The efficiency of electroflocculaters at processing restaurant waste water to reduce pollution

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ABSTRACT

Among many different wastewater treatment technologies, electroflocculation has been employed for treating the restaurant wastewater by the City University of Hong Kong. The efficiency of this wastewater treatment device on removing restaurant wastewater pollutants was investigated. In addition, electroflocculation was compared with another method which was designed in this research. In which, restaurant wastewater was pretreated with adding Alum, and then treated with membrane filtration. The results of experiments showed that the electroflocculater was effective in reduction of several wastewater quality parameters, including suspended solid(SS) and the unit was capable of meeting the wastewater discharge permission standard of Environmental Protection Department of Hong Kong(EPD). However, the removal of total organic carbon (TOC), 5 days biochemical demand (BOD_5) and fat, oil and grease (FOGs) by the unit was all found less than 50%, though the parameter may reach the permission standard. The aluminum residual in electroflocculated restaurant wastewater was 7000 times higher than the aluminum level of the raw nature water. In order to improve the performance of the electroflocculater, it is suggested that optimum aluminum dosage should be carefully considered, and the unit could be coupled with microfiltration.

This research demonstrated that optimum Alum dosage followed by membrane filtration may reduce the TOC and SS in restaurant wastewater by over 99%.

INTRODUCTION

Overview of restaurants and its waste effluent in Hong Kong:

According to the statistics from Food and Environmental Hygiene Department, there are around 10,000 restaurants in Hong Kong at 2004, including general restaurants, light refreshment restaurants, marine restaurants and factory canteens. Over half a million ton of water is consumed and turned into wastewater each month, which contains high oil content, salt content, bacteria, suspended solids and dissolved organic substances, by the food industry. If the wastewater is discharged directly down the drain, it will increase the workload of sewage treatment plants and consequently lower its efficiency. An Electroflocculater is relatively small in size and an economical wastewater treatment system, which is able to reduce pollutants in a huge volume of wastewater within a short period of time. This makes it suitable for a city which is lack of area like Hong Kong.

Background of coagulation:

Traced back to thousands of years ago, the Egyptians have used coagulation since 2000 BC (Faust and Aly 1998). Municipal water treatment using coagulation dates from around 1757. Various chemicals have been used for coagulation, in which, Alum, which is known to early Romans of 2000BC, is still the most commonly used coagulant. This old technique inspired the invention of the latest nowadays electroflocculater. Nevertheless, the chemistry behind the coagulation process is rather complex. And a lot of models have been suggested to explain the phenomenon.

Chemistry of electroflocculation:

The chemistry of electroflocculation involves two parts – electro-coagulation and electro-flotation.

Electro-coagulation:

The chemical coagulation of turbid and colored surface waters involves the interaction of particulates with a destabilizing agent. In this research, the destabilizing agent was aluminum ions which were electrically dissolved into wastewater (see equation (1)). The essential purpose of coagulation is to aggregate the pollutant particles into larger size flocs.

Primary reaction:

$Al_{(s)} \rightarrow Al^{3+}_{(aq)} + e^-$ (1)

Secondary reactions:

$2Cl^-_{(aq)} + 2e^- \rightarrow Cl_{2(aq)}$ (2)

$2H_2O_{(l)} + 4e^- \rightarrow O_{2(g)} + 4H^+_{(aq)}$ at acidic condition (3)

$4OH^-_{(aq)} + 4e^- \rightarrow 2H_2O_{(aq)} + O_{2(g)}$ at alkaline condition (4)

The chemical equations (1) – (4) can conclude the main reaction in the electroflocculater (Chen, Chen and Cheng 2002).

Electro-flotation:

After the pollutants have been coagulated and destabilized, they will then be floated to the wastewater surface by the gas bubble produced in equation (3) and (4). While the wastewater is acidic, equation (3) reaction will proceed. On the contrary, equation (4) will proceed when the wastewater is alkaline.

The basic setup of the electroflocculater:

The electrochemical reactor consists of a number of aluminum anodes (act as sacrificial electro-plates) and stainless steel cathodes which are connected in dipolar mode. Fig 1 illustrates the setup of the whole system.

The restaurant wastewater, after the treatment of the grease trap, enters the reactor from the bottom and flows upward through the narrow spaces between the electrodes. During electrolysis, aluminum dissolves and coagulates with the pollutants. At the same time, gas bubbles which are generated at the electrodes will assist in the flotation of flocs.

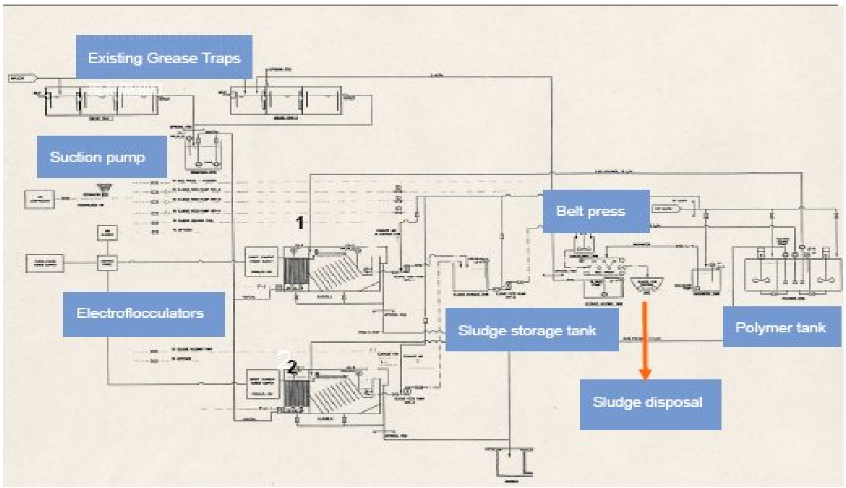


Fig.1. Systematic figure of the electroflocculater

A DC current supply provides the electrical power. The current can be adjusted in the range of 0-1000A, and the potential difference between the electrodes can then be varied from 0 – 18V. The voltage will vary automatically according to the wastewater conductivity.

Literature review:

Most studies seem to agree that an electroflocculater can remove a vast variety of pollutants in wastewater. Robinson (2000) suggested that electroflocculation can typically remove 99% of bacteria in wastewater from agricultural industry by physically destroying it. It was also found that electroflocculation efficiently reduced the color, turbidity, bacteria count and BOD_5 of domestic wastewater, over 99% in most of the cases. The application of electroflocculation on treating monosodium glutamate fermentation wastewater had been investigated (Chen, Chen and Cheng 2002).The experimental results showed that electroflocculation can efficiently remove the organic and color of MSG fermentation wastewater. In addition, the anionic polymer acts as a better floatation agent than both cationic and nonionic polymers.

However, there were also some reports which were not in line with the above studies. Nielson and Smith (2005) suggested that the electroflocculater cannot effectively remove soluble compound such as COD and BOD, although it showed satisfactory result in removing suspended solids.

The purpose of this research:

Although much work has been done to date, few studies have specifically reported on the performance of electroflocculater on treating restaurant wastewater. Therefore, it is suggested that more investigation need to be conducted to ascertain the efficiency of electroflocculater on treating restaurant wastewater, which has a characteristic of high oil content and dissolved organic substances.

The purpose of this study was to ascertain the efficiency of electroflocculater on reducing pollutants in restaurant wastewater. The electroflocculater chosen to be investigated which was located at phase II of City

University of Hong Kong.

This system was setup to treat the restaurant wastewater, which had been pre-treated by an oil trap, produced by the canteen of the University. Facilities Management Office of the university provided information showed that about 100,000 m^3 of wastewater was generated each year from the catering outlets. Therefore, it was necessary to thoroughly examine the quality of the wastewater after electroflocculation. Seven major parameters were selected to determine the quality of the electroflocculated wastewater — pH, turbidity, conductivity, TOC, BOD_5, FOGs and aluminum concentration. In addition, the efficiency of the electroflocculation would be compared with another wastewater treatment method (hybrid method) – chemical dosage of aluminum sulfate followed by membrane filtration.

MATERIALS AND METHODS

Sampling technique

Wastewater samples were collected 1 time per week at the phase II electroflocculater of City University of Hong Kong. 1 liter of wastewater sample was collected respectively from the inlet and the outlet of the system. During sampling, one liter volume glass bottle was used and it was autoclaved beforehand. Wastewater sample would then being measured immediately in laboratory after wastewater sample collection.

pH measurement

Instruments: pH-meter (HANNA HI8484; calibrated with pH 4 and pH 7 buffers respectively)

Shake the 1L non-electroflocculated wastewater (*inlet*) evenly inside the glass bottle, and then pour 30ml wastewater into a 50ml beaker. Temperature of the 30ml wastewater of was measured with a thermometer in a 50ml beaker. Then, measured temperate result would be used to adjust the measuring temperature of the pH-meter. The pH-electrode was then immersed into the 30ml wastewater sample with a magnetic stir bar swirling. The pH reading was taken until the pH-meter give a steady readout. The previous steps were repeated to measure the pH of the electroflocculated wastewater from the electroflocculated wastewater (*outlet)*.

Turbidity measurement

Instruments: turbidimeter (HACH 2100P)

Fig. 2. Turbid-meter

Wastewater sample from the outlet was poured into the turbid-meter glass sample bottle. The sample solution was shaken well to make sure the suspended solid distributed evenly inside the bottle. The bottle was then placed inside the turbidimeter, and the turbidity of sample was measured in the unit (NTU). This procedure was repeated for 2 more times with the outlet wastewater sample.

Wastewater sample from the inlet was poured into the turbidimeter glass sample bottle. The sample solution was shaken well to make sure the suspended solid distributed evenly inside the bottle. The bottle was then placed inside the turbidimeter, and the turbidity of sample was then measured. This procedure was repeated for 2 more times with the inlet wastewater sample.

Conductivity measurement

Instruments: bench-top conductivity meter (Cole-Parmer’s 19000-00-05; calibrated with 0.01M KCL)

The electrode of the conductivity meter was immersed into 50ml 0.01M KCL solution for calibration. After 15 minutes, the readout of the conductivity meter was adjusted to 1413μS and the temperature was set to 20℃.

50ml of the outlet wastewater sample was poured into a 100ml beaker. The electrode of the conductivity meter was immersed into the solution. During measuring, the solution was stirred until stable reading was displayed. This procedure was repeated for 2 times more.

50ml of the inlet wastewater sample was poured into a 100ml beaker. The electrode of the conductivity meter was immersed into the solution. During measuring, the solution was stirred until stable reading was displayed. This procedure was repeated for 2 times more.

Total organic carbon measurement (TOC)

Instruments: TOC analyzer (Shimadzu TOC 5000A)

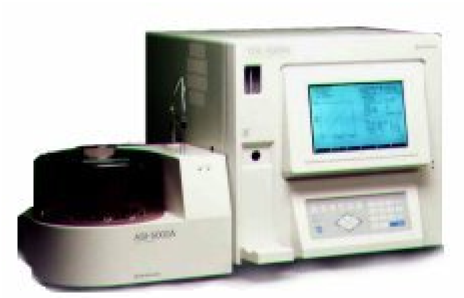


Fig. 3. TOC analyzer

Respective 50ml of the sample from the inlet and outlet was filtered with suction filtration. Then the wastewater sample was filled into a TOC test-tube and being measured. Distilled water was used as blank.

Bio-oxygen demand(BOD_5)

Instruments: Dissolved oxygen-meter (YIS model 58)

Fig. 4. Dissolved oxygen-meter

Reagents: a) Phosphate buffer solution (dissolve 8.5g KH_2PO_4, 21.75g K_2HPO_4, 33.4g $Na_2HPO_4.7H_2O$, and 1.7g NH_4Cl in about 500mL distilled water and dilute to 1L. The pH should be 7.2 without further adjustment.)

b) Magnesium sulfate solution (dissolves 22.5g $MgSO_4$.7H2O in distilled water and diluted to 1L)

c) Calcium chloride solution (dissolves 27.5g $CaCl_2$ in distilled water and dilute to 1L)

d) Ferric chloride solution (dissolves 0.25g $FeCl_3.6H_2O$ in distilled water and dilute to 1L)

Preparation of nutrient solution

1mL each of phosphate buffer, $MgSO_4$, $CaCl_2$, and $FeCl_3$ solutions were added into 1L of distilled water. The solution was then pumped with air for 1 hour to saturate its oxygen gas concentration.

To fill in six 300ml BOD_5 bottles according to table 1:

Table 1. Different dilution of inlet wastewater

	Bottle 1	Bottle 2	Bottle 3
wastewater sample from inlet	10 ml(original concentration)	10ml(previously diluted by 10 fold)	10ml(previously dilute by 100 fold)
Nutrient solution	290ml	290ml	290ml

Table 2. Different dilution of outlet wastewater

	Bottle 4	Bottle 5	Bottle 6
wastewater sample from outlet	10 ml(original concentration)	10ml(previously diluted by 10 fold)	10ml(previously dilute by 100 fold)
Nutrient solution	290ml	290ml	290ml

The initial DO of the solutions in the six BOD_5 bottles was measured with dissolved oxygen-meter. Then, the BOD_5 bottles were incubated in 20℃ for 5 days.

The final DO of the solutions in the six BOD_5 bottles was measured with Dissolved oxygen-meter and recorded.

Fat, oil and grease(FOG) content

Instruments: quick fit for distillation, 1 L separating funnel

Reagents: conc. HCl, n-hexane (Lab-scan, 99% n-hexane), anhydrous sodium sulfate

10ml conc. HCl was respectively introduced into 1L wastewater sample from outlet and inlet of the electroflocculater in glass sampling bottles.

1L of the acidified inlet wastewater sample was poured into a 1L separating funnel, followed by 50ml of n-hexane. Stopper the separating funnel with a glass cork, and then shake it vigorously for about 5 minutes. Meanwhile, the built-up pressure inside the separating funnel should be released by opening the tap of the funnel. The separating funnel was then settled with a funnel ring holder like fig.1 for about 30 minutes until two immiscible liquid layers were formed. The n-hexane layer was discharged into a 250ml beaker. Excess anhydrous $NaSO_4$ power was added into the solution until the turbid solution turned into clear. This was repeated with another 50ml n-hexane solution to extract the same sample.

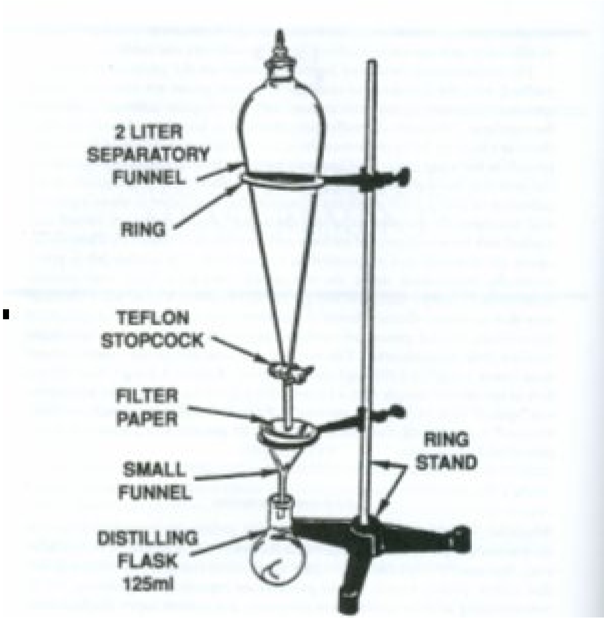


Fig.5. Setup of the separating funnel.

A 250ml round bottom flask with several anti-bumping granules was previously weighted. Then, the two beaker of n-hexane extract was filtered into the round bottom flask through a filter paper.

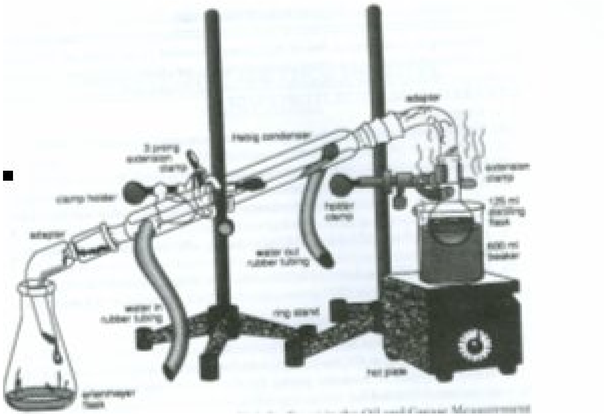


Fig. 6 . Setup of the distillation quick fit.

Assemble the quick fit according to fig. 6 and start the distillation. The distillate which came out at 69℃ was n-hexane; therefore, the remaining solution was the yellowish extracted oil from the wastewater. The heating was ceased when the distillate temperature started to rise over 69℃. The round bottom flask was weighted again. As a result, the amount of oil in the 1L wastewater sample could then be calculated by the weight difference.

The above procedure was repeated to determine the oil content of the wastewater sample from the outlet of the electroflocculater.

Aluminum concentration measurement:

Reagent: conc. HCl, conc. HNO_3

Instrument: ICP-MS, 50ml volumetric flask

Firstly, 5ml conc. HCl and 5ml conc. HNO_3 was introduced into the 50ml inlet wastewater. Then, the solution was boiled for 15 minutes. 1ml of the solution was pipette into a 50ml volumetric flask and was diluted to the mark with DI water. The diluted solution was then measure with ICP-MS.

The outlet wastewater was repeated with the same procedure. And, the acid blank was also measured.

Conventional coagulation using Alum followed by 0.20um membrane filtration(hybrid method):

Reagent: $Al_2(SO_4)3\cdot 18H_2O$ (Hjax Chemicals)

Apparatus: 0.20 μm membrane(sterile-E0)

1g of $Al_2(SO_4)3\cdot 18H_2O$ was added into the inlet wastewater. Continues swirling was necessary for help the aluminum sulfate to dissolve. The pH was maintained in the range 6.5-7.5. When the pH is low, calcium oxide was added. On the other hand, when pH is high, dilute HCl (0.1M) was added to adjust the pH back into the range. Then, the solution was kept standstill for 1 hour.

After the coagulation process, the solution was filtered with 0.20 μm membrane. The TOC and turbidity of it was then measured.

RESULTS AND DISCUSSIONS

Effect of electroflocculater on pH of wastewater:

Table 3. Result of the pH change after electroflocculation

	pH		
sample	Inlet	Outlet	pH change (%)
1	6.03	6.09	-0.995
2	5.83	5.91	-1.372
3	6.47	6.86	-6.028
4	6.43	6.81	-5.910
5	6.07	6.02	0.824
6	6.26	6.42	-2.556
average	6.18	6.35	-2.673

The average pH of outlet wastewater was 6.35, which was very close to the average pH of the inlet wastewater. Although no significant changes in average pH values, it was noticed that, in sample 1, 2, 3, 4 and 6, the electroflocculater tended to neutralize and raise the pH of the wastewater. (In table 3, the –ve sign in pH change means increase in %)

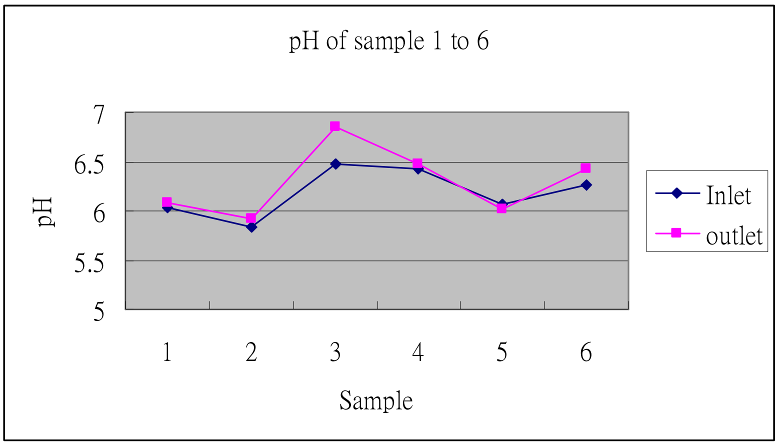


Fig. 7. Trend of pH of sample 1 to 6

The pH of the outlet wastewater was found, 2.673% by mean, higher than the inlet after the treatment of electro-flocculation. This phenomenon coincided with the experimental results of Chen, Chen, and Cheng. (2002), which claimed that the electroflocculater tended to shift the pH of the wastewater close to neutral. And this could be explained by the reaction at the cathode and anode of the electroflocculater as following:

Anode reaction:

$$Al_{(s)} \rightarrow Al^{3+}_{(aq)} + e^{-} \quad (1)$$

Cathode reaction:

$$2H_2O_{(l)} + 2e^{-} \rightarrow 2OH^{-}_{(aq)} + H_{2\,(g)} \quad (2)$$

The hydroxide ions produced at the cathode increase the pH of the wastewater. The pH of the inlet wastewater is in the range 5.83 – 6.47, and the electroflocculater, in average, raises the pH of it by 2.673 %(see table 3). This allow the outlet wastewater to reach the discharge standard (pH 6 - pH 10).

The pH of the inlet wastewater would not affect the efficiency of electroflocculater on removing FOG, SS and COD (Chen, Chen and Cheng 2002), except the pH < 4 or > 9. Since the pH of restaurant wastewater is already at the optimum range, it is believed that the performance of the electroflocculater on lowering other pollutants is independent of inlet wastewater pH. This would be an advantage that it saves an effort on adjusting the pH of the system.

Effect of electroflocculater on conductivity of wastewater:

Table 4. Result of conductivity change after electroflocculation

	Conductivity		
sample	Inlet(μS)	Outlet(μS)	Decrease of conductivity (%)
1	2070	780	62.32
2	690	463	32.10
3	670	549	18.06
4	883	288	67.39
5	1162	374	67.80
average	1095	490.8	49.70

The average conductivity of inlet wastewater was 1095μS. It was found that the electroflocculater can lower the conductivity of wastewater by 49.70%. This parameter can indirectly show the removal efficiency of electroflocculater on decreasing the high $NaCl_{(s)}$ level in restaurant wastewater. Since directive measurement on $NaCl_{(s)}$ concentration would be extremely inconvenient, so this method is relatively fast and easy. In this research, it was found that the electroflocculater could remove 49.70% of salts in average (see table 4).

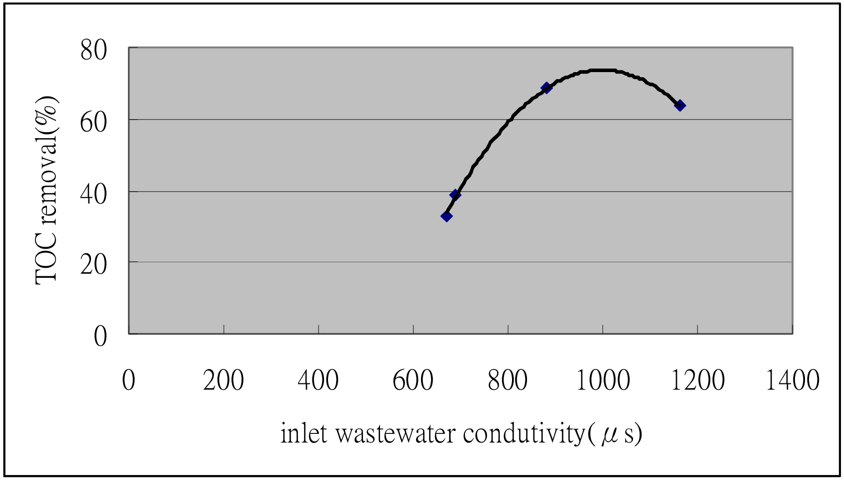


Fig. 8. Change on TOC remval rate upon increase of conductivity

The electroflocculater could alter the potential difference between the electrodes in reactor varied from 0 to 18V. And the voltage varied automatically according to the wastewater conductivity. It was found that when the conductivity was high, the electroflocculater gave a better performance on removing TOC (see graph 2)

Efficiency on removing suspended solid (SS):

The ability of electroflocculater on reducing the SS was examined with the parameter – turbidity. The average turbidity of inlet wastewater was 228 NTU and the electroflocculater could effectively remove 85.05% SS. The average turbidity of outlet wastewater was obtained equal to 32.07 NTU. (see table 2)

Table 5. Result of turbidity change after electroflocculation

	Turbidity		
Sample	Inlet(NTU)	Outlet(NTU)	Removal efficiency (%)
1	150	30.0	80.00
2	276	10.7	96.12
3	205	15.1	92.63
4	249	49.6	80.08
5	276	23.1	91.63
6	212	63.9	69.86
Average	228	32.07	85.05

In that study, the amount of SS was examined with turbid meter. The results showed that the electroflocculater can successfully lower the turbidity of wastewater by 85.05 %(Table4). The average turbidity of discharged treated restaurant wastewater was 32.7NTU, which met the permission standard of EPD (75NTU).

Rose of SS concentration of discarded wastewater upon temperature drop:

A problem is figured out upon the electroflocculater upon SS removal. The turbidity of outlet wastewater soars when temperature dropps (see fig. 2).

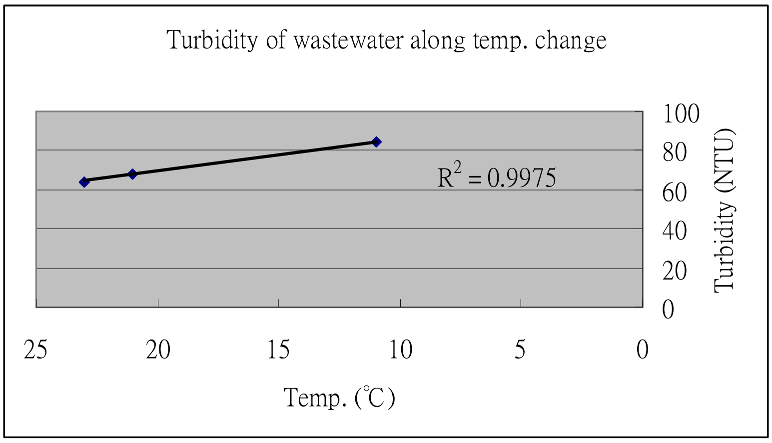


Fig. 9. Turbidity change when temperature drops

A sample of outlet wastewater was investigated. 50ml of the sample was placed in the fringe, the turbidity of the sample increased by 31.92% when its temperature dropped gradually by 12℃. This could be explained that the retention time of wastewater inside the electroflocculater is not long enough. Thus, the dissolved organic substances do not have enough time to form flocs through electro-coagulation and being removed as sludge.

After discard, since the aluminum derivatives and flocs are still reacting, when the temperature drops, the solubility of flocs decreases and is then being speeded up to be precipitated out. It is believed that while the discharged wastewater from the outlet of the system flows along the narrow and cold water pipe, especially in winter when the temperature is usually around 10℃ in Hong Kong, this effect would be much more predominant. This may lead to the turbidity rise over the permission standard of EPD.

In order to improve the performance for the electroflocculater on removing SS, it was suggested that the retention time of the wastewater inside the system should be increased by lowering the flow rate. This provides optimum time for electro-coagulation and electro-flotation.

Efficiency on fat, oil and grease (FOG) removal:

Table 6. Result of FOGs change after electroflocculation

Parameter	Number of sample	Inlet (mg/L)	Outlet(mg/L)	Removal efficiency (%)
FOG	2	3870	3010	22.22

After the treatment of the grease trap, 3870mg of FOG per liter in average of wastewater was found at the inlet of the system. FOG concentration at the outlet was 3010mg/L. The efficiency of the electroflocculater on removing FOG in wastewater was equal to 22.22%.

In this research, the standard method of Jackson (1993) on determining FOGs content was employed. However, there was an amendment. Freon-113 was replaced with another extraction solvent (n-hexane). Thus, FOGs was defined as n-hexane extractable substances. It was necessary to not use Freon-133 as extraction solvent because it was CFCs which had been proved causing damage to the ozone layer. Besides, a vast volume of solvent would be used in each experiment.

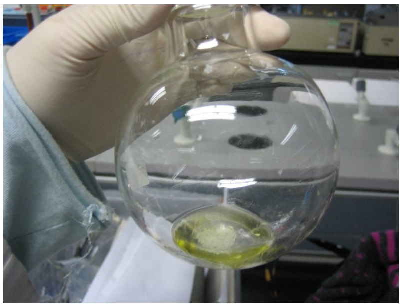


Fig.10. n-hexane extracted FOGs of outlet wastewater from distillation

Before the restaurant wastewater flowed onto the electroflocculater, it was expected that a large proportion of the oily substances would had been removed by the grease trap. However, the FOGs measured at the inlet wastewater were still high, the average was 3870 mg/L. Fig.10 showed the n-hexane extracted FOGs from distillation. On the other hand, the electroflocculater did not remove the FOGs successfully; the removal efficiency was only 22.22% by mean. And, the FOGs concentration at the outlet of the system was 3010mg/L, which was much higher than the permission standard of the EPD(100mg/L).This result was inconsistent with the previous research (Robinson 1999), which claimed that electroflocculater can remove over 99.9% of FOGs.

This large in differences could be attributed to the nature and amount of FOGs in the wastewater. In the research of the Robinson (1999), the wastewater which was examined was industrial wastewater. However, in the current experiment, the wastewater was restaurant wastewater. In restaurant wastewater, the FOGs mostly came from animals, fryers and plant sources, which were relatively much more emulsified. In fig.11, it showed the feature of restaurant wastewater. It could be noticed that no distinguishable layer was found, though the FOGs level was very high.

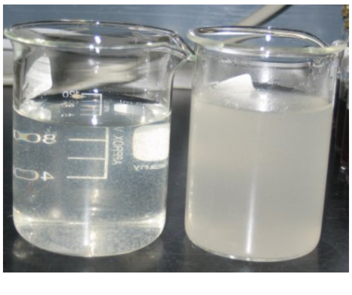


Fig.11. Outlet wastewater (left) inlet wastewater (right)

It is suggested that FOGs could induced sewer system blockages, because FOGs naturally stick to the wall of metal, plastic and ceramic sewer piping.

Efficiency on removing total organic carbon (TOC):

Table 7. Result of TOC change after electroflocculation

	TOC		
Sample	Inlet(mg/L)	Outlet(mg/L)	Removal efficiency (%)
1	284.6	193.3	32.08
2	329.8	191.6	41.90
3	442.2	269.9	38.96
4	547.0	365.9	33.11
5	613.4	192.2	68.67
6	1034	375.6	63.68
Average	541.8	264.8	46.40

In table 6, it showed that the average TOC concentration at the inlet wastewater was 541.83mg/L, and the electroflocculater could remove 46.40% of TOC in the wastewater, in average. An average of 264.75mg/L total organic substances was remaining inside the electroflocculated wastewater, and was discarded at the outlet.

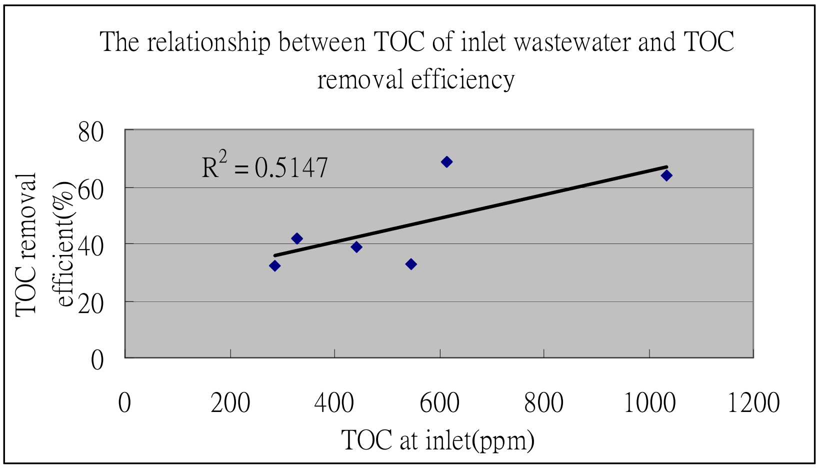


Fig.12. TOC removal rate change upon increase of TOC at inlet wastewater

In graph 4, it showed that the TOC removal efficiency trended to increase when the TOC contend increase in the inlet wastewater. As a result, the TOC concentration of wastewater at the outlet of the system was maintained in the range from 191.6mg/L to 375.6mg/L, while the TOC concentration at the inlet wastewater had a wider range from 284.6mg/L to 1034mg/L.(see table)

Efficiency on removing BOD_5:

Table 8. Result of dissolved oxygen change after electroflocculation

	Inlet		outlet	
Sample	before(mg-O_2/L)	after(mg-O_2/L)	before(mg-O_2/L)	after (mg-O_2/L)
1	9.2	6.3	9.1	7.7
2	9.1	6.6	9.2	7.6
Average	9.15	6.45	9.15	7.65

Bio-oxygen demand was calculated with the following equation:

$BOD_5 = (B_1 - B_2)/P$

Whereas

B_1 = average of initial DO

B_2 = average of finial DO

P = dilution factor (P was taken to 0.03333 in this experiment)

Table 9. Result of BOD_5 change after electroflocculation

	Inlet(mg/L)	Outlet(mg/L)	removal rate
BOD_5	810.1	450	44.45%

Since the dilution chosen was tenfold, the BOD_5 had been multiplied by ten. The mean BOD_5 of the inlet wastewater was 810.1mg/L. And, the electroflocculater could remove 44.45% of bio-degradable dissolved organic substances in wastewater. The mean BOD_5 of the outlet wastewater was 450mg/L, which was lower than the discharge limit of the EPD (1200mg/L). Although it reached the permission standard of EPD, the removal efficiency (44.45%) was not satisfactory. Poor BOD_5 and TOC removal was not abnormal in electro- flocculation, as Nielson and Smith (2005), reported BOD_5 removals of no more than 50-60% and COD removals of only 35% when using electroflocculation technology to treat Gold Bar wastewater. In some cases, it was not rare that the restaurant produced wastewater with BOD_5 over 3000mg/L. Then, the electroflocculater would possible to produce effluent with BOD_5 beyond the EPD permission standard, with that low BOD_5 removal efficiency.

Effect on aluminum concentration:

The aluminum concentration of inlet and outlet wastewater was measured with ICP-MS. Since the aluminum ions may be bound tightly to the organic substances, the wastewater samples were therefore treated with wet digestion. In this processes, the wastewater sample was refluxed with a solution of conc. HCL and conc. HNO3. The purpose was to digest all the organic substances and release the aluminum ions out, for accurate analysis with the ICP-MS.

Table 10. Result of aluminum concentration change after electroflocculation

	Aluminum concentration		
sample	Inlet(ppb)	Outlet(ppb)	Increase of Al concentration (%)
1	1849.0	7139.6	286.1
2	271.6	5888.4	2068.0
3	654.0	3656.3	1988.0
4	1604.0	4727.4	194.73
average	1094.7	7853.0	1134.2

It was found that the electroflocculater could increase the aluminum level of wastewater by 20 times in maximum, and by mean, it increased the aluminum level by 1134.2%. In the worst case, the concentration of aluminum in effluent even reached 7.140 mg /L.

Although there is currently no strict rule on monitoring the aluminum level on wastewater discharge, it has already raised the concern of some environmental scientists. Also, the potential toxicity of aluminum has become a major medical issue.

Fairman and Sanz-Mendel (1995) claimed that, in 1970's, aluminum was first associated with dialysis dementia syndrome. Since then, comparatively high aluminum levels in body tissues have been implicated in various clinical disorders suffered by patients with chronic renal failure undergoing regular haemo-dialysis which water of dialysis fluids high in aluminum has been used.

Moreover, Alzheimer’s disease has been demonstrated a positive relationship with aluminum level in daily intake by epidemiological studies (WHO 1998). If aluminum is unlimitedly discharged into the environment and enters the food chains, it would harm human beings in certain extends.

In addition, aluminum has been proved toxic to aquatic organism. In the river and lakes of U.S.A. and Canada, the decline in fish numbers, and in some cases the elimination of entire fish populations, has been linked to the subsequent increase in aluminum level (Fairman and Sanz-Mendel 1995). It was identified that the $Al(OH)^{2+}$ and $Al(OH)_2^{+}$ species was toxic to fishes. The mechanism could be attributed to two main factors. Firstly, at aluminum concentration (>0.5mg/L), colloidal aluminum hydroxide species could clog fish gill and inhibit proper respiratory function. Secondly, at aluminum concentration (<0.2mg/L), aluminum alters the passive permeability to ions of fish gills. As a result, it disrupted the normal osmo-regulatory balance.

In nature, it has been reported that the normal aluminum concentration was 0.001-0.05mg/L (WHO 1998). In this research, it is believed that the negative effect on the environment would be serious when the electroflocculated effluent, which contains possibly 7, 000 times aluminum level higher than in nature, is discharged into the harbors and seas without proper monitoring. The aquatic ecological system could be severely damaged.

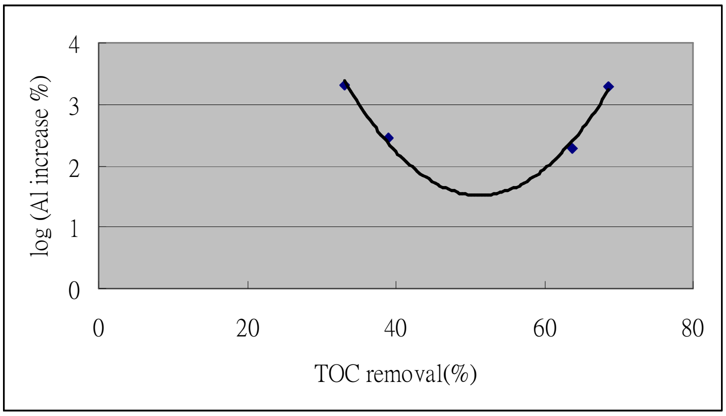


Fig.13. Rate of increase of aluminum according to the increase of TOC removal rate

Fig.13 showed the relationship between aluminum increase percentage and TOC removal efficiency. It was found when TOC removal efficiency was high (68.67%) and low (33.11%), there were large increase in aluminum concentration in wastewater. For the former one, it was possibly due to the over dose of aluminum by the electroflocculater. For the latter one, it was possibly due to the aging of the aluminum plate electrodes. At the process of electro-flotation, the size of the gas bubble produced played a crucial role (Chen, Chen and Cheng 2002). Large gas bubbles had a relatively larger chance of effective contact between bubbles and particles. Consequently, a better TOC removal rate would be obtained. However, while the aluminum plate electrode became old, rough surface was resulted from corrosion. Thus, small gas bubbles would be produced and low TOC removal percentage was obtained. This also leaded to large amount of aluminum residue left inside the effluent and caused large high aluminum increase percentage.

At 2004, according to economic information, the aluminum price was about HK$16/kg. Since the FMO of City University of Hong Kong reported that 100,000 m^3 of wastewater was generated each year and the aluminum remaining in the effluent was around 7mg/L. Therefore, 714 tons of aluminum would be discharged into the sea and wasted. It is estimated that HK$10, 000 of aluminum would be lost per year by discharging the metal ions with effluent, due to the inefficient pollutant removal.

Conventional coagulation using Alum followed by 0.20um membrane filtration (hybrid method):

Table 11. Result of the turbidity change after coagulation with Alum and membrane filtration

Sample	before(NTU)	after(NTU)	Removal efficiency (%)
1	184	1	99.46
2	205	0.35	99.83
3	212	2.57	98.79
4	249	0.88	99.65
5	276	0.73	99.74
average	225.2	1.106	99.49

Table 11 showed that the hybrid method of chemically dosage of aluminum sulfate could on average lower the turbidity of the restaurant wastewater by 99.50%. This removal rate was higher than the electroflocculater which could only remove 85.05% of SS.

The high efficiency of this method could be attributed to the 0.20 μm membrane. With these tiny pores on the membrane, only 0.5% of the SS in restaurant wastewater is capable of passing through. In some cases, the turbidity of treated water was lower than 0.5 which even reached the physical standard (<2NTU) of drinking water.

Table 12. . Result of the turbidity change after coagulation with Alum and membrane filtration

Sample	Before(mg/L)	after(mg/L)	Removal efficiency (%)
1	284.6	193.3	32.08
2	442.2	1.528	99.65
3	462	22.97	95.01
4	613	515.4	15.92
5	1034	811.4	21.53
average	567.2	309.0	52.842

The result showed that this method could remove 15.92 – 99.65% of TOC in restaurant water, and the mean removal efficiency was 52.84%, which was better than the electroflocculater 46.40% by mean.

The large fluctuation of removal efficiency on dissolved organic substance of this method was caused by the amount of dosage of aluminum sulfate in restaurant wastewater. Gao, Yang, Zhang and Hu (2004) reported that the dosage of aluminum sulfate in a rate of 90mg/L of oilfield wastewater could successfully remove >80% of TOC. Thus, the low removal efficiency at sample 5

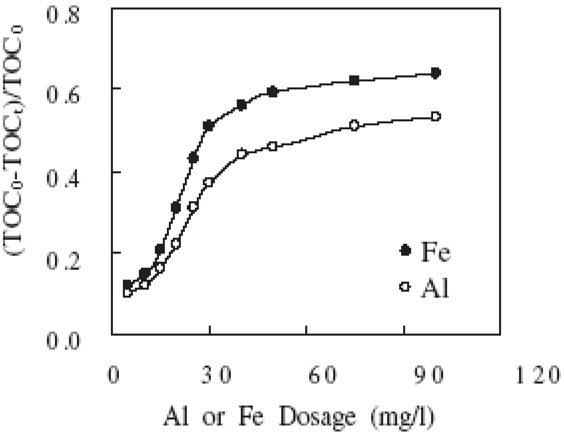


Fig.14. Comparison on Alum and Ferric coagulation on TOC removal (Gao Y.X., M. Yang, Y. Zhang, and J.Y. Hu 2004)

was due to the high TOC(1034mg/L) in restaurant wastewater. In consequence, the added aluminum sulfate was insufficient to precipitate out the dissolved organic substances. Moreover, higher TOC contend needed longer coagulation time (>1hour). To improve the method, the optimum dosage of aluminum sulfate should previously be determined. Different amounts of aluminum sulfate were added into the restaurant wastewater, then, a calibration curve will be plotted according to the increase in turbidity. The dosage which would bring the highest increase of turbidity is the optimum dosage. The aluminum residual would also need to be considered. The lower the residual, the better dosage rate will be obtained.

The pH needs to be keep within the range of 6.5-7.5 to obtain better efficiency of coagulation with aluminum ions of TOC. If the pH is out of this range, the flocs forming would be unstable. As a result, large flocs are not enhanced to be formed. It is suggested that, at alkaline condition, stable $Al(OH)_3$ is formed. Therefore, the function of aluminum ions as coagulant would be lost. On the contrary, at acidic conditions, the aluminum ions are too soluble and not intend to bind with pollutants.

The efficiency of electroflocculater on removing other pollutants:

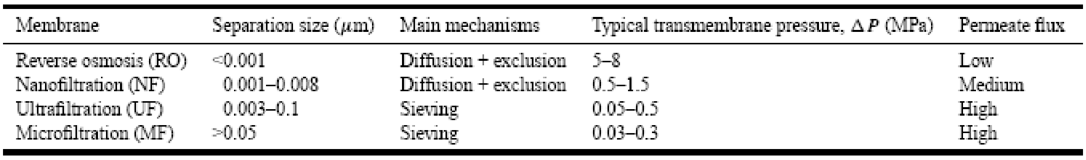
Although the capability of the electroflocculater on removing other pollutants, such as nitrates, phosphates and sulfates, were not being measured in the research. The WHO (1995) reported that the electro-coagulation method reduced those parameters by 77.5% for nitrates, 83.3% for phosphates and 20% for sulfates at the optimum electro-current (40 mA) used for coagulation.

In addition, Huang, Su, Huang, Ho and Tsal (2000) suggested that coagulation triggered with aluminum ions was a good method on removing heavy metal ions, such as Cu, Zn, Pb, Cr,Co, in wastewater. The mechanism is that the heavy metal ions would be absorbed into the flocs during coagulation. It is believed that the electroflocculater could help on removing significant percentage of heavy metal in restaurant wastewater, though unlike industrial wastewater, restaurant wastewater only contains trace amount of heavy metal ions.

Comparing the electroflocculation with membrane filtration:

Membrane filtration could be divided into micro-filtration, ultra-filtration, nanofiltration, utrafiltration, reverse osmosis and nanofiltration. Their characteristics are shown in table 13. In which reverse osmosis could separate particle size down to less than 0.001μm.

Table 13. Characteristic of the four membranes - RO, NF. UF and MF (Zhou and Smith 2002)



Membrane	Separation size (μm)	Main mechanisms	Typical transmembrane pressure, ΔP (MPa)	Permeate flux
Reverse osmosis (RO)	<0.001	Diffusion + exclusion	5–8	Low
Nanofiltration (NF)	0.001–0.008	Diffusion + exclusion	0.5–1.5	Medium
Ultrafiltration (UF)	0.003–0.1	Sieving	0.05–0.5	High
Microfiltration (MF)	>0.05	Sieving	0.03–0.3	High

Zhou and Smith (2002) suggested that even ultrafiltration and microfiltration was already good enough for solid-liquid separation. However, both of them were inefficient in dissolved organic substance removal, the typical removal rate was <15%. Reverse osmosis performance in removing pollutants would be better than any ordinary treatment system. Since it could filter particle size down to less than 0.001μm, with this range, all dissolved organic substances and even ammonium could be filtered by the membrane. Also, unlike electroflocculation, membrane filtration would not leave coagulant in effluent. However, reverses osmosis is far too expensive to be used in wastewater treatment.

In this research, electroflocculater which could typically remove over 50%

of dissolved organic and inorganic substances as well as over 85% of suspended solid. It is believed that electroflocculater could become the mainstream wastewater treatment system, because it is relatively economy.

Suggestions on improving the performance of electroflocculater:

According to the result of hybrid method of this research, this best optimum result was that >99 % of SS and TOC in restaurant wastewater were removed. The reason could possibly be that the optimum dosage of alum is achieved, as a result, relatively large flocs could then be entirely filtered by the 0.20 μm membrane. However, this method has a very serious disadvantage, that is, the coagulation time is too long (>1hour). The restaurant is producing huge amount of wastewater throughout the whole day, and it is impossible to provide such a large area to build a buffering tank for the coagulation process.

To improve, it is suggest that the two treatment method-electroflocculation and membrane filtration could be employed at the same time. Shon ,Guo, Vigneswaran, Ngo and Kim (2004) suggested that microfiltration with a flocculation pretreatment could increase the TOC removal efficiency by twofold. Thus, the best pollutant removal result is expected to obtain when electroflocculater coupled with microfiltration.

Suggestions for future study on electroflocculater:

It is suggested that the optimum dosage of aluminum by the electroflocculater and the method on reducing aluminum residual in effluent is needed to be studied.

In addition, the performance of electroflocculation-microfiltration combined method on wastewater treatment would also be an interesting study area.

CONCLUSION

The present study finds out that the electroflocculater can remove both TOC and BOD5 by nearly 50%. The SS removal efficiency achieves good result, in which the turbidity is reduced by 85.05%. A disadvantage is that the aluminum residual concentration is very high at wastewater effluent which is 7000 times higher than nature raw water. It is suggested that, in order to improve the performance of the wastewater treatment system, the electroflocculater can be coupled with microfiltration.

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