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Treatment and recycling of condensate wastewater for by-product production process of canned tuna factory: batch and continuous adsorption in a real production plant

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ABSTRACT

This research aimed at treating condensate wastewater from the by-product of production processes in the canned tuna factories for recycling into fish oil production by reducing pH and deodorization using activated carbon, Eunicarb ID 900. The research began with batch adsorption to study the effect of pH 7–9 on the chemical oxygen demand (COD) removal (parameters representing odor) followed by continuous adsorption at the production plant using 15 cm diameter and 150 cm height adsorber. The result showed that a faster initial adsorption rate was achieved at lower pH while higher equilibrium COD removal was obtained at higher pH with the highest 90% COD removal. The adsorption was fitted well with Pseudo-second-order kinetic and Freundlich's isotherm. It was found that this treatment could not only removed the odor but also produced higher water quality which meets the limitation of water for fish oil extraction manufacturing. Subsequently this research suggested a six-month operation cycle based on the result operated at an actual condensate production rate of 2.5 m^3/h. No effect in both quantitative and qualitative quality of fish oil was observed after processing with the treated condensate. The economic assessment for the existing plant evaluates a payback period of 2.86 y, reveals it is readiness to be adopted for the factory.

Keywords: Water recycling; Condensate; Canned tuna; Adsorption; Activated carbon

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1. Introduction

The overall demand for canned tuna products has increased remarkably. The global canned tuna market was about USD 8.44 billion in 2021 and is expected to grow at a compound annual growth rate (CAGR) of 4.7% during the period 2023–2028 [1]. Thailand is one of the leading countries for tuna processing. However, the tuna canning industry generates a considerable number of by-products which are mainly utilized as tuna meal, tuna oil and tuna soluble concentrate [2]. The oil can be produced from tuna head and skin by hot water extraction. While the soluble residue from tuna steaming or oil extraction process can be concentrated using evaporation unit (as described in diagram shown in Fig. 1) to produce concentrated fish protein solution, the by-products for further higher value-added such as local delicacy or fish sauce. Therefore, condensate is the only wastewater generated from this process. Although typically the condensate water condensed from evaporation unit should not have much impurity, however since the condensate has a fishy smell, therefore it is not suitable to recirculate it to the process as feed water or even use for cleaning purposes without proper deodorization.

Fig. 1 indicates the solid lines as current production process while the dotted line represents the concept of condensate treatment and recycling. Several advanced technologies, including adsorption, chemical oxidation, catalytic and biological methods, have been applied to remove odor compounds. Among them, adsorption by activated carbon is well known as one of the most utilized methods because it is a highly effective incurs moderate costs, easy to operate and hassle-free approach [3]. There are a number of research revealing that adsorption technology using activated carbon represents excellent performance for water odorization. Siwila and Brink [4] improved drinking water quality by using powdered activated carbon (ProCarb-900), whereby it was found that color and odor could be eliminated, as well as eliminating turbidity by more than 99%. Feng et al. [5] used nanofiltration in combination with activated carbon to remove 10 odor compounds contain in drinking water and found that more than 90% of the odor can be eliminated. Xia et al. [6] also found that the use of ozone followed by activated charcoal can eliminate odors in drinking water effectively. However, related literature concerning deodorization of condensate water from tuna by-product processing, has been rarely found.

Based on a case study of the production of canned tuna of Chotiwat Industrial Manufacturing Public Company Limited, located in Thailand's Songkhla province, 35 m^3/d water is required for feeding to the by-products production line, while a total of 50 m^3/d of condensate wastewater is generated. Thus, the pretreated condensate is considered sufficient for recycling to replace the feed water. Therefore, this study aimed at investigating the suitable operating condition and efficiency of using activated carbon for treating condensate wastewater in both batch and continuous adsorption in the real plant for long term operation. Moreover, the results of the experiment were later used to estimate the cost and saving of the entire by-product line.

2. Materials and methods

2.1. Properties of condensate wastewater

The condensate wastewater was collected from the by-product production process of Chotiwat Manufacturing Industry Public Company Limited, Thailand. The chemical and physical properties of condensate wastewater and the limitation of water for fish oil extraction manufacturing are shown in Table 1.

2.2. Activated carbon

Activated carbon (Eunicarb ID 900), the commercial activated carbon was normally used for tap water

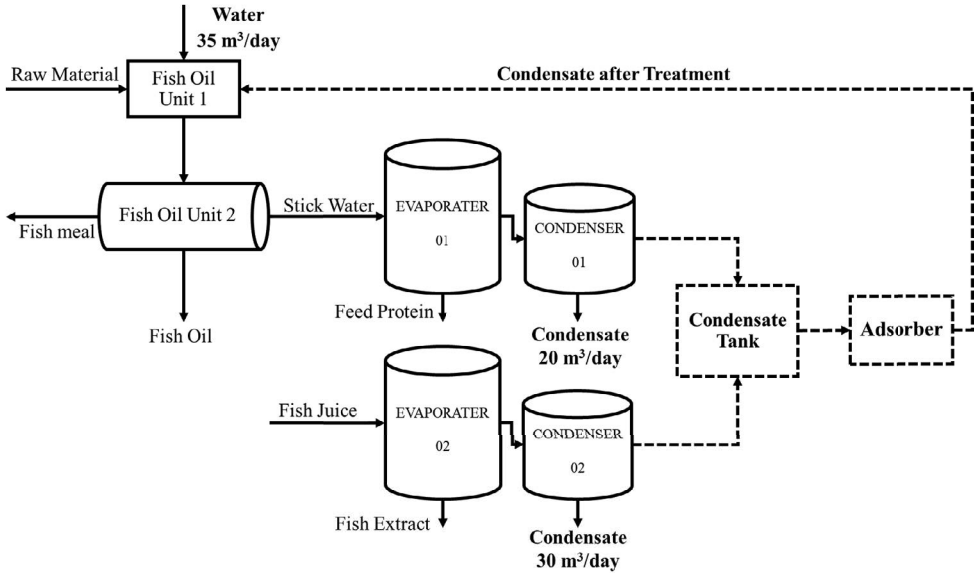

Fig. 1. Simplified diagram of by-product production of canned tuna factory.

production of Chotiwat Manufacturing Industry Public Company Limited, Thailand to treat the condensate in this study. Eunicarb ID 900 produced from coconut shell was purchased from Qualitech Supply Limited Partnership, Thailand, and its properties are presented in Table 2. The porous structure parameters were determined from the nitrogen adsorption isotherm using an automatic Micromeritics ASAP 2460 surface area and porosity analyzer. The specific surface area was calculated using Brunauer–Emmett–Teller method. Total pore diameter was determined by estimating the amount of nitrogen adsorbed at a relative pressure of $p/p°$ 0.99. Adsorption and desorption isotherm of nitrogen gas at a temperature of 77.3 K is shown in Fig. 2. It was found that when the relative pressure increases, the amount of adsorption also increases, and the hysteresis loop was observed after the desorption. According to the IUPAC (International Union of Pure and Applied Chemistry) classification, the adsorption isotherm thus can be classified as type IV (Freundlich adsorption isotherm) mesoporous type adsorbent [7].

Table 1
Chemical and physical properties of condensate wastewater and the limitation of water for fish oil extraction manufacturing

Properties	Condensate wastewater	Limitation of water for the fish oil extraction manufacturing
pH	9.12–9.83	6.5–8.0
Total iron (ppm as Fe^{2+})	0.09–0.16	≤0.3
Total hardness (ppm as $CaCO_3$)	3.6–13.4	≤60
Chloride (ppm as Cl^-)	11–19	≤200
Residual free chlorine (ppm)	0.14–0.23	0.2–2.0
Conductivity (μS/cm)	378–496	Not assigned
Odor	Abnormal (fishy)	Normal

2.3. Chemical oxygen demand removal from condensate wastewater by batch adsorption

The treatment of condensate using batch adsorption was carried out in a 250 mL Erlenmeyer flask. Each flask contained 100 mL of condensate which was adjusted to the pH of 7, 8 or 9 by 0.1 M HCl. Different activated carbon loadings at 25, 50, 100, 125, and 150 g/L were studied. The flask was covered by parafilm before being placed in thermostatic shaker and operated at 150 rpm and 30°C. The condensate sample was withdrawn every hour for 4 h for chemical oxygen demand (COD) determination. COD was chosen as a representative parameter for tracking the adsorption efficiency since the odor of condensate is generated from volatile organic compounds and COD determination is considered as being more reliable than the manual determination, using nose as the odor detector by the expert.

2.4. Condensate wastewater treatment by continuous adsorption

The condensate wastewater treatment system was installed at the by-product plant of Chotiwat Manufacturing

Table 2
Properties of activated carbon (Eunicarb ID 900)

Particle size*	Mesh 8 × 16
Iodine number*	900
Bulk density*, kg/L	0.5
pH*	9–11
Surface area, m^2/g	1,086
Total porous volume, cm^3/g	0.40
Average pore size, nm	3.7

*from the technical specification document.

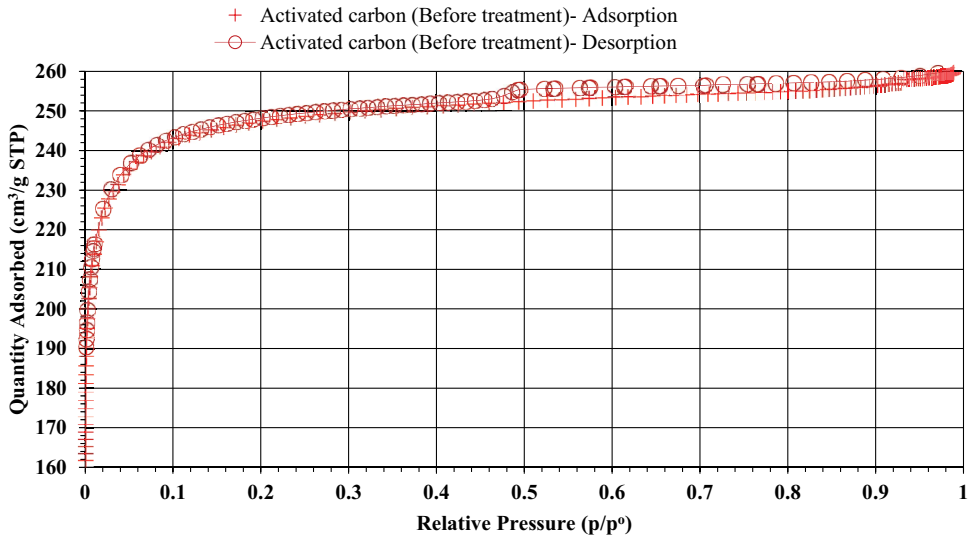

Fig. 2. Adsorption isotherms (+) and desorption isotherm (—○—) of nitrogen gas at a temperature of 77.3 K of activated carbon Eunicarb ID 900.

Industry Public Company Limited, Thailand. The system size and configuration were designed to follow the guidance of the supplier. The system mainly consists of a coarse filter unit inserted with a 3 mm hole sieve, a 100-L plastic drum of acid tank, 15 cm diameter and 150 cm height adsorption column packed with 12 kg, or 24 L activated carbon, as shown in Fig. 3. The condensate was pumped through the filter and mixed with the acid line to adjust the pH to 7.3 ± 0.1 before entering the bottom of the adsorber. The flow rate of condensate was measured by rotary flowmeter. While the pressure inside the adsorption column was monitored by pressure gauge. The experiment was divided into two parts, described as follows.

2.4.1. Effect of flow rate on the quality of treated condensate

The effect of condensate flow rates of 0.5, 1.0, 1.5, 2.0, and 2.5 m^3/h on the quality of treated condensate were investigated. Each flow rate was operated continuously for 3 h. 18 replicates were done for this experiment. The effluent samples were withdrawn every 1 h for analyzing total iron, total hardness, chloride, residual free chlorine, turbidity, conductivity, COD, and odor whereby their measuring values were reported in average.

2.4.2. Long-term operation

For the long-term operation of condensate treatment, the adsorber was continuously operated at 2.5 m^3/h, 18 h/d for 180 d. The original and treated condensate samples were withdrawn every 10 d for analyzing total iron, total hardness, chloride, residual free chlorine, turbidity, conductivity, COD, odor, turbidity, and dissolved oxygen (DO). Ammonia nitrogen, namely the total suspended solid, and chemical compound using gas chromatography–mass spectrometry, GC-MS (GC 7890B, MSD 5977A, Agilent Technologies, USA) of condensate samples were checked for original and treated condensate after one-month operation. While the original and one month used activated carbon was sampled for analyzing the appearance of surface morphology and elements using scanning electron microscopy and the element composition using energy-dispersive X-ray spectrometer, SEM-EDX (JSM-5800LV, Jeol, Japan). The column pressure drop was also monitored every 10 d.

2.5. Recycling of the treated water for oil extraction from fish residue

The nine treated condensate samples of adsorption operation were recycled and fed to the by-product production process (the confidential method of the production is not provided). The physical properties (color, odor, and appearance), chemical properties (moisture, free fatty acid (FFA), and acid value), and specific properties (confidential), and production yield of fish oil as a representative product were compared to the acceptable value assigned from the company.

2.6. Analytical methods

pH was measured by pH meter (Toledo, Germany). Conductivity was measured by a conductivity meter (Orion, USA). Total iron was measured by an iron meter (Orion, USA). Residual free chlorine was measured using a chloride meter (Lovibond, Germany). Turbidity was measured by turbidity meter (Thermo Scientific, USA). The olfactory or odor of a sample is evaluated by the expert of the company. The total suspended solids, COD, DO, total hardness, and ammonia nitrogen were measured according to standard methods [8]. Chloride FFA, acid value, and moisture were determined by the methods according to AOAC official methods of analysis [9].

Statistically significant differences in the results were determined using a one-way analysis of variance (ANOVA) in SPSS v26.0 (IBM, USA) with statistical significance set at 95% confidence level ($p < 0.05$).

2.7. Costs and savings estimation of the treatment and recycling of condensate wastewater

The costs associated with condensate wastewater treatment can be divided in capital costs corresponding to activated carbon, adsorption column, vessels, pumps, piping, measuring devices, etc., whereas operating costs

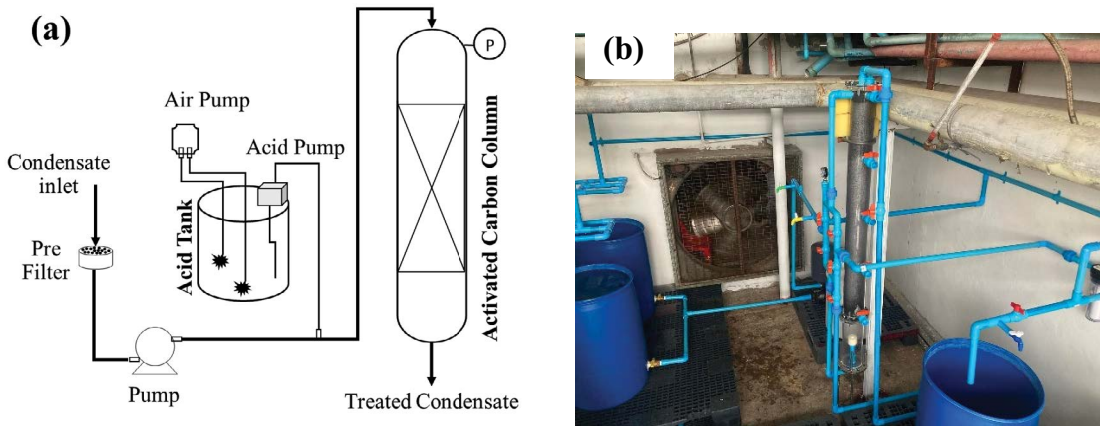

Fig. 3. Condensate wastewater treatment using continuous adsorption (a) diagram and (b) the installed system at the real production plant.

corresponding to chemicals, maintenance, activated carbon replacement, energy, and amortization of capital costs. The cost analysis was calculated based on the condensate generation rate at 2.5 m^3/h while the saving cost was the difference between the treatment cost and the cost of daily supplied water requirement being replaced by the recycle of treated condensate.

2.8. Calculations

2.8.1. Removal efficiency

Removal efficiencies were calculated using Eq. (1):

$$\text{Removal efficiency}(\%) = \frac{V_{\text{in}} - V_{\text{out}}}{V_{\text{in}}} \times 100 \quad (1)$$

where V_{in} and V_{out} is the inlet and outlet measuring value, respectively.

2.8.2. Langmuir adsorption isotherm

The Langmuir adsorption isotherm is expressed by Eqs. (2) and (3) [10].

$$q = \frac{q_m K_L C}{1 + K_L C} \quad (2)$$

where q is the amount of adsorbate adsorbed at the equilibrium, q_m is the maximum adsorption capacity of the adsorbent (mg/g), K_L is the Langmuir equilibrium constant (L/mg) and C is the supernatant adsorbate concentration at the equilibrium (mg/L) assuming a monolayer of adsorbate uptake by the adsorbent. Moreover, Nonlinear Langmuir isotherm can be applied as a linear model or a linear graph by rearranging the equation as follows.

$$\frac{1}{q} = \frac{1}{q_m K_L}\left(\frac{1}{C}\right) + \frac{1}{q_m} \quad (3)$$

The linear graph can be plotted by 1/q and 1/c, The K_L and q_m values can be calculated from the slope and y-intercept values.

2.8.3. Freundlich adsorption isotherm

The Freundlich adsorption isotherm is represented in Eqs. (4) and (5) [10].

$$q = K_F C^{1/n} \quad (4)$$

where q is amount of COD adsorbed by the activated carbon (mg/g), K_F is the Freundlich equilibrium constant ((mg/L)$^{-1/n}$·mg/g) and n is the Freundlich exponent (dimensionless). In addition, nonlinear Freundlich isotherm can be applied as a linear model or a linear graph by rearranging the equation as follows.

$$\log q = \log K_F + \frac{1}{n}\log C \quad (5)$$

Relations between the log$q$ and log$C$ can be plotted through the linear graph. The values of 1/n and logK_F can be inferred from the slope and interception, respectively.

2.8.4. Adsorption kinetics

Several kinetic models are applied to test the experimental data. For the current study, the simple two kinetic models of pseudo-first-order and pseudo-second-order models were used as described in Eqs. (6)–(8) [11].

2.8.4.1. Pseudo-first-order kinetics

$$\log \frac{q_e}{q_e - q_t} = \frac{k_1}{2.303} t \quad (6)$$

A linear model or a linear graph rearrangement of Eq. (6) brings about Eq. (7):

$$\log(q_e - q_t) = \log q_e - \frac{k_1}{2.303} t \quad (7)$$

where q_e and q_t represent the amounts of adsorbate adsorbed (mg/g) at equilibrium and at any time, t is time (min), k_1 is the rate constant (1/min). The values of q_e and k_1 can be deduced from the intercepts and slopes of the linear plots of log(q_e –q_t) against t.

2.8.4.2. Pseudo-second-order kinetics

$$\frac{dq_t}{dt} = k_2 (q_e - q_t)^2 \quad (8)$$

This can be linearized to Eq. (9) when Eq. (8) is integrated in range t = 0 to t = t and q_t = 0 to q_t = t.

$$\frac{t}{q_t} = \frac{1}{k_2 q_e^2} + \frac{1}{q_e} t \quad (9)$$

where k_2 is the rate constant of pseudo-second-order adsorption (g/mg·min), The values of q_e and k_2 can be assumed from the slopes and intercept of the linear plots of t/q_t against t.

3. Results and discussion

3.1. Results on batch adsorption

As shown in Table 1, hardness, chloride, residue free chlorine, and total iron meet the limitation of water for the by-product manufacturing. Fishy odor detected in the condensate needs to be eliminated otherwise it will cause strong stinky odor of the by-products when recycle back to the process. The pH of approximately 9.2 is higher than the limitation set by the company at 6.5–8.0. Therefore, reducing the pH of condensate is required before the reutilization process to prevent products off specification.

GC-MS chromatrogram of condensate wastewater in Fig. 4 shows that methylamine was the main compound detected. Methylamine is a component commonly present

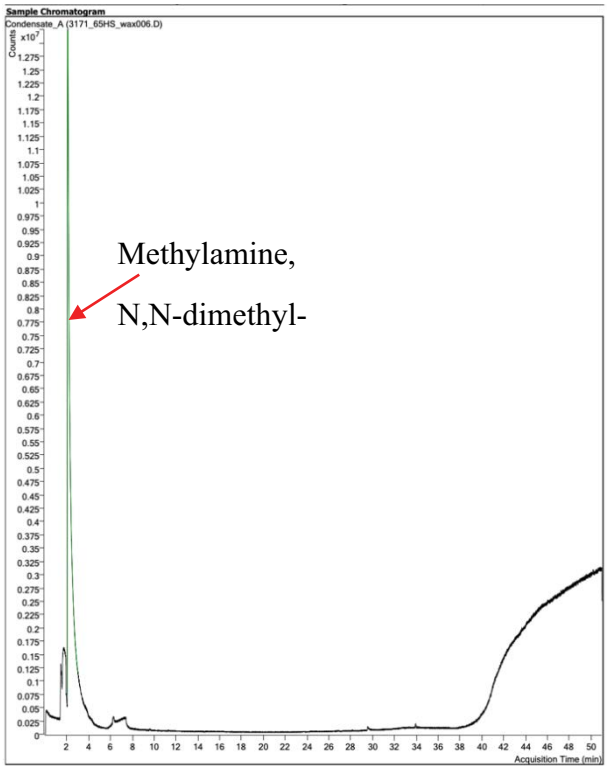

Fig. 4. Gas chromatography–mass spectrometry chromatrogram of condensate wastewater before treatment.

in seafood generated from the degradation of the fish protein [12]. It is a low boiling and basic compound thus causing the condensate to possess a moderately high pH. The methylamine bond length is 0.102–0.147 nm [13], hence it confirms that this undesired compound could be adsorbed on the larger pore size (3.7 nm) of activated carbon Eunicarb ID 900. Moreover, other research reported that methylamine cations can be adsorbed on kaolinite basal surfaces particularly on kaolinite Si–O surface by electrostatic interaction and hydrogen bonds [14]. Therefore, COD can be further used as a representative to track the removal of methylamine odor.

3.1.1. Effect of pH and activated carbon loading on COD removal

Fig. 5 shows a decrease in COD values over the 4 h batch adsorption. It was observed that there was a sharp decrease in COD in the first 1–2 h and began to decrease slowly during the 3–4 h, and with a greater amount of activated carbon, it would be possible to reduce the COD value in condensate extremely faster and more. pH of the solution does not only influence the surface charge of the activated carbon but also the ionization of methylamine, the adsorbate. At lower pH, the higher ratio of protonated amine to free (non-protonated) amine groups are presented [15]. Thus, at lower pH of 7 and 8, the COD removal rates were more rapid initially due to chemisorption of the positive charge of protonated amine and negative charge of the activated carbon. While, at higher pH of 9 the initial rate

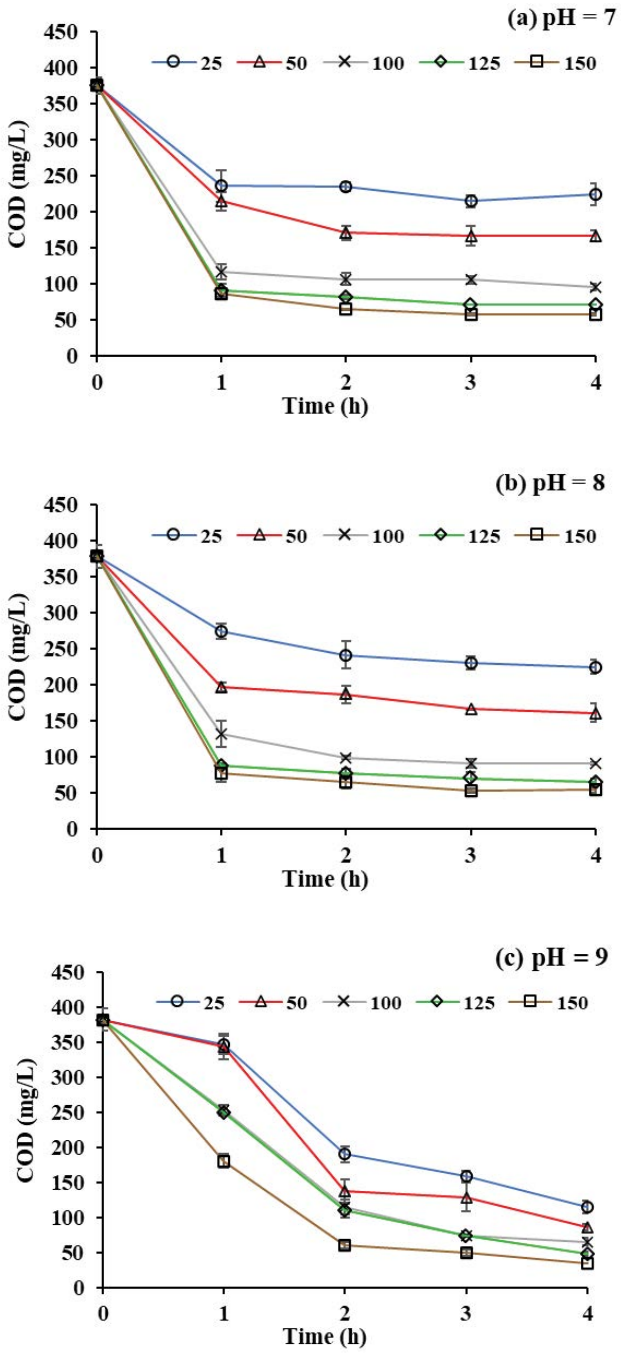

Fig. 5. Reduction of chemical oxygen demand in condensate at different activated carbon dose and different initial pH (a) pH = 7, (b) pH = 8, and (c) pH = 9.

COD removal was lower, hence describing that the adsorption mainly occurred among the non-protonated amine groups through physical multilayer adsorption which has lower initial adsorption rate but able to adsorb more COD at the equilibrium. However, the COD removal efficiency (Fig. 6) were not much different at the higher activated carbon dose of 125 and 150 g/L. This explained that when high amount activated carbon was dosed, there were excess active surface area for COD adsorption.

Whereas when considering the value of the COD amount adsorbed per activated carbon mass (q), it was found that when the amount of activated carbon was increased, the value of q is reduced (Fig. 7). At pH 7 and 8, there was no significant difference of q value for all activated carbon doses. While the q value of pH 9 were higher than that at pH 7 and 8 for the lowere activated carbon dose at 25 and 50 g/L. However, for the higher doses, the pH of condensate does not obviously affect the q value.

3.1.2. Adsorption isotherms

The Langmuir and Freundlich equation parameters of COD adsorption in condensate were evaluated as shown in Table 3. The COD adsorption isotherm in condensate were more closely fitted to Freundlich's equation than that of the Langmuir, which was identical to the nitrogen gas adsorption mentioned earlier. Hence, it can be described as a multilayered adsorption process, whereby as the pH of condensate increased, the q_m value trendily increases as the negative anionic content of hydroxide increases, encouraging greater adsorption of the ammonium ions. This corresponds to the value of the adsorption intensity, $1/n$ of Freundlich's equations which trendily increases with the increase in pH. This indicated that the surface volume of the adsorbent increases as the value of $1/n$ increases that tend to be adsorbed. The investigation is similar to Huang et al. [3]. The researcher reported that most of the odor compounds treated with powdered activated carbon were well fitted with the Freundlich model [3]. It is worth noting that according to the investigation by Huang et al. [3], it was indicated that the neglection of odor threshold and not very high R^2 of the fit models were found in this current study, while the adsorption capacities estimated from isotherm model predictions may not be suitable for the evaluation of treatability of the odor compound. However, it can be concluded that the condensate treatment presents normal adsorption behavior and the investigation on the effect of initial pH of condensate on the adsorption efficiency could be further applied for the continuous process.

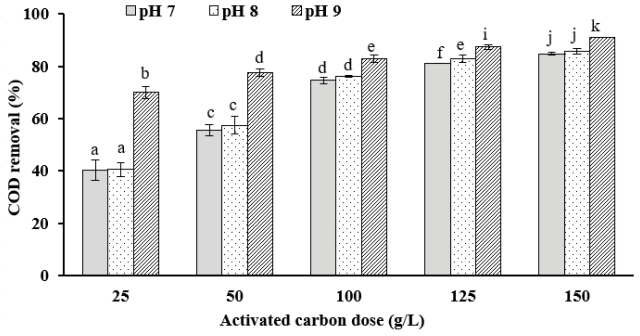

Fig. 6. Effect of initial pH of condensate and activated carbon dose on the chemical oxygen demand removal.

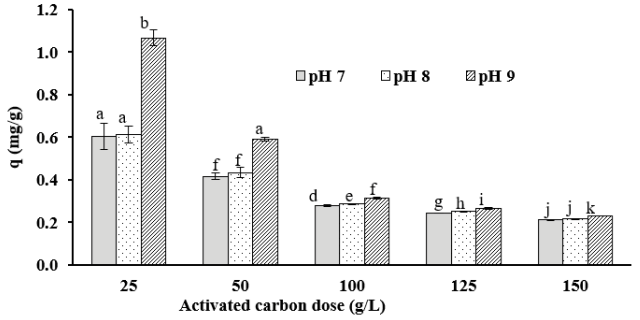

Fig. 7. Effect of initial pH of condensate and activated carbon dose on q-value.

3.1.3. Adsorption kinetics

Kinetic constant for COD adsorption of condensate wastewater of pseudo-first-order and second-order kinetic model are presented in Table 4. From the best values of R^2, it obviously found that the COD removal fit well with pseudo-second-order adsorption kinetic. Many literatures also reported that the adsorption kinetic followed more pseudo-second-order model than pseudo-first-order model for example COD and BOD removal from treated sewage using activated carbon prepared from date palm shell waste [16] as well as COD and color removal from landfill leachate using oat hulls activated carbon [17].

As condensate with pH adjusted to 7–8 gives high adsorption rate along with the limitation of process feed water assign at pH 6.5–8, then the pH adjustment of condensate to average pH of 7.3 before feeding to the adsorption column was selected for the continuous process.

3.2. Results on condensate wastewater treatment by continuous adsorption

3.2.1. Effect of feed flow rates on the quality of treated condensate

Table 5 shows the quality of treated condensate at different condensate feed flow rates. It was observed that the properties of the feed condensate fluctuated. However, it can be concluded that all measured parameters in condensate including the fishy odor (except DO value) were reduced after being treated with the activated carbon for all condensate feed flow rate. Therefore, the designed column size could be effectively operated at the highest flow rate of 2.5 m^3/h which could support the daily condensate volume generated from the existing production plant.

3.2.2. Performance on long term adsorption operation

Condensate properties of the continuous condensate treatment at an average flow rate of 2.5 m^3/h were monitored

Table 3
Langmuir and Freundlich isotherms parameter for chemical oxygen demand adsorption of condensate wastewater

pH of condensate	Langmuir isotherm			Freundlich isotherm		
	q_m (mg/g)	K_L (L/mg)	R^2	K_F	$1/n$	R^2
7	1.10	0.00399	0.969	0.010	0.74	0.977
8	1.05	0.00472	0.974	0.013	0.70	0.984
9	1.62	0.00452	0.830	0.007	0.96	0.832

Table 4
Kinetic constants for chemical oxygen demand adsorption of condensate wastewater

Pseudo-first-order kinetic									
Activated carbon dose (g/L)	pH = 7			pH = 8			pH = 9		
	k_1	q_e	R^2	k_1	q_e	R^2	k_1	q_e	R^2
25	1.52	0.01	0.7317	1.12	0.61	0.9999	0.83	1.92	0.9591
50	2.54	1.29	0.9987	0.99	0.24	0.8723	0.89	0.99	0.8191
100	0.38	0.03	0.8467	0.16	0.00	0.4231	1.60	1.01	0.9911
125	2.08	0.00	0.6479	0.74	0.04	0.9969	1.05	0.44	0.9944
150	1.97	0.00	0.5125	1.97	0.00	0.6294	1.13	0.25	0.9144
Pseudo-second-order kinetic									
Activated carbon dose (g/L)	pH = 7			pH = 8			pH = 9		
	k_2	q_e	R^2	k_2	q_e	R^2	k_2	q_e	R^2
25	49.37	0.64	0.9905	1.14	0.72	0.9988	0.279	1.752	0.9646
50	2.13	0.46	0.9957	2.35	0.47	0.9971	0.250	0.748	0.9524
100	11.11	0.29	0.9991	3.23	0.30	0.9993	0.007	0.590	0.8421
125	11.58	0.25	0.9997	9.87	0.26	0.9999	0.003	0.513	0.8629
150	4.70	0.22	0.9998	7.08	0.22	0.9997	0.024	0.296	0.9787

Table 5
Quality of treated condensate at different condensate feed flow rate (3 h operation)

Parameters	Original condensate	Treated condensate at different flow rate[a] (m^3/h)				
		0.5	1.0	1.5	2.0	2.5
pH	9.12–9.83	7.3	7.3	7.4	7.5	7.4
Total iron (ppm as Fe^{2+})	0.09–016	0.08	0.1	0.04	0.02	0.02
Total hardness (ppm as $CaCO_3$)	3.6–13.4	8.5	4	3.7	3.6	3.2
Chloride (ppm as Cl^-)	11–19	19	18	11	9	12
Residual free chlorine (ppm)	0.14–0.23	0.1	0.11	0.08	0.06	0.08
Chemical oxygen demand (mg/L)	281–394	68.5	115	96.5	71.8	79.3
Turbidity (NTU)	4.32–6.91	0.62	0.76	0.68	0.72	0.64
Conductivity (μS/cm)	378–492	252	321	372	287	326
Odor	Fishy	Normal	Normal	Normal	Normal	Normal

[a]The averaged values.

for 180 d as presented in Fig. 8, and their removal efficiencies are summarized in Table 6. The pH of treated condensate was slightly raised to 7.4–7.5, perhaps due to the dissolved carbon dioxide and some acidic compounds were adsorbed on the activated carbon. All the very low amount of iron present in condensate was almost totally removed. Chloride and residue free chlorine were also reduced after passing through the activated carbon bed. Total hardness was about 32% reduction according to the increase of Ca on the used activated carbon surface as shown in Table 7. Removal of the cations and anion was indirectly confirmed by the decrease of conductivity. More than 75% of turbidity was removed while the disappearance of total suspended solid was found. Reduction of COD and ammonia nitrogen related to the deodorization in the condensate and the undetected methylamine compound in the treated condensate. The reduction of the organic compound was also confirmed by the increment of carbon on the used activated carbon. The reduction of compounds and ions in the treated condensate resulting in more oxygen solubilization confirmed by the increase of DO value. Moreover, as presented in Table 7 it was found that reduction of K and Na in activated carbon were observed. There are previous studies that reported K and Na can be mainly leached into water from the biomass derived-activated carbon and biochar [18,19]. However, the leaching process will affect the treated condensate contaminant only at the early phase of the adsorption operation. In addition, the surface of activated carbon before and after used of condensate treatment were characterized by SEM as shown in Fig. 9. It can be observed that the deposit form adsorbed element which made the activated carbon to have smaller pore size.

However, for the long term-monitoring, most treated condensate properties were slightly constantly fluctuated,

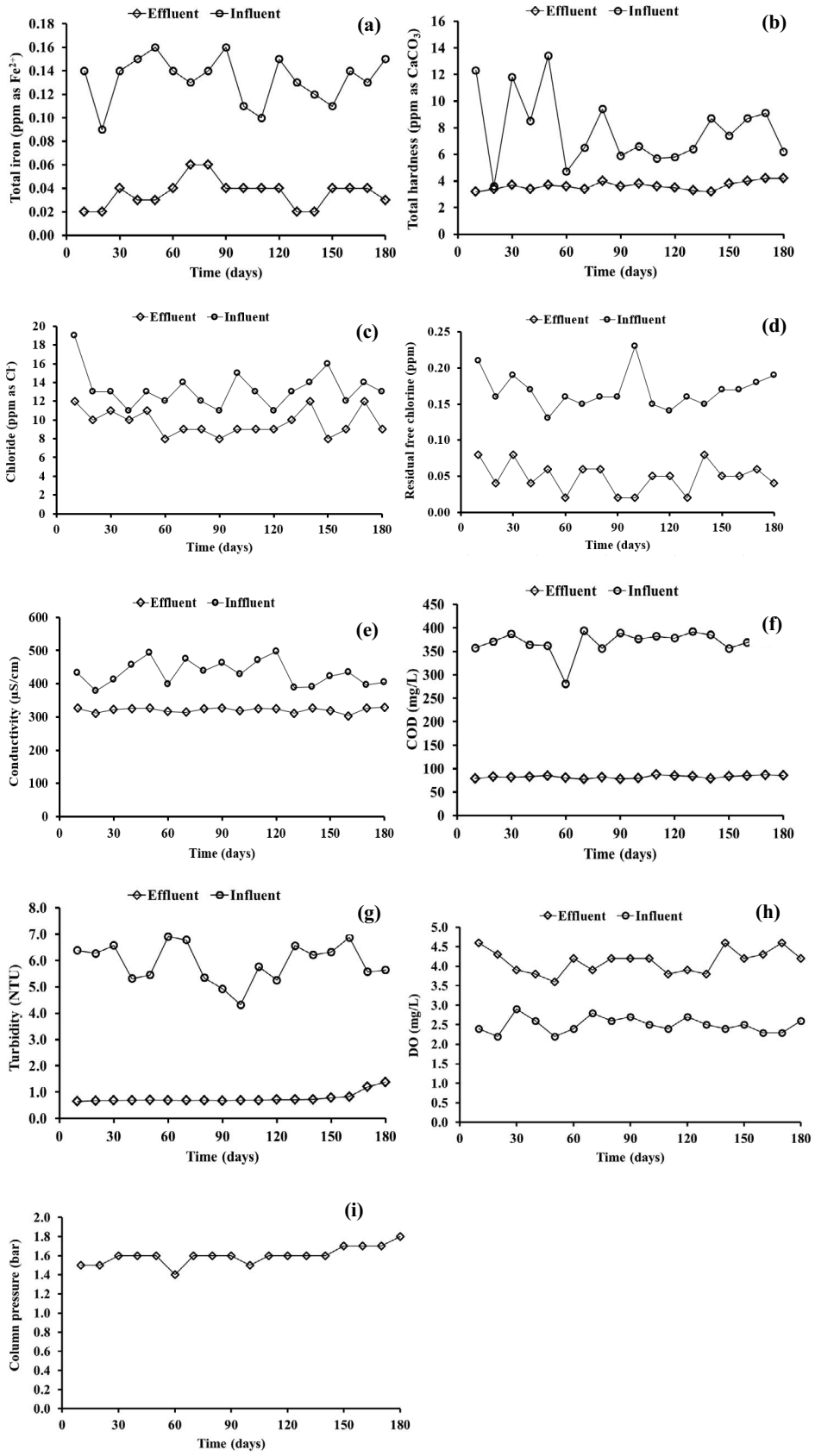

Fig. 8. Condensate properties during long term operation of the adsorber (a) total iron, (b) total hardness, (c) chloride, (d) residual free chlorine, (e) conductivity, (f) chemical oxygen demand, (g) turbidity, (h) dissolved oxygen, and (i) column pressure.

Table 6
Summary of the treated condensate quality at condensate feed flow rate 2.5 m^3/h (after 6-month continuous operation)

Parameters	Original condensate[a]	Treated condensate[a]	Removal efficiency (%)
pH	9.58[b]	7.45	–
Total iron (mg/L as Fe^{2+})	0.15	0.03	80.00
Total hardness (mg/L as $CaCO_3$)	6.2	4.2	32.26
Chloride (mg/L as Cl^-)	13	9	30.77
Residual free chlorine (mg/L)	0.19	0.04	78.95
Chemical oxygen demand (mg/L)	381	85.2	77.64
Turbidity (NTU)	5.64	1.38	75.53
Conductivity (μS/cm)	405	329	18.77
Dissolved oxygen (mg/L)	2.6	4.2	–
Total suspended solids[c] (mg/L)	10	<0.5	>99.9
Ammonia nitrogen[c] (mg/L)	128.14	8.95	93.02
Odor	Fishy	Normal	–
Detected compounds by GC-MS[c]	Methylamine	None	–

[a]The averaged values;
[b]The pH of condensate was adjusted to 7.3 ± 0.1 before feeding to the adsorber.
[c]The parameter collected after one-month operation.

Table 7
Elements composition (% by weight) in activated carbon before and after use for condensate treatment (after one-month continuous operation)

Element	Original activated carbon	One month used activated carbon
C	92.71 ± 0.83	93.59 ± 0.59
O	4.34 ± 0.40	4.42 ± 0.52
Na	0.24 ± 0.07	Not detected
Mg	0.11 ± 0.03	0.10 ± 0.02
Si	0.15 ± 0.07	0.12 ± 0.03
P	0.15 ± 0.03	0.25 ± 0.02
Cl	0.19 ± 0.04	0.17 ± 0.03
K	1.63 ± 0.50	Not detected
Ca	0.12 ± 0.05	0.23 ± 0.05
Cu	0.19 ± 0.04	0.50 ± 0.08
Zn	0.17 ± 0.04	0.42 ± 0.08
S	0 ± 0.00	0.20 ± 0.03

the turbidity and hardness obviously dropped after 160 d but the quality of treated condensates is still at acceptable levels. The column pressure increased slightly and more rapidly after the 150 d of operation and reached 1.8 bar at the 180 d. Moreover, at the duration of 150–180 d, the fouling accumulation in the column was observed. Therefore, a maximum operation of 180 d of the adsorber should be suggested for the plant. Then the activated carbon replacement can be simply scheduled twice a year.

3.3. Effect of using treated condensate for oil extraction from fish scraps

Production yield, physical, chemical, and specific properties of the fish oil after using treated condensate as feed water are presented in Table 8. The quality of the fish oil meets all the specification requirements of the factory. It reveals the success in the condensate treatment using the pre-pH adjustment and adsorption process.

3.4. Costs and savings of the treatment and recycling of condensate wastewater

A preliminary economic estimation was conducted, considering the adsorption plant to treat the condensates wastewater. The basic assumptions considered in the calculations are summarized in Table 9. The cost was assessed based on 2.5 m^3/h condensate wastewater. The size of column was raised to support the higher activated carbon volume of 35 L calculated by safety factor of 1.4. A total investment cost of 7,757 USD was calculated from the cost of activated carbon, adsorber, pipes and valves, instruments and controls, tanks and frames, and miscellaneous. While the variable cost of 2,095 USD/y was calculated from the cost of chemical, energy, activated carbon replacement, and maintenance. The savings cost calculated from the supplied water and ordinary condensate wastewater treatment to be 5,938 USD/y. Then the payback period of 2.86 y was estimated for the designed plan capacity.

The operating costs per unit volume of treated condensate was 0.24 USD/m^3. Water treatment and recycling costs vary depending on the original condensate quality, facilities, the scale, and final application of the plant. It is not easy to find the application of condensate treatment and recycling similar to this study, thus direct comparison in term of cost is difficult. However, mainly due to the proven technology of adsorption by activated carbon in this research in treating and recycling the condensate, the operating cost was found to be lower than others. 0.97 USD/m^3 of operating costs was attained in flash cooler condensate treatment to produce reusable water using nanofiltration with plant capacity 20 m^3/h [20]. Chmiel et al. [21] obtained a cost of

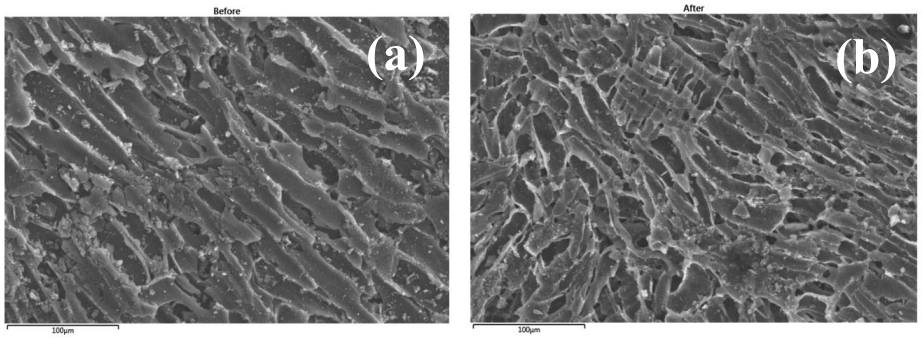

Fig. 9. Scanning electron microscopy images of activated carbon (a) original and (b) after one-month continouos operation for treatment of condensate.

Table 8
Production yield, physical, chemical, and specific properties of fish oil after using treated condensate as feed water

Run no.	Condensate flow fed to adsorber (m^3/h)	Yield (% fish oil/raw material)	Physical properties			Chemical properties			Specific properties[c]		
			Color	Odor	Appearance	Moisture (%)	Free fatty acid (%)	Acid value (%)	x	xx	xxx
Required specification		>5.89%	Good	Good	Good	<0.5%	<5%	<10%	>30%	>25%	>5%
1	2.61	6.32	Good[a]	Good	Good[b]	0.08	2.8808	5.7328	35.24	25.19	6.38
2	2.53	5.90	Good[a]	Good	Good	0.11	3.2439	6.4554	n.d.	n.d.	n.d.
3	2.48	6.05	Good[a]	Good	Good	0.10	2.7816	5.3540	n.d.	n.d.	n.d.
4	2.66	6.32	Good	Good	Good[b]	0.07	2.8732	5.7177	34.88	25.29	6.03
5	2.53	5.97	Good[a]	Good	Good[b]	0.06	2.9505	5.8715	n.d.	n.d.	n.d.
6	2.56	6.17	Good	Good	Good[b]	0.10	3.4848	6.9348	n.d.	n.d.	n.d.
7	2.55	6.11	Good	Good	Good	0.08	2.4635	4.9074	33.76	25.48	5.79
8	2.53	5.94	Good	Good	Good[b]	0.08	2.0447	4.0960	n.d.	n.d.	n.d.
9	2.52	6.25	Good	Good	Good	0.06	2.5198	5.0144	n.d.	n.d.	n.d.
Untreated condensate		5.8%–6.2%	Good	Fishy	Good	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.

[a]slightly darkened b slightly thick;
[c]confidential;
n.d. = not determined.

Table 9
Economic estimation of condensate treatment to produce reusable water for the oil extraction process

Category	Cost
Investment costs (USD)	
Stainless steel adsorption column: size 20 cm × 150 cm	821
Piping and instruments (PVC) for adsorption system	205
Piping and instruments (stainless-steel) for delivering treated water to the production process, distance 40 m	880
Pressure water pump (900 W)	880
Chemical injection pump 5–6 bar (250 W)	293
Air pump (80 W)	29
Polyethylene plastic tank for acid solution: size 100 L	29
Stainless steel tank for condensate storage: size 1,000 L	440
Stainless steel tank for treated water storage: size 10,000 L	3,519
Miscellaneous equipment and spare parts	73
Installation	587
Total	7,757

Table 9 (Continued)

Table 9

Category	Cost
Variable costs (USD/y)	
Eunicarb ID 900 activated carbon replacement[a]	88
Acid solution[b]	78
Electricity cost[c]	779
Labor wages[d]	374
Maintenance costs (10% of the investment cost)	776
Total	2,095
Total cost per year (USD)	
Salvage value[e]	717
Depreciation cost[f]	704
Interest on investment[g]	424
Fixed cost[h]	1,128
Variable costs	2,095
Total[i]	3,223
Cost per volume of treated condensate produced[j]	0.24
Savings cost (USD/y)	
Water used in the process[k]	3,959
Condensate treatment using the central wastewater treatment system[l]	1,979
Total	5,938
Profit[m] (USD/y)	2,715
Payback time[n] (y)	2.86

1.25 USD/m^3 in a nanofiltration plant for treating vapor condensate from milk processing to boiler makeup water.

4. Conclusions

According to this study, the condensate wastewater generates from the production process of fish extract and feed protein, which are the by-products of canned tuna plants, requires pH reduction and deodorization before being used as a recycling water in the process. It has been found that pH adjustment contributes to faster adsorption rates. A 15 cm diameter and 150 cm height adsorbent column packed with commercial activated carbon, Eunicarb ID 900 ASTM mesh size 8 × 16 was designed to treat the pH adjusted condensate at 2.5 m^3/h which is the actual flow rate of condensate generated from the process. The experiment run at the production site of the factory guaranteed a duration of up to 6 months operation that could maintain the treated condensate water to meet the water standards set by the company, before being able to be recycled back as feed water to produce fish oil without the effect on the product quality and yield. In addition, economic assessments have shown that it can reduce 5,938 baht/y in terms of the cost of the process feed water and condensate wastewater management using ordinary technology of the factory with a payback period of 2.86 y. This research has confirmed the prompt condensate recycling technique to be further used by the represented researched factories.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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