Separation of pollutants from restaurant effluents as animal feed, fertilizer and renewable energy to produce high water quality in a compact area

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This paper demonstrates that oil and grease (O & G), chemical oxygen demand_{settled} (COD_{S}) and chemical oxygen demand_{total-settled} (COD_{T-S}) levels in restaurant wastewater can be reduced to less than 50, 400 and 160 mg/L, respectively, even during busy hours (1200–1400 h), provided it is subject to chemical treatment with dissolved air flotation (DAF). After treatment the wastewater turned very clear and may be reused for various applications. The sludge generated from flotation can be recycled as an animal feed to give a mean protein content of 8.26%, a mean phosphorus level of 0.11%, and a mean calorific value of 6690 cal/g. This can be utilized as a fertilizer and a biofuel with nitrogen and phosphorus level equivalent to those of pig manure and a calorific value higher than that of wood and coal, respectively.

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1. Introduction

Biological treatment of wastewater is generally agreed to be the best method [1]. However, most restaurants in Hong Kong are located in commercial buildings and it is difficult to find sufficient space to install a large biological treatment plant. Furthermore, the biodegradation rate of microbes is quite slow [2], so that the method is unsuitable to be applied in Hong Kong especially during peak hours (1200–1400 h). In fact, many commercial biochemicals, microbial cultures and enzymes are available in the market, but trials over 20 years have not given satisfactory results, especially during the peak hours. It seems that the biological method is not a practical and effective solution under the circumstances. Thus, it is important to
find an alternative and more suitable method. Karlsson [3] has suggested that chemical precipitation provides an alternative approach to biological wastewater treatment. The former occupies less space for installation and is easier to maintain than the latter; in addition, chemical precipitation is not subject to disturbance (due to pH variation of effluent) by most industrial wastewaters and the reaction occurs quickly. Accordingly, chemical treatment is attempted here.

The Hong Kong Drainage Services Department (DSD) claimed in 2000 that more than 60% of sewer blockage was due to clogging from grease. In Hong Kong, most restaurants use grease traps (a gravity separation method) to treat their effluents. However, it has been noted that many restaurants have been prosecuted by the Environmental Protection Department (EPD) for failure to meet the conditions of their WPCO (Water Pollution Control Ordinance) licences, especially for O & G content (the highest limit is 100 mg/L). Cheremisinoff [4] pointed out that most food industry effluent contains insignificant free oil, and the gravity separation method removes little or no emulsified oil. Sokolovic et al. [5] also demonstrated that conventional gravity separation is not effective for fine oil-in-water dispersion (oil droplets < 10 μm), since most of the O & G is finely dispersed in this emulsion and cannot be separated in the grease traps (except oil droplets with a diameter > 20 μm) [4]. Alkaline detergents have been used extensively for cleaning purposes in most restaurants. They containing surfactants that emulsify free oils are present in most of the trade effluents. Most surfactants used have either anionic or non-ionic polar groups that emulsify free oil [6]. In fact, high temperature food preparation may break the oil and grease into small droplets. Furthermore, tap water used for washing is not deionised so that it carries both negative and positive charge. As a result, most of the oil becomes emulsified with water, passes through the grease trap and is discharged in the effluent. Experience over 20 years in this field revealed that this is why almost 100% of the restaurants monitored have been found to exceed their licence limit for the O & G level. Kemmer [6] claimed that the dielectric properties of water and oil cause emulsified oil droplets to carry negative charges. Hence, a cationic emulsion breaker should be used to destabilize the emulsion. Roggatz and Klute [7] managed to use a ferric salt emulsion breaker and enhanced this with DAF and pressure flotation (induced air) for O & G removal in municipal wastewater. Hence, DAF enhanced with chemicals to reduce O & G content was conducted for our compact commercial areas.

On the other hand, the Drainage Authority [8] has since 1995 set COD levels as the only criterion for assessing the water quality of all trade effluents (other than domestic and institutional type) in order to collect surcharges from the dischargers. At present, the TES (Trade Effluent Surcharge) for restaurants is HK $3.05/m3. If the COD$_S$ (S = Settled for 1 h) content of a trade effluent discharged to a public foul sewer is less than 400 mg/L and the COD$_{T-S}$ level is also less than 160 mg/L, there is no TES. Berne and Richard [9] explained COD as representing everything that can be oxidized, particularly certain oxidizable mineral salts (sulphides, sulphites etc.) and most organic compounds while Kemmer [6] defined COD as a measure of organic matter and other reducing substances in water. It implies that COD is a measure to include O & G as well. Odegaard [10] revealed that effluents from food-processing industries contained mainly soluble organics and about 40–70% of COD were related to total suspended solids (SS). Since the turbidity of a sample for this trade effluent comes from the presence of SS and emulsified oil and the effluent arisen from the food industry is heavily loaded with these pollutants, COD can be used to evaluate its water quality.

Cassell et al. [11] and Berne and Richard [9] stated that the finer is the bubble (~50 μm and 40–70 μm, respectively), the more colloidal sized impurities will be separated from wastewater. In fact, for the design of an effective saturator for DAF system, air to solids (A/S) ratio is one of the criteria to be considered [12,13]. Many of the suspended solids in raw water sources are colloidal clay particles [14]. Berne and Richard [9] listed DAF with 20% recirculation system is the best for removal of fine suspensions and flocculated particles. DAF produces very fine bubbles [4: 10–100 μm] to form “white water” [9: water running from a tap on a high pressure main]. If “white water” is formed in the treatment system, it indicates that the operation of flotation unit is properly running.

For the mechanism of SS removal, the flotation of suspended solids is by collision of high concentration of micro-bubbles with flocs (or solid particles) of any given size [9,11,15]. Hence, the attachment of the former on the latter will promote the removal efficiency. However, large bubbles will break the flocs and generate turbulence inhibiting their floating and separating [11]. This explains why DAF is much better than induced air flotation in removing SS, O & G and hence, COD in wastewater. Thus, DAF may improve the COD removal efficiency because it generates finer bubbles (40–70 μm) than blown air flotation (100–500 μm) in water treatment [9].
Though the grease trap is not an appropriate treatment facility for emulsified oily wastewater, EPD [16] and Rayan [17] did suggest that the residence time of wastewater in the trap should be 20 min. Berne and Richard [9] proposed the retention time for aided flotation is 5–15 min while that for DAF is 20–40 min. It is further supported by Joint Committee [13] that the detention time for flotation is 11–22 min. Hence, the design of the chemical treatment for this study was based on those data listed aforesaid in order to achieve TES = 0.

Most of the Chinese style restaurants are usually a large type with a daily discharge of between 100–400 m³. Vegetables such as Chinese cabbage, lettuce, choy sum and other leafy varieties require a high amount of water for washing [18]. They pose a high impact on the workload of the government sewage treatment plants (STP) as well as the sewerage systems. Therefore, EPD has a high priority to control them. A large flow of 400 m³/d from a Chinese food restaurant was selected because if it can solve the O & G problem and COD reduction, other small discharges must also be settled. Furthermore, TES depends on discharge flow and COD content of effluent. It implies that restaurant operators with high discharge will pay an additional and higher surcharge to the government depending on their effluent quality and flow. The incentive of the TES not only protects the aquatic environment by facilitating higher water quality, but it also encourages the operators to reduce their water consumption. Hence, COD₅ and COD₇₅ contents were evaluated for a large flow restaurant. In this case, a Chinese food restaurant is a typical one with a daily discharge flow of 400 m³ so that it was chosen for this study.

In this work, we examined an alternative to tackle the unsolved O & G problem for restaurant operators who run a business in compact commercial buildings. A study to reduce TES for high discharge flow restaurants was also attempted. Furthermore, it is our concern to know if the pollutants in the food origins can be removed and recycled as useful products after the chemical treatment.

Viitasari et al. [19] showed that the wastewater of a typical foodstuff industry was rich in oils and fats, proteins and carbohydrates, therefore, the sludge may contain these organic matters. Therefore, it is expected the sludge generated from flotation can be reused as renewable products such as biodiesel, animal feed and fertilizer.

Beaulieu [20] claimed that energy, protein and phosphorus are the three most expensive nutrients in most animal feeds. Animals get these nutrients from feed by the process of digestion, through secretion of enzymes and then absorption of them from the gastrointestinal tract. Nutritional sources of energy are mainly obtained from carbohydrates and fat of feeds. Excess protein is utilised as an energy source. Animals require energy for maintenance, growth and work. Protein is composed of amino acids which contain carbohydrates, nitrogen and sometimes sulphur. It is important for growth, reproduction and maintenance. It is also a critical building block for muscles and other tissues. Aside from nutrition effects, protein acts as antigenic factors and anti-nutrition agents in the immune system. Phosphorus is present in all cells of an animal body. It is one of the most important minerals in animal nutrition. About 80% of phosphorus is found in the bones and teeth while the remainder is located in the body fluids and soft tissue. It plays a key metabolic role. Phosphorylation is responsible for intestinal absorption, glycolysis and oxidation of carbohydrates, transport of lipids, exchange of amino acids, renal excretion, etc. ATP (adenosine triphosphate) is of prime importance in muscular activity during which chemical energy is converted into mechanical energy.

Nitrogen and phosphorus are two indispensable nutrients for plant growth. Animal manures have been used extensively in the past as organic fertilizers by most farmers for pond fish rearing and plant growing [21,22].

Therefore, energy, total nitrogen and total phosphorus content of the sludge generated from flotation will be evaluated if it is suitable to be reused as a biofuel, an animal feed and a fertilizer.

2. Materials and methods

2.1. Description of the wastewater treatment unit for a Chinese food restaurant

The “experimental” restaurant, which operated from 0600 to 2400 h daily, offered both western and Chinese style food. Two level regulators and two submersible pumps (each 1.5 kW, 0.45 m³/min) were installed in the underground Equalization Tank (ET) where the inlet was screened with a stainless steel
strainer (10 mm Φ holes). The activation and deactivation of the latter and the chemical metering pumps were controlled by the former. The Chemical Reaction Tank (CRT) with the dimensions of 3(L) × 1(W) × 1(H) m has six chambers where a nozzle was installed in each chamber. Air supplied by an air compressor (130 L/min, 0.8 MPa, 0.75 kW) was introduced into a saturator (≤ 0.85 MPa, 50°C) with the dimensions of 0.416(Φ) × 1.85(H) m. A centrifugal pump (6 m³/h, 2900 rpm, 2.2 kW) continuously returned treated effluent from the last chamber of the Sedimentation Tank (ST) to the saturator. The ST composed of three chambers has a total volume of 3 m³. This study was conducted from April to May, 2009 while the daily operation started at 0830 h (except on 19 May 2009 at 0630 h) and ceased at 1800 h. All the treatment facilities and their automatic operations for this study are outlined in Fig. 1.

2.2. Estimation of the discharge flow rate of the restaurant during operation hours and the appropriate amount of chemicals used for optimum treatment

The daily effluent flow rate of 400 m³ was estimated based on water consumption bills and the WPCO license of this restaurant so that its daily consumption of chemicals can be estimated while the incident effluent discharge rate was calculated from the water consumption rate shown on the water meter at site. We also took readings from the water meter during weekday and weekend in order to compare their flow rates. Moreover, it was preferred to take flow readings and water samples simultaneously because it was expected that COD levels may fluctuate with the variation in flow rate and strength of the effluents.
**Table 1**
Reduction of COD\(_T\) and comparison of COD\(_T\) with COD\(_S\) at various flow rates by chemical treatment enhanced with dissolved air flotation for the Chinese food restaurant.

<table>
<thead>
<tr>
<th>Time</th>
<th>Flow rate (L/min)</th>
<th>COD(_T)^a of influent (mg/L)</th>
<th>Treated COD(_T) (mg/L)</th>
<th>COD(_T) reduction (%)</th>
<th>Treated COD(_S)^b (mg/L)</th>
<th>Treated COD(_T) - COD(_S) (mg/L)</th>
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<tbody>
<tr>
<td></td>
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<td>Day 2^d</td>
<td>Day 3^e</td>
<td>Day 1</td>
<td>Day 2</td>
<td>Day 3</td>
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<td>349</td>
<td>1760</td>
<td>1773</td>
<td>1587</td>
</tr>
</tbody>
</table>

| ± SD^g | ± 95 | ± 68 | ± 81 | ± 781 | ± 842 | ± 787 | ± 115 | ± 62 | ± 78 | ± 16.6 | ± 8.7 | ± 1.6 | ± 82 | ± 58 | ± 60 | ± 35 | ± 20 | ± 20 |

^a Chemical oxygen demand without settling.
^b Chemical oxygen demand settled for 1 h without mixing.
^c 15 May 2009 (Friday).
^d 17 May 2009 (Sunday).
^e 19 May 2009 (Tuesday).
^f Mean.
^g Standard deviation. COD\(_T\) significantly different from COD\(_S\) (p < 0.05).
2.3. On site tests—Jar tests and observation in treatment tanks

The selection of a suitable coagulant and flocculant to treat the wastewater was carried out at site with a series of jar tests for the study. The efficiency of the treatment was preliminarily justified by visual and microscopic inspections. Effective treatment was assumed if clear water was successfully produced when subjected to chemical treatment enhanced with micro-bubbles (generated by strong shaking) under jar tests. When the abundance of oil droplets and suspended solids were hardly found in a clear water sample under low and high power microscopic observations, the treatment was said to be effective. The optimum pH and level of alum (50–90 mg/L) and the cationic polymer (Ciba, Zeta 7563, 3 mg/L) have been determined. Similarly, it was made sure that there was good separation to produce clear effluent in the last chamber of the ST. The dosage of chemicals for the metering pumps was adjusted according to the trials confirmed by the jar tests.

2.4. O & G and CODT during busy hours (1200–1400 h)

The first study was conducted between 30 April and 10 May 2009. Water samples were collected at the outlet of the ST during busy hours (1200–1400 h) and a grab sample was also collected on a day when there was no chemical treatment. The samples were analysed based on APHA [23] for O & G (5520B) and for COD (5220D). All samples were analysed in triplicates and their means were used to plot figures and draw tables.

2.5. COD profiling—CODT, CODS and CODT-S during operational hours

CODT is defined as the COD measured after the whole sample has been shaken and a portion is taken for analysis while CODS is defined as the COD measured after the sample stands at room temperature (25 °C) for one hour and a portion is taken from the middle layer (no oil nor residue) of the sample [8].

The second study was conducted in mid May 2009. Untreated samples (influent) were collected at the inlet of the CRT at 0900, 1300 and 1700 h while treated effluent samples were collected at the outlet of the last chamber of the ST at time intervals of one hour on each study day, respectively. The results of CODT and CODS content for each sample were compared using the t test to check if there was any significant difference between them [24].

2.6. Other samplings, storage and sample analysis

Sludge samples were taken from the surface of the first chamber of the ST during the study. All the samples taken were kept at 4 °C in ice-chest boxes till they were delivered to laboratory for analysis on each sampling day. For COD samples, they were also acidified to less than pH 2 with sulphuric acid while O & G samples were acidified to less than pH 2 with hydrochloric acid as well. For water content, sludge samples were dried in oven at 105 °C till a constant weight was obtained [23: 2540B]. Partition-gravimetric method was used for O & G analysis [23: 5520B]. Water samples were extracted by hexane–ether solvent and the gain in weight of the tared flask was arisen from O & G extracted from a sample. For COD analysis, closed reflux colorimetric method was applied. Water samples were oxidized and digested by excess potassium dichromate and sulfuric acid at 150 °C for 2 h and then the unconsumed dichromate was measured by spectrophotometer [23: 5220D]. For calorific (heating) value, water content of the sludge sample was first removed by drying to a constant weight at 105 °C [23: 2540B] before applying the LECO AC-300 isothermal-jacket bomb calorimeter [25: D-3286] [25]. For total phosphorus, sludge produced from flotation was dried in oven for 8–10 h at 105 °C to a constant weight. The dry sample was oxidized and digested by a strong oxidant, ammonium persulfate in strong acid at 121 °C (103–138 kPa). Then it was left cool, filtered and adjustment of pH to convert into ortho (reactive) phosphate. The orthophosphate content was finally measured by the ascorbic acid method [26]. For total nitrogen, the wet-oxidation method (e.g. Kjeldahl) was referred [27]. Both organic and inorganic nitrogen were converted to ammonia by potassium permanganate,
reduced iron and heated at 100 °C for 1 h. The measurement of ammonia content by spectrometry was finally carried out with phenol and hypochlorite method. Protein content was estimated by multiplying total nitrogen level by a conversion factor of 6.25 \[28\]. All samples were analysed in triplicates and their means were used to plot figures and draw tables.

3. Results and discussion

3.1. Flow rate of the Chinese food restaurant

The flow rates of the effluent show that, on 15 May 2009 (Friday), the peak rate at 1300 h was 452 L/min and the busy hours were 1200–1400 h (Table 1); on 17 May 2009 (Sunday), the peak rate again at 1300 h was 465 L/min and the busy hours were also 1200–1400 h; on 19 May 2009 (Tuesday), the two peak rates at 1000 h and again at 1300 h were 465 and 448 L/min, respectively. The peak rate at 1000 h on 19 May 2009 was due to floor and table washing on that morning.

As a rule, the higher the flow, the worse the water quality during peak hours (1200–1400 h). This follows this trend (Table 1). If the level of O & G and COD\textsubscript{T} can be treated to meet the license standards during this busy period, other non-peak hours can be overcome as well. It is noted that both the O & G content (Fig. 2) and COD\textsubscript{T} level (Fig. 3) of all chemically treated effluents were below the standards.

For a grease trap used to treat kitchen and restaurant wastewaters, some investigators [29] have pointed out that the improper design of it gave low O & G removal efficiency while Sokolovic et al. [5] also demonstrated that a traditional gravity separator is not effective in separating emulsified oil from wastewaters. This explains why almost all restaurant operators breached the highest limit of O & G (<100 mg/L). Viitasaari et al. [19] and Zouboulis and Avranas [30] concluded that DAF is proven technology in the treatment of foodstuff industry wastewaters. Thus, the chemical treatment for O & G and COD\textsubscript{T} reduction in this study demonstrates that it is also efficacious even during the worst period (peak hours).

The restaurant was in a recreation park, together with various amusement activities. Therefore, the number of customers varied between weekdays and weekends, and the park was crowded with customers during Saturdays, Sundays and public holidays, so that the related effluent discharge was much higher than on weekdays. In order to compare the treatment efficiency between a weekday and weekend, water samples were collected at both times. Since taking a grab sample is not reliable, a whole day sampling was used to evaluate the reliability of the chemical treatment. Table 1 demonstrates that peak hours were from 1200 to 1400 h and the effluent discharge rate was the
highest at 1300 h because each value during this period was higher than 400 L/min. The peak rate at 1000 h on 19 May 2009 was due to floor and table washing on that morning.

3.2. Water quality of treated effluents

Fig. 2 shows that the O & G content of the two controls (no chemical treatment) collected on 4 May and 8 May 2009 breached the licence limit (< 50 mg/L) and its value was 366 and 258 mg/L, respectively. However, the O & G content of all the chemically treated samples (the highest value—31 mg/L) complied with the licence conditions.

Fig. 3 indicates that the CODT levels for both the controls (no chemical treatment) and the chemically treated samples complied with the licence limit (< 2000 mg/L). The highest CODT level for the chemically treated samples was 102 mg/L while all other values were less than 90 mg/L. For the controls, the CODT level of the samples collected on 4 May and 8 May 2009 at the outlet of the ST was 1747 and 1418 mg/L, respectively. Thus, the chemical treatment enhanced with DAF for O & G and CODT reduction in this grab-sample study shows that it is effective during the peak hours.

Table 1 shows the highest mean CODT level of the chemically treated samples was 173 mg/L collected on Sunday (17 May 2009) while the lowest mean of that was 128 mg/L collected on Friday (15 May 2009). For the controls (no chemical treatment), the highest mean CODT level of the samples collected on Sunday was 1773 mg/L while the lowest mean of that was 1587 mg/L collected on Tuesday (19 May 2009). The % of CODT removal was calculated as 60.5, 97.1, 94.0 at 0900, 1300, 1700 h, respectively, on 15 May 2009 and the mean was 83.9. Similarly, the percentage (%) of CODT removal was calculated as 73.1, 92.1, 91.1 at 0900, 1300, 1700 h, respectively, on 17 May 2009 and the mean was 85.4 while the % of CODT removal was calculated as 90.5, 94.4, 92.1 at 0900, 1300, 1700 h, respectively, on 19 May 2009 and the mean was 92.3 (Table 1).

In food industry wastewaters, O & G, proteins, carbohydrates, nutrients and suspended solids are in high concentrations [19,31]. Kemmer [6] explained COD that it is a measure of organic matter and other reducing substances in water. Thus, they concluded that all these pollutants are oxygen consuming and, therefore, the higher the concentration of the pollutants in the wastewater, the higher the resulting COD level. As a result, the Hong Kong Drainage Authority [8] has taken COD as the critical factor for assessing water quality of trade effluents from the foodstuff industry (and other industries) as a basis for determining the TES. The mean % of CODT removal for the three days was calculated as 83.9, 85.4 and 92.3, respectively (Table 1). It is normal that the treated CODT level was higher while its reduction was lower (Table 1) in the morning than those afterwards because chemical treatment stopped at 1800 h (but still incoming influents) on each study day. Since the treatment tanks were full of non-chemically treated effluents in the next morning, then, the treatment unit has to warm up. The treated CODT level taken at 0900 h was so low (93 mg/L) on 19 May 2009 because the treatment unit
has commenced to run early at 0700 h to give good water quality. The comparatively high values of treated COD↓ for the 3-day study at 1300 h (Table 1) were due to the high strength of COD↑ of the incoming influents (Table 1).

3.3. COD profiling—COD↑, COD↓ and COD↑-S during operational hours

On 15 May 2009 (Friday), the DAF unit and chemical metering pumps started at 0830 h, and thus the first sample, collected at 0900 h, was slightly turbid and the COD↑ level was 450 mg/L (Table 1). After one hour of settling, the weakly turbid sample had COD↓ content of 330 mg/L. The treated effluents turned clear after 1000 h and the COD↑ level was below 100 mg/L after 1200 h. Since the samples were rather clear, even after one hour settling, there was not much precipitate formed. As a result, the COD↑-S level was below 20 mg/L after 1000 h. The mean COD↑, COD↓ and COD↑-S values were calculated as 128, 103 and 26 mg/L, respectively.

On 17 May 2009 (Sunday), the first sample was collected at 0900 h whereas the DAF unit and the chemical metering pumps started half an hour before (0830 h). The COD↑ value of the first sample collected at 0900 h was 301 mg/L (Table 1). The treated effluents turned clear after 1000 h. Aside from the early morning warm up period, both the COD↑ and COD↓ content at the busy hour (1300 h) gave the highest COD↑ content higher than 100 mg/L. Both the COD↑ and COD↓ content at the busy hours (1300–1400 h) were greater than 200 mg/L. Similarly, the mean COD↑, COD↓ and COD↑-S values were calculated as 173, 131 and 21 mg/L, respectively.

On 19 May 2009 (Tuesday), the first sample was collected at 0700 h whereas the DAF unit and the chemical metering pumps started half an hour before (0630 h). The COD↑ value of the first sample collected at 0700 h was 360 mg/L (Table 1). The treated effluents turned clear after 0800 h. Apart from the early morning warm up period, both the COD↑ and COD↓ content during peak hours (1300 h) gave the highest values. Similarly, the mean COD↑, COD↓ and COD↑-S values were calculated as 133, 112 and 21 mg/L, respectively.

Statistical analysis [24] revealed that the values of COD↑ and COD↓ for the 3-day study were significantly different at p < 0.05.

Though the level of COD↑-S was low, the value of COD↑ was significantly varied with that of COD↓ since the calculated values of them (from the t test at p < 0.05) were greater than their tabulated ones [24]. It implies that part of soluble COD was beyond the scope of the chemical treatment resulting in it being untreated. This explains why biological treatment is the best option if a large space is available.

Table 1 shows all the COD↑ and COD↑-S values were lower than 400 and 160 mg/L, respectively. According to the sewage charge regulation of the Drainage Authority [8], no TES is required. Hence, this implies that if more funding is available for an operator to invest in installing a chemical treatment unit in such a compact commercial building, he will be rewarded without paying TES resulting from generating high water quality.

3.4. Sludge generated from flotation

3.4.1. Overview of sludge generated from flotation

Table 2 demonstrates that the sludge generated from the treated effluents can be recycled as useful products such as an animal feed, a fertilizer and a biofuel. It shows some comparative data of protein (nitrogen), phosphorus and energy level from different types of animal feeds, food wastes, biofuels and pig manure with those of the sludge generated from flotation. Food wastes collected by livestock farmers are usually utilized as animal feeds containing high water content.

3.4.2. Water content and amount generated of the sludge

Table 2 reveals that the water content of all the sludge samples collected was less than 70% for the study period (15 May–22 May 2009). The highest water content was 63.7% while the driest one was 45.6% and it gave a mean value of 54.7%. Its value was nearly the same as those of food wastes except bread waste [32: 10.7%] and tomato waste [33: 81.4%]. The food wastes were collected and used as feeds or mixed with other ingredients for livestock rearing. Therefore, the sludge generated from
Table 2
Characteristics of sludge from flotation of the restaurant and some comparative data for various types of animal feeds, food wastes, biofuels and pig manure.

<table>
<thead>
<tr>
<th>Item</th>
<th>Date</th>
<th>Sludge/flow % (v/v)</th>
<th>Water content (%)</th>
<th>Protein (%)</th>
<th>Phosphorus (%)</th>
<th>Calorific value (cal/g)</th>
<th>Reference</th>
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<tbody>
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<td>Animal feed:</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>Native hay</td>
<td>–</td>
<td>–</td>
<td>Dried</td>
<td>09.00</td>
<td>–</td>
<td>2130</td>
<td>Government of Alberta [35]</td>
</tr>
<tr>
<td>Wheat straw</td>
<td>–</td>
<td>–</td>
<td>Dried</td>
<td>03.90</td>
<td>–</td>
<td>1800</td>
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<td>Food waste:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bread waste</td>
<td>–</td>
<td>–</td>
<td></td>
<td>10.7</td>
<td>15.79</td>
<td>0.17</td>
<td>4387</td>
</tr>
<tr>
<td>Noodle waste</td>
<td>–</td>
<td>–</td>
<td></td>
<td>55.1</td>
<td>15.47</td>
<td>0.11</td>
<td>4521</td>
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<tr>
<td>Tomato waste</td>
<td>–</td>
<td>–</td>
<td></td>
<td>81.4</td>
<td>18.85</td>
<td>–</td>
<td>5196</td>
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<tr>
<td>Guava waste</td>
<td>–</td>
<td>–</td>
<td></td>
<td>49.6</td>
<td>09.61</td>
<td>–</td>
<td>5257</td>
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<tr>
<td>Chemically treated</td>
<td>15 May 2009</td>
<td>0.27</td>
<td></td>
<td>63.7</td>
<td>8.44</td>
<td>0.12</td>
<td>6650</td>
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<td>Sludge from flotation</td>
<td>17 May 2009</td>
<td>0.45</td>
<td></td>
<td>59.6</td>
<td>7.50</td>
<td>0.11</td>
<td>6580</td>
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<td>19 May 2009</td>
<td>0.29</td>
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<td>46.7</td>
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<td></td>
<td>0.30</td>
<td>62.3</td>
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<td></td>
<td></td>
<td></td>
<td>0.34 ± 0.06</td>
<td>54.7 ± 7.4</td>
<td>6690 ± 79</td>
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<td></td>
<td></td>
<td></td>
<td>0.34 ± 0.06</td>
<td>54.7 ± 7.4</td>
<td>6690 ± 79</td>
</tr>
<tr>
<td>Coal</td>
<td>–</td>
<td>–</td>
<td></td>
<td>20–60</td>
<td>–</td>
<td>–</td>
<td>5815–6643</td>
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<tr>
<td>Wood</td>
<td>–</td>
<td>–</td>
<td></td>
<td>26–50</td>
<td>–</td>
<td>–</td>
<td>4707–5067</td>
</tr>
<tr>
<td>Used cooking oil</td>
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<td>–</td>
<td></td>
<td>8891–9058</td>
<td>–</td>
<td>–</td>
<td>8480</td>
</tr>
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<td>Free oil collected</td>
<td>3 May 2009</td>
<td>–</td>
<td></td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>8540</td>
</tr>
<tr>
<td>From the ST&lt;sup&gt;b&lt;/sup&gt;</td>
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<td>–</td>
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<td>–</td>
<td>–</td>
<td>–</td>
<td>8540</td>
</tr>
<tr>
<td></td>
<td>5 May 2009</td>
<td>–</td>
<td></td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>8630</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
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<td></td>
<td>0.34 ± 0.06</td>
<td>54.7 ± 7.4</td>
<td>8550 ± 62</td>
</tr>
<tr>
<td>Pig manure</td>
<td>–</td>
<td>–</td>
<td></td>
<td>7.69</td>
<td>0.11</td>
<td>–</td>
<td>Ye et al. [37]</td>
</tr>
</tbody>
</table>

<sup>a</sup> Sedimentation tank of the restaurant.<br><sup>b</sup> Mean.<br><sup>c</sup> Standard deviation.
flotation with the similar water content is suitable to be utilized as a food waste feed for poultry and swine. On the other hand, since the mean water content of the sludge (54.7%) was higher than that of wood [34: 26–50%] and coal [34: 20–60%], more expense will be required in removing water content of the former by drying before it can be recycled as a biofuel (Table 2).

From Table 2, it shows that the amount of sludge generated from flotation was 0.27–0.45% of the daily discharge flow of this restaurant and its mean value was 0.34%. It implied that the amount of sludge generated was about 1.36 m³ per day for a restaurant with a daily discharge flow of 400 m³. In other words, the higher is the flow, the more will be the sludge generation. However, it is commonly recognized that the dirtier the effluent is, the more chemicals that will be used for treatment, which means more money will be spent.

3.4.3. Recycling of sludge generated from flotation as useful products

It was confirmed by the local authority that the sludge generated from flotation was not a chemical waste because both alum and the polymer were used for drinking water treatment and their dosages were applied in low concentration. Therefore, the sludge from flotation can be used as a feed or a supplement and was nontoxic for livestock. Table 2 demonstrates the protein, phosphorus and energy levels of various animal feeds and food wastes.

### 3.4.3.1. Sludge as an animal feed

Table 2 reveals that the highest protein content of the sludge generated from flotation was 8.88% while the lowest one was 7.5% and it gave a mean value of 8.26%. Similarly, the richest phosphorus level of the sludge generated from flotation was 0.12% while the poorest one was 0.1% and it gave a mean value of 0.11%. For the calorific value, the highest energy value of the sludge generated from flotation was 6840 cal/g while the lowest one was 6580 cal/g and it gave a mean value of 6690 cal/g.

Vegetable, fruit, corn, food wastes are used for the rearing of poultry and swine in the past. The calorific value of various animal feeds and food wastes selected for comparison with that of the sludge from flotation of this study attempts to be utilized as energy for animal growth and metabolism.

Kurian et al. [31] and Viitasaari et al. [19] demonstrated that O & G, proteins, carbohydrates, nutrients and suspended solids are in high concentration in food industry wastewaters. Thus, the sludge generated from flotation was rich in these pollutants. From Table 2, it reveals that the mean calorific value of sludge generated from flotation was higher than that of the animal feeds and food wastes because the sludge from flotation gave a mean value of 6690 cal/g while that of the highest of them was only 5257 cal/g [33: Guava waste]. Therefore, the sludge from flotation was a potential candidate to be reused as an animal feed with high energy value. Table 2 also shows that the mean total phosphorus level (0.11%) of the sludge from flotation approached that of the food wastes [32: Bread and noodle waste—0.17 and 0.11%]. The bread and noodle waste were usually collected by farmers from restaurants and food processors to feed their swine and poultry. Therefore, the sludge generated from flotation may be utilized as a feed for this farming. The table also reveals that the mean protein content level (8.26%) of the sludge generated from flotation approached that of the animal feeds (Native hay and Wheat straw: 9.0 and 3.9%)[35] and the guava waste [33: 9.61%] but lower than that of most of the food wastes. Lira et al. [33] claimed that guava waste was used to feed poultry (i.e. Broiler and laying hen). Therefore, the sludge generated from flotation may be recycled as a feed for the poultry farming.

### 3.4.3.2. Sludge as a fertilizer

Cheremisinoff [4] also indicated that kitchen and other similar wastes contain a high concentration of phosphorous. Furthermore, nitrogen and phosphorus level were high in the wastewater of food industry [36]. Table 2 shows the mean total nitrogen content [28: 8.26% protein=13,217 mg/kg nitrogen calculated with a conversion factor of 6.25] of the sludge from flotation as dry basis was slightly richer than that of pig manure [28: 7.69% protein=12,300 mg/kg nitrogen calculated with a conversion factor of 6.25] which is traditionally utilized as an organic fertilizer by most farmers [37]. Similarly, the mean total phosphorus level [1133 mg/kg=0.11%] of the sludge from flotation was nearly the same as that of the swine manures [37: 1100 mg/kg=0.11%].
Therefore, the sludge generated from flotation can be recycled as a fertilizer. Furthermore, no malodour had evolved from this waste and did not generate an environmental nuisance to the public.

3.4.3.3. Sludge as a biodiesel. Table 2 reveals that the mean heating value (6690 cal/g) of the sludge from flotation was near the same as that of coal in the high range [34: 5815–6643 cal/g] while it was higher than that of wood [34: 4707–5067 cal/g]. Therefore, the sludge generated from flotation can be recycled as a biodiesel.

Kurian et al. [31] and Viitasaari et al. [19] showed that the wastewater of a typical foodstuff industry was rich in oils and fats, proteins and carbohydrates, therefore, the sludge may contain these organic matters. The United States Department of Agriculture (USDA) [28] claimed that the energy values are 4.0 kcal/g for protein, 9.0 kcal/g for fat and 4.0 kcal/g for carbohydrates. In other words, the calorific value of proteins and carbohydrates is only about half that of oils and fats, respectively. In fact, the sludge from flotation may include proteins and carbohydrate other than oils and fats alone [19,31] so that the mean heating value of the sludge from flotation was lower than that of the free oil samples (i.e. 8550 ± 62 cal/g) collected from the ST and used cooking oil [38: 8891–9058 cal/g]. However, the sludge from flotation should be dried to lower water content before it can be utilized as a biofuel.

4. Conclusions

Chemical treatment enhanced DAF is effective in reducing organic pollutants in oily and turbid effluents in a limited area. This form of treatment can be applied practically and economically elsewhere. It not only protects the environment by improving water quality, it also encourages large flow restaurant operators to recycle treated water. Operators have an incentive to reduce effluents as they could be eligible for reductions or even an exemption from the trade effluent surcharge. In addition, the clear water produced from the treated effluent can be utilized for various applications such as flushing, floor washing, plantation, irrigation, etc., while the wastes (sludge from flotation) can be recovered and recycled as potentially valuable products (as biofuel, animal feed and fertilizer). Such applications can protect the atmospheric and aquatic environments.

Apart from the use of an efficacious treatment technology to produce a high quality effluent and to recover wastes, good management and practices are also important to ensure proper collection and waste recycling rather than just disposing effluent into drains.

Acknowledgements

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References

References:

[16] EPD (Environmental Protection Department, Hong Kong), Grease Traps for Restaurants and Food Processors, Government Printer, Hong Kong, 1996.