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Review

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ABSTRACT

This review intends to discuss on greywater treatment technologies, which are the physiochemical, biological and advanced oxidation process (AOP) treatment technologies that are used to remove organic, nutrient and surfactant pollutants in greywater. The focus of this study is to compare the treatment technologies to remove greywater pollutant in coastal area. Each technology will be compared in terms of its advantages and disadvantages including its potential in greywater treatment technologies development. Measurement parameters of water quality from other studies includes physicochemical, organic content, nutrient and surfactant that are developed from each greywater treatment mode. AOP has a huge potential in greywater treatment since the technology has low cost of development, easy to install and able to be deployed in small scale. The AOP could be combined with other treatment techniques to produce an improved output..

1. Introduction

Public wastewater is estimated contributing around 7% towards organic waste in the rivers in Indonesia cities. A large number of those wastewater is coming from greywater that flows from residence area into the river through water channels without a proper water treatment process, which heavily impacted the ecosystem of river and its water quality (Firdayati et al., 2015). The greywater volume produced from residence could be as high as 95 L out of 135 L of clean water used per person per day, which corresponds to around 70 – 75% of the total consumed water. Total produced greywater by public depends on the location, lifestyle, climate, infrastructure, culture, and other factors (Oteng-Peprah and Nanne, 2018; Peeples, 2006).

Most of public greywater waste is coming from kitchen and toilet (Mohamed et al., 2017), in which leftover of food and drinks are coming from kitchen that dominates organic waste whereas waste due to cleaning agents such as soap and detergent and urine waste is coming from toilet. Waste from toilet has high surfactant such as ammonia, nitrite, and phosfforus, in which the main source is the laundry waste that possess the surfactant element (Noutsopoulos et al., 2017). Chemical contaminant found in greywater has severe effect if it is consumed by the public and thus additional effort is needed to remove the waste to safeguard the health of general public (Peeples, 2006).

Total number of people in Indonesia cities is about 150.9 million or around 55.8% of total Indonesia population. The incremen t is contributed by rapid development of facilities and numerous economic activities in cities (Mardiansjah, 2018). People in cities are the main factor of river pollution in Indonesia since most of greywater waste in cities goes directly into river through water channel without a proper treatment process (Firdayati et al., 2015). A number of cities in Indonesia used the main rivers as their clean water supplies and the issues of high volume of greywater waste in the river could become a major factor of public to avoid using river as clean water supply.

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Greywater treatment has attracted public interest recently not only due its high volume in the river but also the greywater waste has the potential to be a source of clean water. Focus in greywater treatment technology hovers around the easiness of its implementation, low cost and does not produce any residue elements. Therefore, this study is carried out to review the existing greywater treatment technologies, which are physicochemical treatment, biological treatment and AOP treatment, in terms of their advantages and drawbacks.

2. Characteristics of greywater

2.1. Definition of greywater

Greywater is defined as low polluted wastewater originating from bathtubs, showers, hand washing basins and washing machines excluding wastewater from toilet flushing system (Murthy et al., 2016). Waste quality is measured based on the parameters referred to the regulation as stated in *The Water and Wastewater Monitoring and Analysis Method* (Zheng et al., 2015). The parameters are chemical oxygen demand (CODcr), five-day biochemical oxygen demand (BOD5), total organic carbon (TOC), and amount of ultraviolet (UV) light absorbed by organic compounds in a water sample at the 254 nm wavelength (UV254) (Zheng et al., 2015).

2.2. Quantity of greywater

The average usage of clean water for each household is between 100 L and 200 L/s, which is mostly used for bathing and washing clothes (Mohamed et al., 2017). The figure is relatively similar to the figure reported by Morel and Diner by Li et al. (Li et al., 2009) that the average volume of waste greywater is between 90 and 120 L/p/d. As reported by Firdayati et al. (Firdayati et al., 2015) in her case study in Bandung, Indonesia, there are different consumption between high incomes and low-income families in term of cleaning product variation. The low income families consume relatively small amount of clean water but the waste content is mostly dominated by total dissolved solids (TDS) and electrocougulan (EC). This situation occurs due to the greywater waste produced is influenced by water supply and infrastructure as well as the number of families and the distribution of family ages. This statement was supported by Morel and Diner (Li et al., 2009) that the volume of greywater for low-income families in cities is between 20 and 30 L/p/d.

2.3. Quality of greywater

The content of greywater can be divided into two categories: (1) light greywater, (2) heavy grewater (Noutsopoulos et al., 2017; Li et al., 2009). Light greywater is a type of greywater that has a low pollutant content, whereas heavy greywater has a high pollutant content. The element in greywater consists of organic elements, surfactants, nutrients and small amount of metal. Although the quality of greywater varies due to its influence on the quality of water used, water activities and lifestyle, the main pollutants of greywater are mostly laundry and kitchen waste (Noutsopoulos et al., 2017; Li et al., 2009). Physical parameters such as pH values are generally in the range of standard values that are safe for the environment (Mohamed et al., 2017; Lamine et al., 2007), whereas the total suspended solids (TSS) values vary and normally above the standard value. The highest TSS value comes from kitchen waste, i.e. leftovers from drinks and food (Noutsopoulos et al., 2017). Compared to black water, organic material in greywater is lower (Temmink et al., 2010), however the COD and BOD values of greywater still above the standard level of clean water (Mohamed et al., 2017; Noutsopoulos et al., 2017; Lamine et al., 2007; Barzegar et al., 2019). The high level of organic elements are influenced by detergent waste and the low amount of water used in the washing process using cleaning products (Firdayati et al., 2015; Mohamed et al., 2017; Noutsopoulos et al., 2017). The biodegradability is determined using the BOD5/COD ratio (Oteng-Peprah and Nanne, 2018) and the organic material contained in greywater normally has good biodegradability which means it can easily to be decomposed.

As previously mentioned, laundry waste contributes to the highest volume in greywater types, however the biodegredability of laundry waste is high, which is around 67% (Noutsopoulos et al., 2017). Therefore, the organic elements contained in the greywater could be processed without the complex treatment process (Firdayati et al., 2015; Mohamed et al., 2017; Dandapani, 2017). On the contrary, if the waste is not well treated, there is a concern on its impact towards the aquatic environment, because most of the greywater waste contaminates water sources such as river. Another pollutant produced by greywater is surfactact named xenobiotic organic compounds (XOC) containing anionic detergent linear alkybenze solfunate (LAS). XOC is produced by chemical household products such as detergents, soaps, shampoo, bleaches and cleaners (Eriksson et al., 2002). LAS concentrations in greywater is ranged between 7 and 436 mg/L (Noutsopoulos et al., 2017). The environmental effects caused by these surfactants are quite serious since it can interfere with the growth of algae, bacteria and fish, even in the presence of surfactant concentration as low as 0.2 mg/L in waters (Ivankovic & Hrenovic, 2010). The physicochemical treatments can reduce surfactants in wastewater (Noutsopoulos et al., 2017) and it also can be degraded by microbes in aerobic processes (Ivankovic & Hrenovic, 2010; Ramcharan et al., 2017).

The third elements in greywater is nutrients and it can be in the form of dissolved nitrogen and phosphorus. Total nitrogen (TN) consists of nitrate (NO_3-N), nitrite (NO_2-N), ammonia (NH_3-N) and organically bound nitrogen (Satria et al., 2019). The nitrogen in the greywater can come from the water source used, residue of living things or derived from urea that present in human urine (Shaddel, 2019). According to Noutsopoulos et al (Noutsopoulos et al., 2017), the total concentrations of nitrogen and phosphorous in greywater were quite low between 2.5 and 6.5 mg/L. Also, it was found that the presence of ammonia was not significant, which was only ~ 3 s/d or 25% from measured TN ranges from 0.2 to 1.4 mg/L. Besides, the highest TN content as reported by Li et al. (Li et al., 2009) was 74 mg/L for greywater waste from the kitchen waste.

Similar values were measured for TN concentrations as reported by Carey and Migliaccio (Carey & Migliaccio, 2014). These results prove that the presence of ammonia especially from human urine is minimal and TN is more dominated by the presence of nitrates in greywater (Noutsopoulos et al., 2017). However, ammonia concentrations of more than 0.2 mg/L are not good for aquatic ecosystems, especially for fish growth. The large concentrations of ammonia can cause poisoning and inhibit fish growth (Padmavathy, 2017; Boyd, 1984; Luo et al., 2015). In contrast, the highest ammonia concentration comes from laundry waste (Noutsopoulos et al., 2017) and this ammonia may come from the type of detergent used and dirt stuck to clothes (Bajpai & Tyagi, 2007). Conversely, nitrogen and phosphorus elements in greywater comes primarily from urine (Mohamed et al., 2017). The example of greywater characteristics is shown in Table 1.

2.4. Water quality standard in aquaculture

Deep water conditions are essential since they affect the growth of fish and other plants. An ideal water conditions for fish growth

Table 1
Greywater characteristics (Noutsopoulos et al., 2017).

Greywater source	pH	TSS	COD	BOD	TN	LAS
Bathroom	7.5 ± 0.1	73.5 ± 38	390 ± 125	263 ± 83	2.7 ± 2.2	78 ± 34
Hand basin	7.6 ± 0.2	69.2 ± 35	427 ± 192	305 ± 129	2.5 ± 1.9	42 ± 26
Laundry	6.9 ± 0.4	90.5 ± 68	1119 ± 476	831 ± 358	6.5 ± 5.0	87 ± 76
Kitchen	8.3 ± 0.8	58.9 ± 48	2072 ± 1401	1363 ± 950	6.2 ± 5.3	436 ± 288
Dish washer	10 ± 0.2	319 ± 209	411 ± 59	184.6 ± 24	<0.5	7 ± 5.6

must meet several elements, including temperature, pH, dissolved oxygen (DO), BOD, COD, alkalinity, hardness, density, level of nitrate, nitrite, ammonia, sulfate and phosphate (Padmavathy, 2017). Table 2 shows the standard quality of water for growing freshwater fish.

Water temperature and pH level affect the metabolism rate of the fish; excessive temperature and acidic water might cause fish mortality. High concentration of BOD affects the DO rate in water and high concentration of COD indicating many organic and inorganic pollutants contributing to fish mortality. High level of nitrate, nitrite and ammonia are poisonous to the fish whereas low level of nitrate raise the growth of plankton, resulting in decreasing of food supply for fish (Boyd, 1984). The phosphate element is also influential as other nutrient elements, however an immense amount of phosphate elements in water could kill fish (Padmavathy, 2017) and boost algae growth in water (Bajpai & Tyagi, 2007). Normally, sulfate is incorporated in TDS and essential for fish growth, but too much sulfate concentration can cause toxins in the air that are capable of killing the fish (Padmavathy, 2017). The phosphate and sulfate content mainly comes from detergent pollutants.

3. Greywater treatment technologies

3.1. Physicochemical treatment

Physicochemical treatments for greywater primarily employ filter and disinfectant methods (Edwin & Gopalsamy, 2014). The filter method is effective for reducing TSS, TDS and turbinity. Sand filters are effective at reducing TSS, TDS and turbidity greywater levels above 80% (Noutsopoulos et al., 2017; Radha et al., 2019; Friedler and Alfiya, 2010). This occurs because the fine particles of sand can remove ions (negative charge of waste colloids) using absorption and ion exchange mechanisms (Radha et al., 2019). In addition, sand has hydrophobic properties that can interacts strongly with solids such as TSS. The sand filter will also form pore layers that can trap solids (Juniar et al., 2016). However, using a sand filter alone without any prior sedimentation steps for the greywater treatment will require a shorter filter cleaning period (Noutsopoulos et al., 2017). Sand filter itself is not an effective method to reduce carbon pollutants in greywater because most of the carbon elements are dissolved (Friedler & Alfiya, 2010). Besides, the presence of carbon–oxygen bonds increasing the hydrophilic properties of carbon pollutants (Radha et al., 2019).

Table 2
Standard water quality for fish culture.

Culture Category	Physical parameters (Padmavathy, 2017)	Organic Parameters (Buttner et al., 1993)	Nutrient Parameters (Padmavathy, 2017)
Tropical	Temp: 26–32C pH:6–8.5 DO:greater than4–5 mg/L TDS:<172 mg/L TSS: <86 mg/LHardness: <15 mg/L Alkalinity:5–500 mg/L	COD: <250 mg/L BOD: <30 mg/L	Nitrat:0.2–10 mg/L Nitrite:<0.3 mg/L Ammonia:<0.05 mg/L Posfat:0.05–0.2 mg/L Sulfat:5–100 mg/L

In general, the effectiveness of the sand filter to reduce carbon pollutants can be increased by combining the sand filter with the active carbon filter (Noutsopoulos et al., 2017; Radha et al., 2019), or by adding the coagulation and sedimentation steps before filtration (Friedler & Alfiya, 2010).

Other type of filter to reduce TSS and COD in greywater is geotextile filters such as nonwoven with pore size of 0.10 mm to 0.18 mm. Although most suspended solids are smaller than 0.032 mm, this type of non-woven geotextile filters can reduce the suspended solids concentration up to 50% (Ochoa et al., 2015), proportional to the volume of waste loaded. Moreover, non-woven geotextile reduced COD, BOD_5 and TSS levels by an average of 65%, 68% and 78%, respectively (Spychała & Nguyen, 2019). As a result, the removal of the LAS greywater element is done by combining the geotextile filter with a sand filter. LAS itself is biodegradable when its concentration does not exceed the specified concentration of 20–50 mg/L (Ochoa et al., 2015). The reduction in organic and suspended solids content occurs due to the deposition of suspended solids, agglomeration and flow of fluids passing through the geotextile filter (El-Khateeb & Emam, 2019). In addition, aerobic condition of the geotextile filter surface determines the effectiveness of organic components removal process from greywater (Spychała & Nguyen, 2019).

Physiochemical treatments are quite effective in reducing suspended solids in greywater (Radha et al., 2019; Friedler & Alfiya, 2010), but less effective at degrading carbon pollutants. Besides, the removal of nutrient greywater elements such as phosphorus and ammonia is also ineffective and thus the coagulation process is needed in this treatment. The coagulation process involves the addition of coagulant chemicals such as calcium hydrochloride ($CaOH_2$) and ferrochloride ($FeCl_3$) to increase the removal of organic elements and disinfectant. The addition of $CaOH_2$ and $FeCl_3$ was able to reduce COD and BOD levels by up to 90% (Abdel-Shafy & Al-Sulaiman, 2014). However, the addition of coagulant material affect the pH value because of the direct reaction between nitrate and aluminum or iron (El-Khateeb & Emam, 2019) and this becomes a limitation in reducing the overall greywater pollutant using physicochemical treatment. The summary of physiochemical process for greywater treatment is given in Table 3.

3.2. Biological treatment

The biology treatment mainly uses aeration techniques and membrane bioreactors (Edwin & Gopalsamy, 2014). The aeration technique is carried out by providing sufficient oxygen levels to the water so that it helps bacteria to degrade organic pollutants, whereas the bioreactor membrane technique is a combination of biological treatments and physical separation of solids (Iorhemen et al., 2016). One method of aeration technique is sequencing bath reactor (SBR) and this method removes COD levels up to 90% (Lamine et al., 2007; Temmink et al., 2010). This condition occurs because most of the COD in greywater is colloid, which is easier to decompose by aerobic process (Temmink et al., 2010).

Another method of aeration technique is rotating biological contactor (RBC). RBC is selected to remove TSS and BOD greywater with TSS levels can be removed up to 95%, whereas the BOD concentration can be removed up to 93% (Abdel-Kader, 2013). The low efficiency in solids removal of greywater due to low flock formation during the aerobic process due to low level of DO in the water (Abu-Ghunmi et al., 2019). The oxygen transfer in the aeration process is influenced by the concentration of gas particles, the particle size and the viscosity of the solution (Germain & Stephenson, 2014). Therefore, in order to increase the efficiency of removing physical solid particles using aeration techniques, the concentration of DO plays an important role through the biological treatment (Fajri et al., 2018). The aeration technique has limitations in infrastructure, hence, the membrane bio-reactor (MBR) technique is chosen for smaller scale project. MBR is significant in reducing organic elements and the levels of COD and TSS greywater can be reduced up to 80% and 90%, respectively (Smith & Bani-Melhem, 2012). However, the removal of organic elements using MBR was mainly influenced by the biodegradation of carbon elements (BOD/COD) (Judd, 2016). Therefore, low percentage of waste carbon elements removal found in low biodegradation condition.

In contrast, the aerobic process can be used to remove surfactant material in greywater. This is because most of surfactant ingredients in greywater come from anionic surfactant group (Temmink et al., 2010). In addition, sulfonate could not be degraded significantly under anaerobic conditions due to the oxygen-limited conditions that inhibit the rate of mineralization of sulfonates (Bajpai & Tyagi, 2007). The aeration technique using the SBR method is able to remove surfactants up to 97% (Temmink et al., 2010), in contrast to the bioreactor membrane technique which is able to reduce with a smaller value, which is 95% (Smith & Bani-Melhem, 2012). This means that both aeration and membrane bioreactor techniques have the ability to remove surfactant elements from greywater waste, provided that the type of surfactant is an anionic surfactant group (Bajpai & Tyagi, 2007).

Reduction of nutrient in greywater using biological streamers produces varying percentages. The aeration process of ammonium nitrogen (NH_4-N) and Nitrite (NO_2-N) can be reduced up to 91% within 2.5 days, whereas the concentration of phosphate (PO_4-P) can be reduced up to 66% (Lamine et al., 2007). This process normally takes place in aerobic conditions. The removal of elemental NH_4-N and lower concentrations of element phosphate around 31% (Temmink et al., 2010). The removal of nitrogen elemental is done through aerobic conditions. Generally the nitrogen element in greywater comes from urine and is mostly ammonium (Temmink et al., 2010). The decomposition of nitrogen in greywater through a nifrication process produces nitrite and nitrate elements (Lamine et al., 2007). The nitrification process can only occur under aerobic conditions (Udert et al., 2015). Phosphate in greywater mostly comes from detergents and soaps because they contain high concentration of phosphate (Noutsopoulos et al., 2017) and a small portion of phosphate comes from urine (Mohamed et al., 2017). The reduction of phosphate in greywater using biological treatments currently relatively low (Lamine et al., 2007; Temmink et al., 2010; Smith & Bani-Melhem, 2012). Low release of phosphate through biological processes is influenced by the nitrates concentration from nitrate denutrification process that use organisms for phosphate biological release (bio-P removal) (Lamine et al., 2007). The highest reduction of elemental phosphate was 65% (Lamine et al., 2007).

Both the aeration and the MBR techniques are effective in reducing ammonium nitrogen because the aerobic conditions during the nitirification process (Smith & Bani-Melhem, 2012). However, both techniques are ineffective when decomposing phosphate in greywater. Another technique of biological treatment to overcome this problem is the physcoremediation technique. The percentage of phosphate decomposition using the physcoremediation technique is quite high at 99%. This condition occurs because of the microalgae cells that dissolve phosphate in water and reabsorption by cells through the assimination process. However, this condition does not apply if the phosphate element is dominant (Mohamed et al., 2017). Table 4 lists the biological process for greywater treatment.

3.3. Advanced Oxidation Process (AOP) treatment

AOP is an oxidative chemical technology which mostly producing hydroxyl radicals (OH*) as strong oxidants in liquid media.

Table 3
Phycochemical process for greywater treatment.

Process	Greywater source	Target	Result	Ref
Coagulation + Sedimentation + Sand filter + GAC filter	The greywater was collected from three residencies in AthensCity, Greece	Turbinity, TSS, Organic carbon, surfactant	Remove Turbidity, 90%, TSS 60%, COD 60% and Surfactant 80%	Noutsopoulos et al. (Noutsopoulos et al., 2017)
Nonwoven textile filter	Semi-natural greywater (simulating bath/showeroutflow) preparationwere based with the aim of achievinggreywater properties that were comparable to polish households	COD_{Cr}, BOD_5,TSS	Reducing chemical oxygen demand (COD_{Cr}) and biochemical oxygen demand (BOD_5) between 58.8 and 71.6% and 56.7–79.8%. The relatively high efficiency of total suspended solids (TSS) removal (67.0–88.4%).	Marcin Spychała and ThanhHungNguyen (Spychała and Nguyen, 2019)
Filter layer of Gravel +Sand + Activated carbon + Cotton and CaOCl2 as disinfectant	The mixture from three different sources such as kitchen sink, shower and washing machine in Fahaheel, Salmiya and Farwaniya areas, Kuwait	pH, color, TDS, Turbinity, total coliform and E coli.	The efficiency of removal for some of the analyzed parameters was measured as 23%, 95%, 52%, 88%, 100% and 100% for pH, colour, TDS, turbidity, total coli form and E. coli, respectively.	DhanuRadha Samayamanthul,Chidambaram Sabarathinam, andHarishBhandary (Radha et al., 2019)
Two type: (1) Sand filter alone, (2) Sand filter + Floatation - sedimentation	Greywaterwas collected from a wet well in the basement of the building of the Faculty of Civil and Environmental EngineeringintheTechnion, Israel	Turbinity, TSS, COD_t, COD_d, BOD_5	Theremovalefficiencies of 92, 94,65 and 57% of turbidity, TSS, COD_t and BOD respectively	Eran Friedler and Yuval Alfiya(Friedler and Alfiya, 2010)
Chemicalcoagulant lime + FeCl3 + Sendiment ation	Municipal wastewater was separated from the origin into Black (B), Grey (G) and Yellow(Y) water assegregatedand collected from one house across the Training Demonstration Centre (TDC) site in the National Research Centre (NRC), Cairo,Egypt.	TSS, COD, BOD, oil & grease, E. Coli	Removal rates of TSS, COD, BOD and oil & grease enhanced to 94.9, 91.8, 94.2 and 97.2%, successively. The E. coli count and the number of cells or eggs of Nimatoda in the final effluent reached 100/ml and 1 count/l, respectively	H.I. Abdel-Shafy and A. M. Al-Sulaiman(Abdel-Shafy and Al-Sulaiman, 2014)

Table 4
Biological process for greywater treatment.

Process	Greywater source	Target	Result	Ref
Physcoremediation	The discharger point of greywater from household	BOD_5,COD,NO_3^-, NH_3, PO_4^{3-}, K, Ca	Reduction BOD_5 ranged from 85.3 to 98%, 71.22 and 85.47% COD, $NO_3^-$with 98%, NH_3 and PO_4^{3-} ranged from 86.21 to 99 and 39.12 to 99.3%, respectively. The high removal K 97% dan Ca 95%.	R.M. Muhamed et al. (Mohamed et al., 2017)
SequencingBatch Reactor (SBR)	The greywater was collected from students' house at outlet of showersroom.	COD, NO_2-N, NH_4-N and PO_4-P	Removal COD 90%, NH_4-N 91%, NO_2-N 50%, PO_4-P 66%.	M.Lamine,L. Bousselmi,A. Ghrabi (Lamine et al., 2007)
Sequencing Batch Reactor (SBR) and Up flow anaerobic sludge blanket (UASB)	Greywater was collected from the 32 houses of the Decentralized Sanitation and Reuse (DeSaR) demonstration project in Sneek, the Netherlands	COD, anionic surfactants, NH_4-N, P, N	Removal COD 90%, anionic surfactants 97%, NH_4-N 92%, P 31% and N 35%.	Luci´a Herna´ndez Leal et al. (Temmink et al., 2010)
Aerobic and Anaerobic System	Greywater source was obtained from a dormitory, of 150 students at the Jordan university campus, Jondania	COD_t, BOD_5, Solid, Volatile solids	Removal achieved by the aerobic unit are COD_t 45%, BOD_5 37%, Solid 24% and Volatile solids 33%. Removal achieved by the anaerobic unit are COD_t 53%, BOD_5 40%, Solid 5% and Volatile solids 18%.	L.A. Ghunmi et al. (Abu-Ghunmi et al., 2009)
Membrane Bioreactor	Greywater was collected from a facility services building on the AUC campus located in New Cairo, Egypt.	COD, TSS, colour, turbidity, ammonia nitrogen, anionic surfactants, and coliform bacteria	Removal color, turbidity and TSS excess of 90%, NH_3-N reduction nearly 97%, Phosphorus removal was <60%, anionic surfactants were reduced by 95%, COD removal being <80%,	E. Smith and K. Bani- Melhem (Smith and Bani-Melhem, 2012)
RotatingBiological Contactor	The greywater was collected from lodging buildings whereas the plumbing system was segregated as black water and greywater.	TSS, BOD, TKN	BOD removal was ranged between about 93.0% and 96.0%, TSS removal was ranged between about 84.0% and 95.0%. And TKN removal in range 57% to 85%.	A.M. Abdel Kadir (Abdel-Kader, 2013)

These OH* are highly reactive and non-selective (Karamah et al., 2019). Two types of AOP are widely used in wastewater treatment, namely: (1) Photochemical, and (2) Chemical (Bin and Sobera-Madej, 2014).

The photochemical method commonly used in the water treatment process is UV light. The UV light can produce OH* when applied to water because the radiation produces excitation and ionization processes. The UV light is also selective in order to reduce various waste organic components but this method is not efficient in removing other pollutants in waste thus it needs to be combined with other materials to increase the effectiveness (Jing & Cao, 2012). For chemical type, the AOP treatment type uses ozone or hydrogen peroxide (H_2O_2) as an ingredient to produce OH*, the use of ozone and H_2O_2 alone is not effective because of the low removal of organic wastewater. Besides, the treatment time required is also relatively long compared to combining these two chemicals; i.e. UV/ozone or UV/H_2O_2 (Jing & Cao, 2012). The removal of organic elements using AOP via UV/H_2O_2 technology shows an increase in the biodegradable index during the treatment process which allows wastewater to be further treated both chemically and biologically (Rana et al., 2016). The combination of ozone with EC was able to reduce COD and TOD levels up to 65% and 50% respectively (Barzegar et al., 2019). EC with iron electrodes can activate ozone to produce OH*. The dose of ozone has a crucial role in the formation of OH* for the degradation of organic compounds. The higher the ozone dose, the lower the COD and TOC levels, but it should be noted that the dose of 47.4 mg/L is sufficient to reduce COD up to 70%. If the reduction is more than 70%, the ozone tends to prevent the formation of hydrosil radicals rather than form it. The significant removal of BOD greywater due to the combination of membrane filter and aeration, with the aeration process an increases DO elements to help microorganisms break down dissolved organic elements (Chao et al., 2019). The presence of UV does not play a significant role in this degradation process, whereas the use of sand filters in the pre-treament and membrane filters in the post- treatment can help reduce TSS levels and waste turbidity (Chao et al., 2019). The use of UV and ozone to reduce the TDS and TSS elements is not as significant as reported by Bhatta et al. (Bhatta et al., 2015), however, both can be used to reduce COD concentrations excellently.

Besides, the UV/ozone-biologically active filtration (BAF) combination can reduce COD levels up to 1.6 times compared to the standalone ozone-BAF combination. Ozone treatment alone without involving UV cannot fully oxidize COD because of the UV presence can help the formation of H_2O_2 and O_2, which then reacts with ozone or UV to produce OH^- (or OH*) (Hadiyanto et al., 2020). As mentioned previously, the combination UV/ozone or UV/H_2O_2 treatments can produce a direct reaction in the formation of OH* (Simonenko et al., 2015; Asaithambi et al., 2015) compared to the use of UV or ozone alone, whereas the best combination is when the three methods were combined, namely UV/H_2O_2/ozone (Asaithambi et al., 2015). The advantage of ozone treatment is that it can decompose dissolved nitrogen elements into ammonia or nitrate ions so that it has the potential to breakdown nutrients in greywater (Bhatta et al., 2015). The reduction of nitrogen in wastewater was also reported previously and depicts that UV/ozone treatment can reduce total nitrogen in waste by 69.2%. Even the addition of ozone with UV radiation can reduce the nitrite concentration to below 0.1 mg/L (Hadiyanto et al., 2020). However, the reduction of the phosphorus using UV/ozone is less significant because orthophosphate as a form of dissolved phosphorus reacts with water to form phosphoric acid, which affects the pH value in wastewater (Hadiyanto et al., 2020). The change in pH affect the decomposition process in greywater. Moreover, the combination of UV/H_2O_2 can reduce LAS detergent levels up to 96.5% within 30 min (Gharderpoori & Dehgani, 2016). The degradation of O-O into OH* can occur by photolysis with the aid of UV radiation. These results prove that H_2O_2 material will be effectively used to remove LAS detergent in greywater waste when combined with UV. The use of ozone and biodegradation materials can also be used to reduce anionic and non-anionic surfactants through the process of ozone mineralization, which is then decomposed by microorganisms (Lechuga et al., 2014). The advantage of the AOP method in greywater treatment is due to its simple setup with a small system scale. The main consideration is the usage of AOP in combination with a biodegradation process or filter to improve treatment performance. Table 5 lists all the advanced oxidation process for greywater treatment.

Table 5
Advanced oxidation Process for greywater treatment.

Process	Greywater source	Target	Result	Reference
Flow constructed wetland and H_2O_2/UV	Synthetic Greywater (SSGW) was prepared by using detergents, bathing soap, shampoo, hair oil, paste, washing soda in tap water by following standard method (28) for 50 L.	COD, BOD, PO_4^{-3}, Biodegradability Index, pH	Maximum removal after two hours treatment in COD (93%), BOD (81.74%), Phosphate (75.64%) and Biodegradability Index(0.75). pH = no change	D. B. Rana, M. K. N. Yenkie and N. T. Khaty (Rana et al., 2016)
Electrocoagulant / O_3	Greywater samples were manually collected from Jahanara dormitory, Abadan, Iran. The collected sample was kept in 40C to prevent biological activity and reduction of organic content.	COD, TOC, Escherichia Coli	The results showed that 85% of COD and 70% of TOC were removed during 60 min electrolysis time. In the presence of UV irradiation, 95% of COD and 87% of TOC were eliminated. Moreover, 4 logs of total coli form and 96% of Escherichia coli were removed byEC/ozone/UV process	Gelavizh Barzegar, Junxue Wu, Farshid Ghanbari (Barzegar et al., 2019)
Membrane filter-UV-Aeration bubble	Water collected from Penchala River is one of the main rivers in Klang basin, Malaysia	turbidity, TSS, TDS, BOD, DO, and pH	Reducing BOD up to 58%, Turbidity 93%, TSS 92%, TDS 11%. Increasing pH from 6 to 8.5 and DO from 1,26 mg/L to 8,61 mg/L	O. Chao et al. (Chao et al., 2019)
Ozone treatment	The wastewater samples were collected from Guheshwori wastewater treatment plant (WWTP), Kathmandu, Nepal.	DO, EC, pH, TDS, COD, Nitrate	Increasing DO from 4,36 to 9,41 mg/L and Nitrate 4000 to 12,000 (mg/L), increase pH from 7 to 8. TDS and EC does not change significantly, Decreasing COD from 368 to 275	Bhatta et al. (Bhatta et al., 2015)
UV/Ozone-Biological Aerating Filter (BAF)	Secondary effluent from a WWTP in Nanjing, Jiangsu China	COD, BOD_5	UV/O_3 oxidation with BAF could remove more than 61% of COD	Zhaoqian Jing dan Shiwei Cao (Jing and Cao, 2012)

4. Knowledge gap

As pointed out in the discussion in the previous section, in general, all the treatment technologies are beneficial in removing waste in the greywater as shown in Fig. 1. The physicochemical treatment is able to eliminate the compact waste element successfully, nevertheless it is less effective in removing surfactant, nutrient and organic elements. The biological treatment removes organics and nutrient elements adequately but unproductive on dissolved solids and surfactant elements removal. Thus, researchers are focusing on the advancement in AOP technology, which could be combined with either filter or biological process. As most of the study are looking on the removing of both organic and nutrient elements in greywater, However, the removal of organic pollutants and nutrients using the AOP method is still very low, as well as other elements such as dissolved solids that cannot be done without the aid of a filter. Therefore, the development of AOP technology to treat greywater need to be combined with other

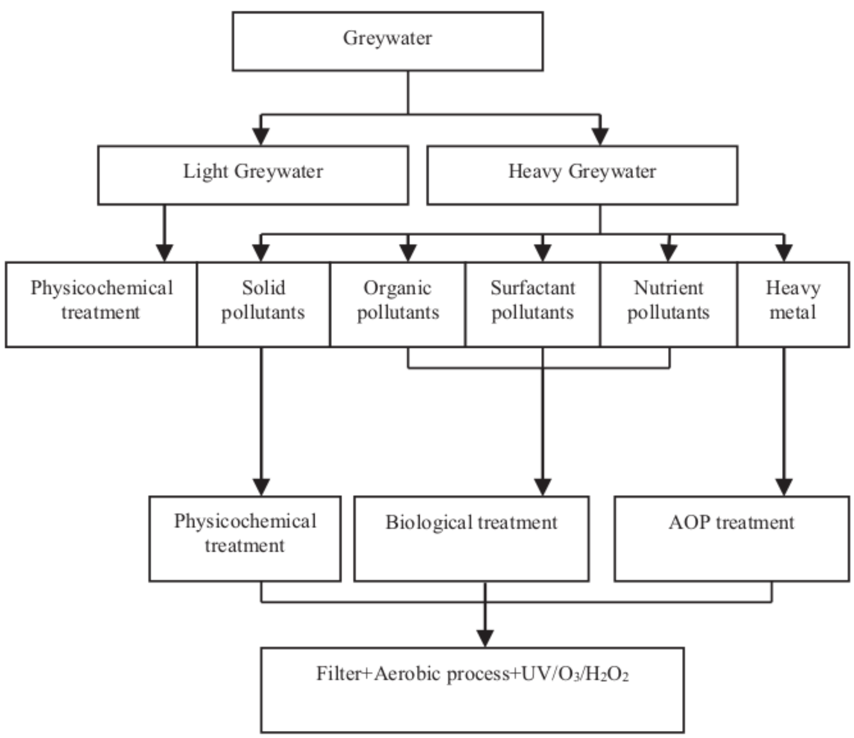

Fig. 1. The greywater technology treatment for aquaculture safety.

treatment methods must be studied due to the improvement of greywater treatment technology for public mass should look into other issues such as easiness of installation, deployment scale and cost of operation.

5. Conclusions

This review covers a comprehensive study on the existing greywater treatment technologies, namely physiochemical, biological and AOP, which are used to remove greywater pollutant such as organic, nutrient and surfactant pollutants. The AOP technology has a potential to be developed as greywater treatment for mass public due to its easiness of installation and deployment in small scale. Besides, AOP is capable of degrading all greywater pollutant elements that made it a great alternative to reduce the greywater pollutant in the coastal area. It is anticipated that the AOP could be combined with the aeration process and filter to enhancement reducing solid pollutants and nutrients in greywater.

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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