulation; Sludge; COD removal; Adsorption

## 1. Introduction

Slaughterhouse wastewater is a typical source of pollution and creates serious environmental concerns [1]. Characteristics of slaughterhouse wastewater, including biochemical oxygen demand (BOD), chemical oxygen demand (COD), total dissolved solids (TDS), suspended solids (SS), fats, oil and grease and colour, are inconsistent and pollution parameters vary seasonally, daily or even on a shift basis, and also with the number and type of animals slaughtered [2]. Such characteristics render slaughterhouse wastewater treatment very difficult [3]. Therefore, there is a need to develop a cost effective, efficient and an integrated wastewater treatment system for the slaughterhouse wastewater.

There is a wide range of conventional and advanced wastewater treatment technologies. Conventional treatment processes like biological and physico-chemical, have long been applied in removing many chemical and biological contaminants [4,5]. Biological treatment methods are simple and also generate energy but require high operational and maintenance cost. The disposal of a large volume of sludge generated through biological treatment processes is another disadvantage of biological techniques. However, physico-chemical methods such as coagulation and flocculation have been used effectively to treat slaughterhouse wastewater [6–9]. These methods have been found to be cost effective, easy to operate and energy saving [10]. Other advantages of coagulation are greater removal efficiency; feasibility of using high overflow rates; and more consistent performance [11]. Over the last 20 years, different types of coagulants have

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been used for the removal of organic matter and total suspended solids, particularly for the treatment of slaughterhouse wastewater [7]. Different types of coagulants, both inorganic (aluminium sulfate, sodium alumninate, aluminium chloride, polyaluminium chloride, polyaluminium sulfate, ferric chloride, ferric sulfate) and organic (polyacrylamide, sodium alginate) are being used for the treatment of slaughterhouse wastewater [7,11]. For maximum removal efficiency of pollutants, coagulants vary in their type, dosage and pH of the medium [12–14].

The coagulation method of wastewater treatment is very effective in removing the suspended solids and as much of organic material as possible [15]. However, the rate and effectiveness of the coagulation process employed is dependent on the composition of wastewater, its temperature, the rate of mixing and the order in which coagulants and flocculants are introduced into the wastewater [8]. Some studies have reported on COD removal efficiencies using coagulation process in the treatment of slaughterhouse wastewater [6,9].

Powdered activated carbon (PAC) was used as adsorbent in various industrial wastewater treatments [16–18] as it is well known to remove the colour and odour of wastewater [19,20]. Furthermore, activated carbon could be used together with other wastewater treatment processes for increasing the removal efficiency [21].

It is noteworthy that no single treatment system is 100% effective in treating the pollution rich slaughterhouse wastewater. Several treatment systems are currently being integrated to maximize the advantages of each process [2,22–24].

This research project is mainly centred on the characterization of slaughterhouse wastewater and its treatment using coagulation and adsorption with activated carbon. The work focuses on the optimization of process conditions like coagulant type and dose, and removal efficiency of the treatment process.

## 2. Materials and methods

In this study, a town municipal slaughterhouse located near Bakarmandi, Band Road, Lahore, was selected because about 75% of the total meat supply to the city is contributed by this slaughterhouse. About 200 cows and buffaloes and 3500 goats and sheep are being slaughtered per working day. Water is extensively used for washing at all steps of slaughtering. There are several channels for the outflow of wastewater, which collectively meet in a main drain that ultimately falls into the municipal drain about 200 m away from slaughterhouse. There is no wastewater treatment system at the premises.

### *2.1. Sampling*

Keeping in view the merits and demerits of the grab and composite sampling techniques [25,26], both composite and grab samples of slaughterhouse wastewater were collected. One litre grab sample was taken in a plastic bottle at 1 h time interval in a working day. These water samples were then mixed and homogenized to prepare a composite sample and stored in a 10-l capacity can. The composite sample was then preserved at 4°C in a refrigerator for characterization. Similarly, another composite sample of wastewater of 50 l was stored in a PVC (polyvinylchloride) tank for treatment.

### *2.2. Analyses*

Wastewater was characterized in terms of pH, BOD, COD, TDS and TSS concentration. These parameters were determined following analytical methods given in the series of standard methods for the examination of water and wastewater. Methods 4500-$H^+$ B, 5210-B, 5220-B, 2540-C and 2540-D were used for the measurement of pH, BOD, COD, TDS and TSS, respectively [26].

### *2.3. Coagulation experiments*

The coagulation process is generally achieved by using inorganic coagulants, polymeric coagulants and/or natural organic coagulants. Inorganic coagulants are easily available at commercial level and are of low cost. Use of polymeric coagulants is restricted because of the production of chlorinated by-products in water, which have adverse impact on human health [27].

In this study, inorganic coagulants like alum, ferric chloride, ferrous sulphate and lime were used in coagulation process for treating slaughterhouse wastewater. Jar test procedure was applied for the selection of coagulant and its dose [11]. The experimental setup comprised of six graduated glass cylinders each of 1 l capacity. 1 l of slaughterhouse effluent was introduced to each cylinder. Each coagulant was then added to the series of cylinders in different doses, and stirred with a glass rod. Settled sludge volume was observed after 30, 60 and 120 min. After a settling time of 2 h, supernatant of each cylinder was analyzed for COD. COD removal efficiencies were also calculated by using the following formula:

$$\% \text{ removal efficiency} = \frac{(C - C_0)}{C} \times 100$$

where $C$ = COD value in untreated effluent; $C_o$ = COD value in treated effluent.

The dose of each coagulant was optimized for maximum removal of COD. Combinations of different coagulants were also used for better removal efficiency of COD.

### *2.4. Adsorption experiments*

Powdered activated carbon (PAC) was also used in this study for the adsorption of pollutants. A glass column with internal diameter of 5 cm and length 20 cm was packed with PAC and slaughterhouse wastewater was passed through the column at the rate of 3 mL/min. The treated effluent was then analyzed for BOD, COD, TDS, TSS and pH.

*2.5. Combined treatment processes*

The coagulation process and adsorption onto activated carbon were combined by improvising an integrated treatment system of 5 l capacity. The treatment system was comprised of a sample receiving tank fitted with screening of 1 mm and a tap at the bottom in order to regulate the flow of effluent into the main reactor equipped with a mechanical stirrer and a glass funnel. Chemically treated wastewater was then passed through a sand filter bed, which was connected with a PAC packed glass column emptying into a collection tank.

## 3. Results and discussion

*3.1. Wastewater characterization*

Table 1 shows the characteristics of slaughterhouse wastewater. The effluent was almost neutral with pH of 7.32. BOD, COD and TSS contents of the effluent were 5703, 6605 and 4089 mg/L, respectively.

The contents of these pollutants were alarmingly higher than the permissible limits given in the National Environmental Quality Standards (NEQS) [28]. Exceptionally higher concentrations of BOD, COD and TSS owe to the organic load due to the presence of blood, waste meat and fat, urine, undigested food, faecal matter and soluble proteins [15].

Table 1
Characteristics of slaughterhouse wastewater

| Parameters | Contents (mg/L) | NEQS |
|---|---|---|
| pH* | 7.32 | 6–10 |
| BOD | 5703 | 80 |
| COD | 6605 | 150 |
| TSS | 4089 | 200 |
| TDS | 2168 | 3500 |

*Without unit

*3.2. Coagulation treatment*

Coagulation is one of the most important treatment processes in reducing organic pollution load from industrial wastewater that contributes to the BOD and COD content of wastewater [15,29]. Coagulants destabilize the particulate matter present in wastewater and floc are formed due to particles collision, which is settled down in the form of sludge after sedimentation [30].

Different types of inorganic coagulants such as lime, alum, ferric chloride and ferrous sulphate were used in this study for the treatment of slaughterhouse effluent. The coagulants were applied both individually as well as in combination in order to maximize their advantages for an optimal reduction in the pollution load [7,8].

*3.2.1. Sludge volume*

Sludge volume at various settling times with different types and doses of coagulants was measured. Sludge volume appeared to be decreased with settlement time and sludge was dense after 120 min. However, there was a linear relationship between sludge volume and coagulant dose as shown in Fig. 1. The volume of sludge increased with an increase of the coagulant dose. That increase in sludge volume was up to a certain dose, beyond which there was no increase in the sludge volume. This may be due to hydrolysis of the coagulants up to a certain level for destabilizing the small particles in effluent [11]. Hydrolysis results in the formation of corresponding gel like hydroxides and some positively charged mononuclear and polynuclear species.

These positively charged compounds combined with negatively charged colloidal particles present in the wastewater by charge neutralization mechanism and at the time of settling under gravity these hydroxides and complexed hydroxides sweep away the colloidal particles of the wastewater with them and precipitate out [31].

Maximum volume of sludge (400 mL/L) was observed in the effluent treated with alum at settlement time of 120 min. Amuda and Alade [6] also reported maximum sludge formation while treating slaughterhouse wastewater with alum coagulant.

*3.2.2. COD removal*

COD removal efficiency of various coagulants measured at 2 h sludge settlement time is shown in Fig. 2.

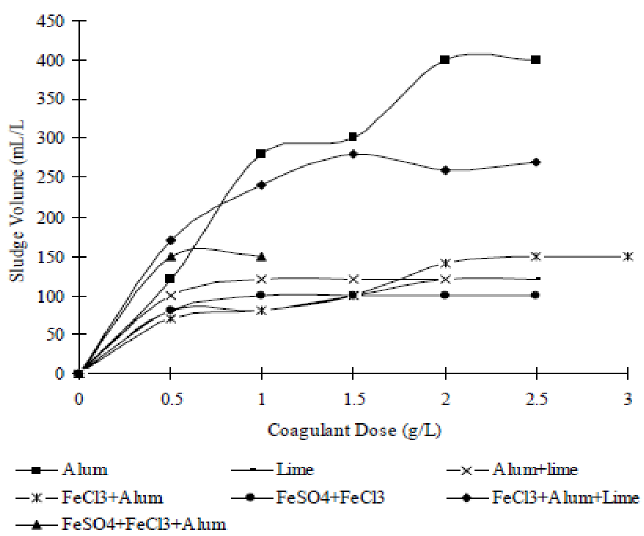


Fig. 1. Effect of coagulant dose on the sludge volume.

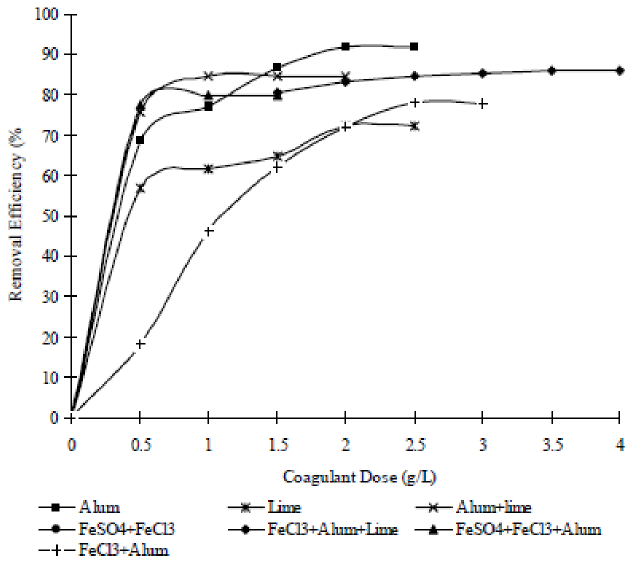


Fig. 2. Effect of coagulant dose on COD.

Reduction in COD content with increasing the coagulant dose was obvious. However, reduction was up to a certain level, beyond which COD removal was negligible. Doses of different coagulants were optimized on the basis of maximum reduction in COD value. COD removal efficiencies at these optimal doses are presented in Table 2. A dose of 2.0 g/L of alum was found to be the optimal for maximum removal (91.8%) of COD. In contrast, Amuda and Alade [6] have reported maximum COD removal efficiency of 65% in slaughterhouse effluent with alum.

Combinations of various coagulants like ferric chloride + alum + lime, lime + alum, ferrous sulfate + ferric chloride + alum, ferric chloride + alum, ferrous sulphate + ferric chloride and lime showed 86.1%, 84.5%, 79.7%, 78.0%, 76.5% and 72.4% removal efficiencies, respectively.

COD contents appeared to be decreased as the sludge formation is increased when the effluent is treated with different coagulants.

Table 2
COD removal efficiency of coagulants at optimal doses

| Coagulant | Optimal dose (g/L) | Removal efficiency (%) |
|---|---|---|
| Alum | 2.0 | 91.8 |
| Lime | 2.5 | 72.4 |
| Lime + alum | 2.5 + 0.7 | 84.5 |
| $FeCl_3$ + alum | 1.0 + 1.0 | 78.0 |
| $FeSO_4$ + $FeCl_3$ | 1.0 + 0.4 | 76.5 |
| $FeCl_3$ + alum + lime | 1.0 + 1.0 + 2.5 | 86.1 |
| $FeSO_4$ + $FeCl_3$ + alum | 1.0 + 0.4 + 0.4 | 79.7 |

Higher volumes of sludge indicated removal of more soluble matter from effluent ultimately lead to the COD reduction. Alum treatment produced the maximum amount of sludge resulting in an optimal removal of COD as compared to other coagulants. Therefore, the sludge volume may be an indicator of COD removal during the coagulation process in treating slaughterhouse effluent.

### *3.2.3. Removal efficiency of coagulation process*

Coagulation process conditions such as coagulant type, coagulant dosage and settlement time were optimized in treating the slaughterhouse effluent. It was found that a 2.0 g/L dose of alum showed maximum removal of pollutants from the slaughterhouse effluent. Fig. 3 shows the removal efficiency of the coagulation process for various pollutants at optimal process conditions.

COD and BOD contents were reduced to 91.8% and 93.5%, respectively. Maximum removal (98.6%) was observed in TSS, while TDS reduction was minimum (15.9%), which may be due to the presence of soluble salts of coagulant. The results are in agreement with the findings of several workers [6,7,8,32].

## *3.3. Combined treatment system*

Activated carbon is used as an adsorbent for the removal of dissolved organic matter [11]. An integrated treatment system was developed by combining the coagulation and adsorption processes. The optimized operational conditions such as coagulant type, coagulant dose and sludge settlement time were applied for the integrated treatment system. A 5-l composite sample of slaughterhouse wastewater was treated with this integrated treatment system. Fig. 4 presents the removal efficiency of the integrated treatment system for various pollution parameters. The removal efficiency of the integrated system appeared to be 96.8%, 96.1% and 100% for BOD, COD and TSS values, respectively. A comparison of removal efficiencies of the coagulation process alone and combined treatment system is shown in Fig. 5.

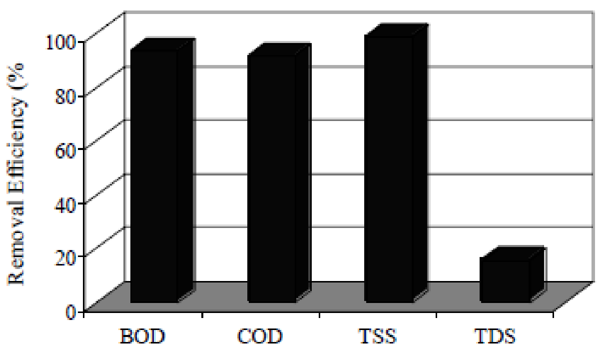


Fig. 3. Removal efficiency of the coagulation process.

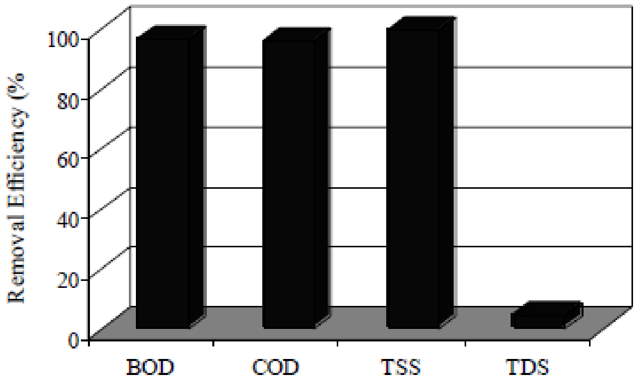


Fig. 4. Removal efficiency of the combined treatment system.

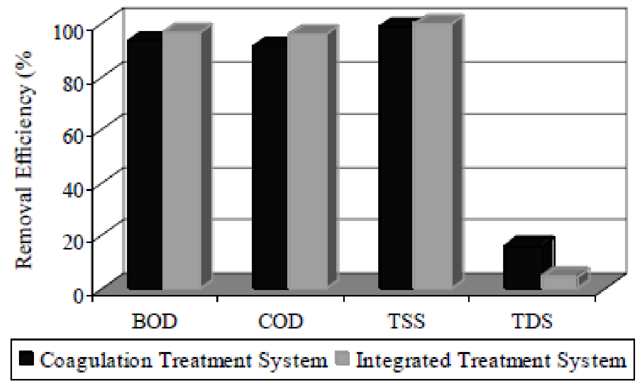


Fig. 5. Comparison of removal efficiencies of the coagulation treatment process and combined treatment system.

## 4. Conclusion

Wastewater of Town Municipal slaughterhouse was characterized in terms very high COD, BOD, TDS and TSS contents when compared with NEQS. The higher contents attributed to the presence of organic load comprised of blood, fat, urine, hair, undigested stomach waste and soluble proteins in slaughterhouse wastewater.

The effluent was treated with coagulants like alum, lime, ferrous sulfate and ferric chloride. The process conditions like coagulant type, coagulant dosage and settling time were optimized. Activated carbon was also applied for the treatment of slaughterhouse effluent. A combined treatment system was developed by integrating coagulation and adsorption processes. Activated carbon was used as an adsorbent.

In coagulation treatment, maximum sludge volume was observed in effluent treated with alum coagulant at settlement time of 120 min. Alum was found to be an extremely effective coagulant in removing COD from the effluent. COD removal increased with the dosage of different coagulants but that increase was up to a certain level, which may be due to the maximum removal of soluble solids by coagulation and flocculation. A dosage of 2.0 g/L of alum was proved to be optimal for COD removal. The volume of sludge was found to be an indicator of maximum removal of COD.

Up to 92% removal efficiency in pollution load at the set optimal conditions was observed with the coagulation process. A combined treatment system comprising coagulation and adsorption processes increased the removal efficiency up to 96%. Coagulation treatment process proved to be extremely efficient as compared to the integrated treatment system.

## Acknowledgement

The authors are thankful to Pakistan Council of Scientific and Industrial Research Laboratories Complex for providing an excellent working environment in completion of the present research work. Thanks are also due to the University of the Punjab for providing academic guidance throughout the research study.

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