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Water Sustainability: Emerging Trends for Water Quality Management

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Abstract

Water sustainability needs an integrated approach to meet the water need of the present without compromising the ability of future generations to meet their own need of water. It includes water security and water scarcity. The water demand is increasing every year, while the planet's capacity to sustain increasing demands for water is challenged. The main global water problems fall into three categories. The first is too much of it, secondly is too little of it and thirdly, it is too dirty. The first category is due to extensive flooding, the second category is due to serious drought and the third category is due to pollution and misuse of water which needs water quality management. Nowadays, there are 1.2×10^9 people live in areas of water scarcity and 2.6 billion people in global are lacking safe water supply. There are (6 to 8) $\times 10^6$ humans being are killed each year from water-related disasters and disease. In Indonesia, there is about 37×10^6 people lack access to safe water due to water quality issue. In this paper, emerging trends in water quality management to support water sustainability and the water-energy nexus will be discussed.

Keywords: water quality; water sustainability; water management.

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1. Water Sustainability

We all understand that everyone needs water, though not everyone thoroughly understand the issue of water sustainability. What is water sustainability? It involves in people participating which talking about communication and dialogue, political process and also operated between science and society which needs creatively, holistically and broadly thought. It is an integrated approach to meet the water needs of the present without compromising the ability of future generations to meet their own need of water. Water sustainability includes water security and water scarcity. There are (6 to 8) $\times 10^6$ humans being killed each year from water-related disasters and disease. The demand and scarcity of water is greater every year which can be seen in Fig. 1 and Fig. 2. In Fig. 1, it is clear that the demand of water will increase up to 60 % by 2050. The planet's capacity to sustain increasing demands for water is questioned. Failure in governance and development has generated tremendous pressure on water resources affecting water quality and availability. About 1.2×10^9 people live in areas

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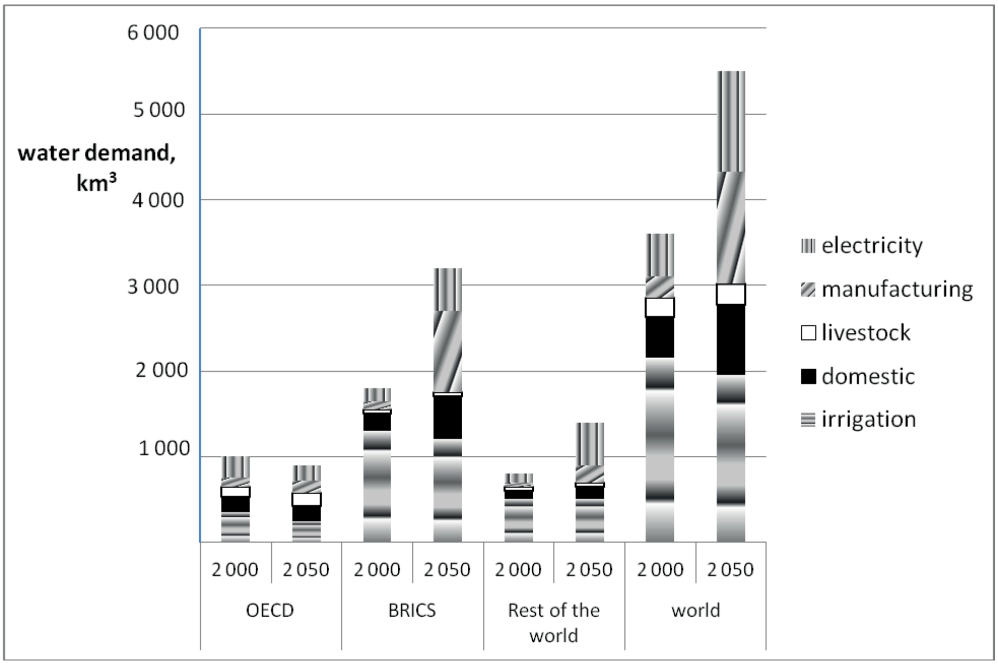

Figure 1: Global water demand, baseline 2 000 and 2 050.(adapted from globalsherpa.org) BRICS = Brazil, Russia, India, China and South Africa.

of water scarcity and 2.6 × 10^9 people in global are lacking safe water supply. In Indonesia, it is about 37 × 10^6 people lack access to safe water. Fig. 2 shows the global trends and change of water availability which is a concern of water scarcity. The main global water problems fall into three categories. Firstly, it is too much due to extensive flooding. Secondly, too little of it due to serious drought and thirdly, it is too dirty due to pollution which needs water quality management. Water sustainability interacts with ecological/environmental, social and economic system which is shown in Fig. 3. Indicator categories for environmental systems involve water quality and quantity which needs water resource and water quality management. The indicator is human and environmental effects. Hence there is a standard of water discharge to ensure water security. Water treatment which involves emerging technology will be discussed further.

2. The Water-Energy Nexus

As only 2.5 % of the earth's total water supply is fresh water, companies are encouraged to address water concerns in manufacturing products. Fig.1 shows that energy production needs water, though energy is also required to make use of water. These two are always unavoidable linked. Companies have been working to manage both efficiently and sustainably. The inseparable water and energy is because of: i) water is required to produce energy. Water is utilized in the production most energy production

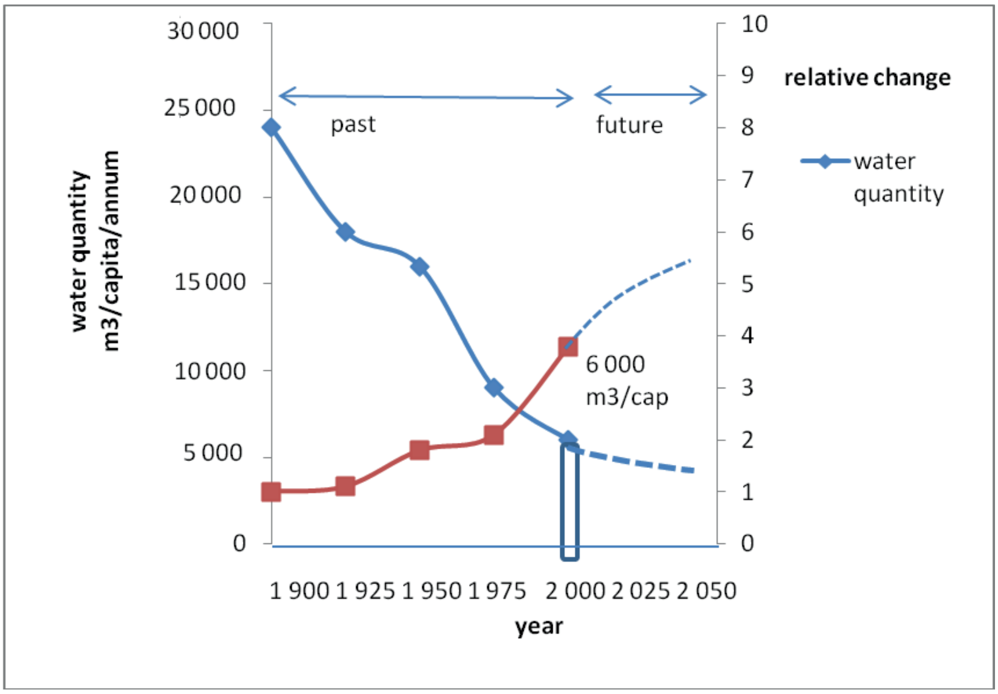

Figure 2: Global changes and trends for water availability.

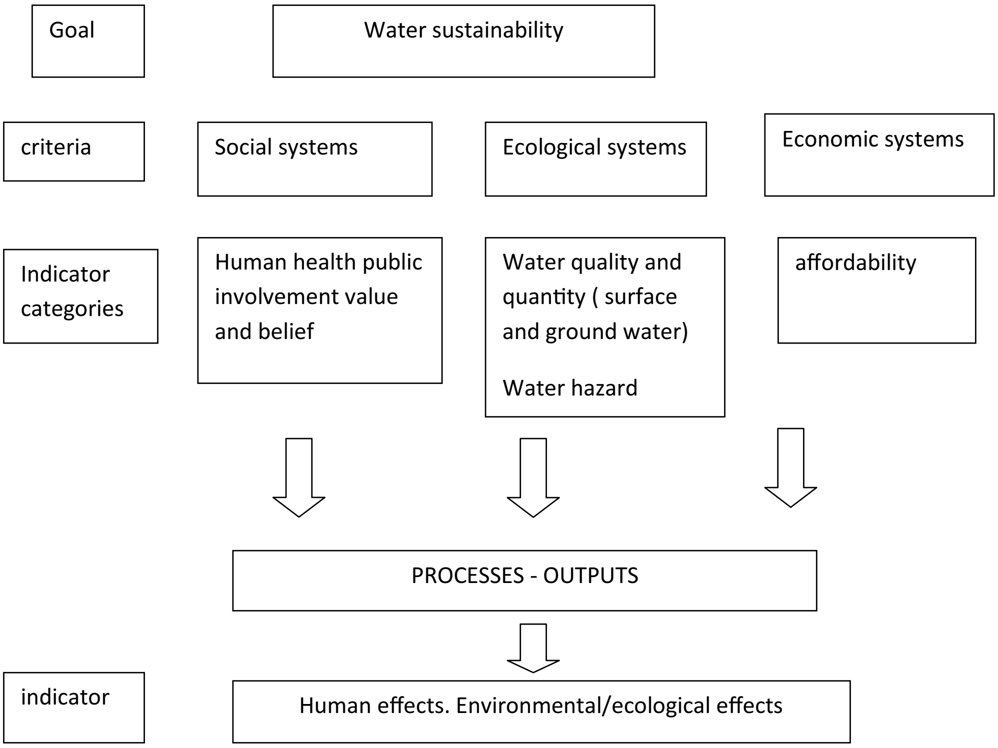

Figure 3: Water sustainability hierarchy model.

both directly and indirectly, ii) Energy is required to make use of water. The current trend in water quality management is minimizing energy use in water treatment.

Fig. 4 shows inseparable of water and energy relationship which is necessary for efficient and sustainable use of water and energy. To manage both water and energy,

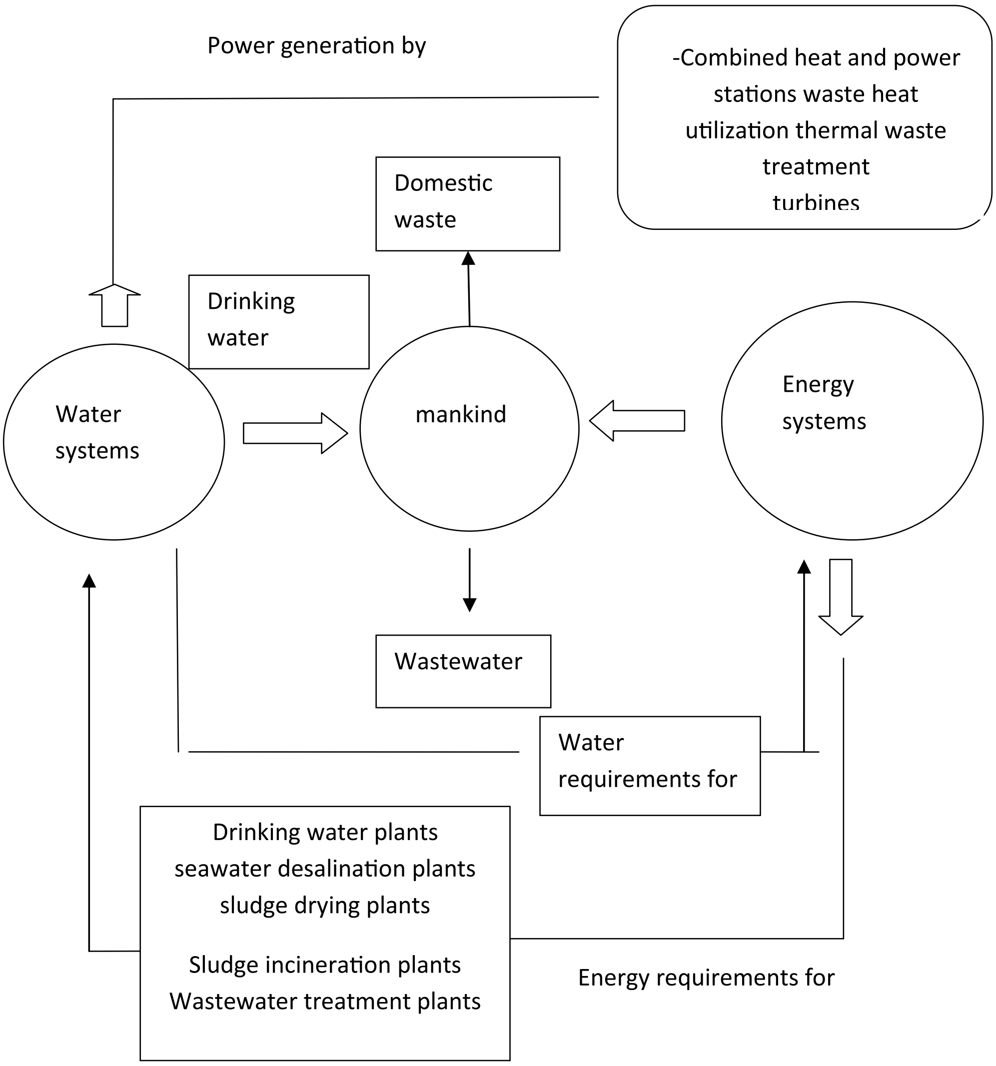

Figure 4: The water-energy nexus.

scientist and engineer consider how to maximize the supply of one and minimizing the other use. Hence, a multidisciplinary team is needed to identify and implement emerging trends in water quality management.

3. Emerging Trends in Water Quality Management

Water quality management can be described in Fig. 5. This flow chart shows water resource management and water quality management. As can be seen in Fig. 5, secondary treatment can be done either aerobically and/or anaerobically. Recently, there are many emerging contaminants such as pharmaceutical organic contaminants, personal care products, endocrine disrupting compounds, surfactants, pesticides and industrial additives went to water body system. They may range from a few $ng \cdot L^{-1}$ to few hundred $\mu g \cdot L^{-1}$. Such a concentration in water ecosystem may cause

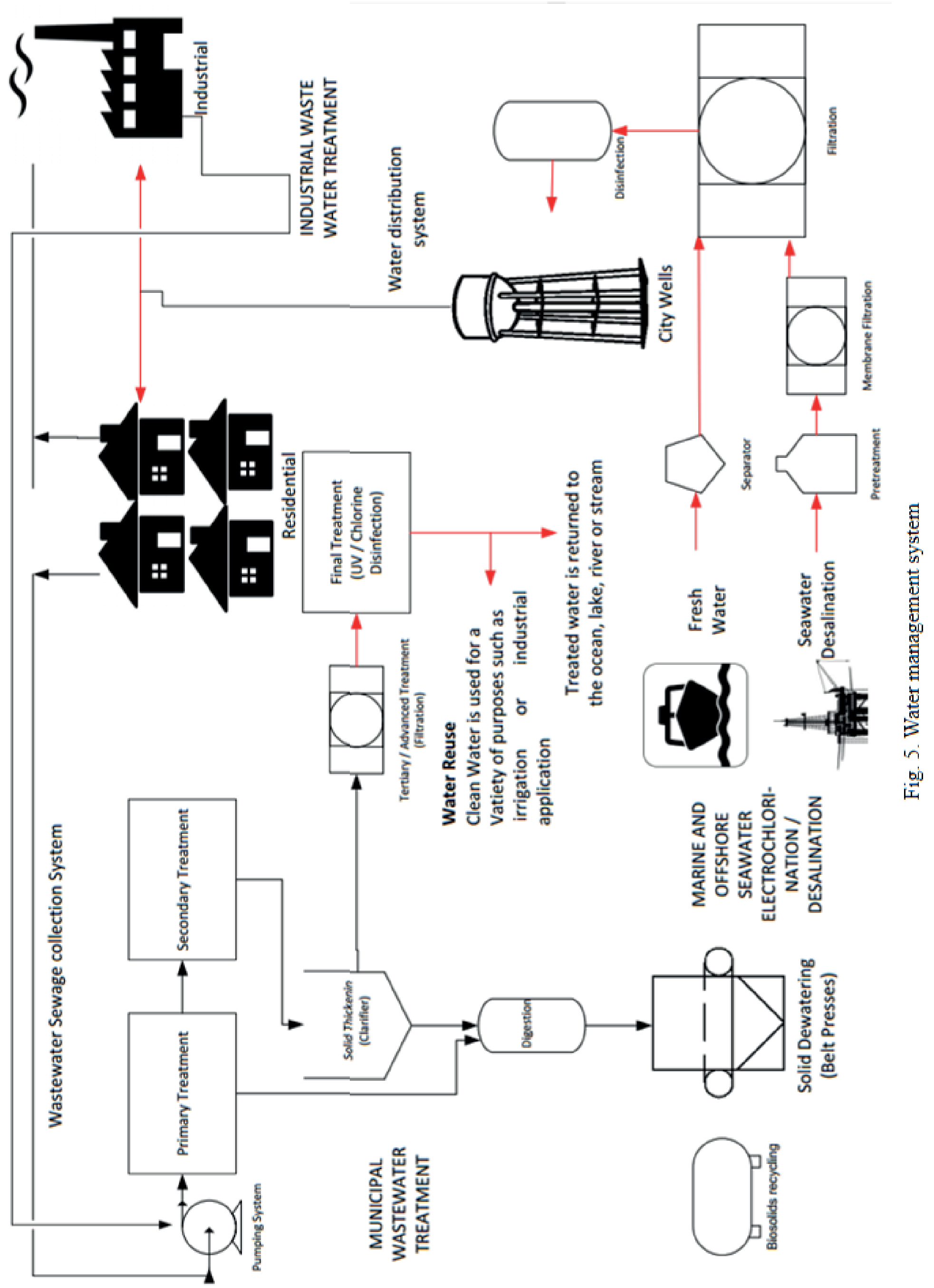

Figure 5: Water management system.

ecological risk i.e. interference with endocrine system of microorganism, microbiological resistance and accumulation in soil, plants and animals. On the other hand, high strength waste water also become an issue to be solved due to economic feasibility. Conventional wastewater treatment process can not completely remove these new emerging contaminants and also high strength wastewater. Therefore, the emerging trends of technology to treat these emerging contaminants using biological approach and non-biological treatment process will be discussed. Hybrid treatment system which are membrane bioreactors, combined anaerobic-aerobic treatment system, integrated anaerobic and aerobic treatment will be discussed as biological approach system to treat such emerging contaminants, whereas advance oxidation processes as non-biological approach are also discussed for the same issue. The hybrid system has been known to be a less energy extensive process.

The new emerging contaminants usually known as Endocrine Disrupting Compounds (EDCs), Personal Care Products (PCPs), pharmaceuticals and other organic compounds which contribute to high-strength waste water with Chemical Oxygen Demand COD concentration above 4 000 mg $\cdot$ L^{-1}. Conventional biological treatment processes such as activated sludge, trickling filter and lagoon fail to treat high strength wastewater which result in failing to produce high quality effluent.

3.1. Hybrid treatment system

3.1.1. Membrane Bioreactor (MBRs)

A MBR is a hybrid of biological treatment and membrane filtration. MBRs have been successfully used for the treatment of industrial wastewaters [1–5], which provides physical separation of suspended solids and biomass, and uncoupling Hydraulic Retention Time and Sludge Retention Time [6]. The introduction of membrane filtration in the biological system eliminates the need for secondary clarifiers. Operation of MBR at a shorter HRT results in significantly reduced footprint. A MBR offers advantages over conventional activated sludge, as following: high-quality effluent, higher volumetric loading rates, shorter reactor Hydraulic Retention Time, longer Sludge Retention Time, less sludge production, and potential for simultaneous nitrification/denitrification in long Sludge Retention Time [7–10].High-strength wastewater has been successfully treated using the MBR technology [11]. Textile industrial wastewater in a pilot-scale MBR has been investigated with a reactor volume of 500 L [11]. The reported removal of pollutants are: 70 %, 97 % and 70 % removal of color, COD and $NH4^{+}$-N respectively at mixed liquor suspended solids (MLSS) concentration of 15 kg $\cdot$ m^{-3} and HRT of 2 d. Spagni et al. [12] investigated the treatment of synthetic textile wastewater containing azo dyes under anaerobic conditions using MBR system. Results from their study showed 99 % color removal in azo dye concentration of up to 3 200 mg $\cdot$ L^{-1}. This high performance eliminates the need for a downstream step. This indicates a strong potential for the application of MBR in the treatment and reclamation of textile wastewater.

Personal Care Products (PCPs) such as salicylic acid and propylparabene were removed by around 100 % in MBR system. Some pharmaceuticals can be well removed but other pharmaceuticals were found to be poorly degraded in MBR [13–17]. For example: antibiotics (azithromycin, erythromycin, and sulfamethaxazole), analgesics (carbamazepine, citalopram, ibuprofen, lorazepan, metronidazole, preimidone and trazodone), anti-inflammatory drug (acetaminophen) and stimulant (caffeine). Endocrine Disrupting Compounds (EDCs) such as testosterone, nonyphenol can be removed around 98 % to 99 %. The overall trend of Emerging Contaminants and high strength waste removal by MBR can be written as textile > Endocrine Disrupting Compounds > Personal Care Products > pharmaceuticals. The efficiencies of diverse microbial populations in the elimination of selected Emerging Contaminants (especially pesticides and pharmaceuticals) and the optimization of design and operating parameters are needed to provide focus for further research in this area [18].

3.1.2. Combined anaerobic-aerobic treatment system

Combined anaerobic-aerobic treatment, especially biofilm aerobic system, can reduce operating cost by a factor of eight when compared with only aerobic treatment due to reduction in energy consumption [19, 20]. In terms of sludge production, for most wastewaters, the net sludge yield from aerobic activated sludge treatment is of the order of 0.5 kg of volatile suspended solid (VSS) per kg COD removed as opposed to less than 0.1 kg VSS per kg COD removed sludge yield from anaerobic treatment [1]. If the two systems are combined, anaerobic and aerobic processes can generate lesser amounts of sludge and the overall cost of waste treatment can be considerably reduced. The emerging technology for combined treatment, especially for aerobic part is biofilm support. This support will reduce the amount of sludge since the microorganism forms film in the support.

Biofilm support

Biofilm application has been a long time known as one prominent technology in wastewater treatment. The emerging trend in biofilm application is the development of biofilm support to be applied in trickling filter, moving beds reactor, packed bed biofilm reactor, sequence biofilm batch reactor and membrane bioreactor. In the past few years the biofilm technology has become more common and widely used in the world to meet the requirement for clean water sources for the growing population. The conventional wastewater treatment plants like activated sludge process present inflexible method, so better system is needed to provide clean water with the least possible cost. Biofilm application will also reduce area compare to that in activated sludge. Some biofilm supports have been developed and patented. Fig. 6 shows some biofilm support which has been developed to meet the requirement of many sectors in treating their wastewater. The supports were designed to enlarge surface area to make microorganism easily attached to the supports.

The benefits of the combined anaerobic–aerobic process are [1, 19]:

- Great potential of resource recovery; the organic pollutants are removed in the anaerobic pre-treatment and converted into a renewable energy source, biogas
- High overall treatment efficiency; aerobic post-treatment "polishes" the anaerobic effluent and results in excellent overall treatment efficiency.
- Less disposal of sludge; when excessive aerobic sludge is digested anaerobically, a minimum total sludge is produced reducing the sludge disposal cost.
- Low energy consumption; anaerobic pre-treatment serves as an influent equalization tank, reducing diurnal variations of the oxygen demand and resulting in a further reduction of the required aeration capacity.
- Minimum volatilization in the aerobic treatment; when volatile organics are present in the wastewater, the volatile compound is degraded in the anaerobic treatment, removing the possibility of volatilization in the aerobic treatment.

3.1.3. Intergrated anaerobic and aerobic treatment

Integrating anaerobic and aerobic system in a single reactor employing granular sludge provides a promising technology. Granule development is from a mixture of suspended anaerobic and aerobic cultures under alternating cyclic anaerobic-aerobic. The developed granules were composed of both anaerobic and aerobic cultures as shown in Fig. 7. The minimum granule size is 0.2 mm and can develop up to 2 mm. This technology was recently developed for treating high strength wastewaters containing organics, nitrogen, phosphorus, toxic substances such as phenol and derivatives, pyridine, textile dye wastewater and xenobiotics. The granules are densely packed which consist of microbial aggregates and their densities are much higher than that of conventional activated sludge.

The granules were known as:

- Regular, smooth and nearly round in shape
- Excellent settle-ability
- Dense and strong microbial structure
- High biomass retention
- Ability to withstand high organic loading
- Tolerance to toxicity

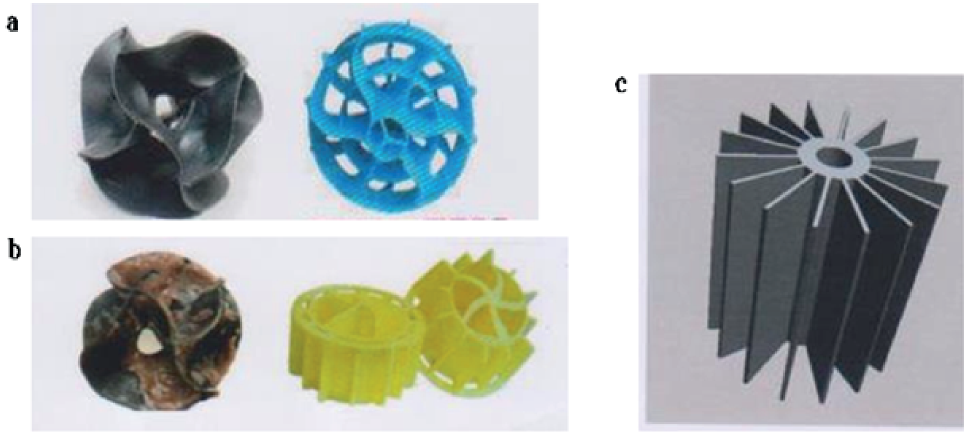

Figure 6: Biofilm support® (bio-fill).

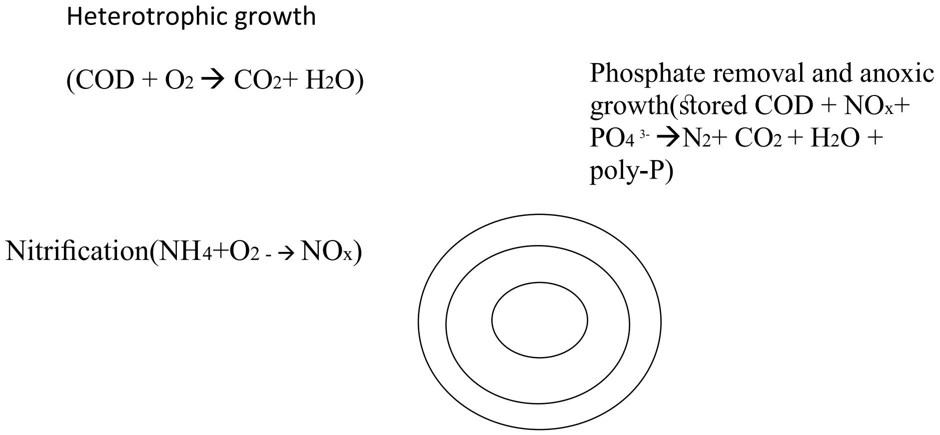

Figure 7: Granules sludge.

3.1.4. Advance Oxidation Process

Another trends in water quality management is advance oxidation processes which are used for treating micro pollutants such as hormone, pharmaceuticals and personal care products or for wastewater which the COD/BOD is higher than 6.0. Many Advance Oxidation Processes have been used for this kind of pollutants and wastewater. There are UV/Ozone-Hydrogen Peroxide Oxidation technologies; Fenton and modified Fenton methods. Ozone is a very reactive agent and has higher standard redox potential. Ozone will react with hydroxyl and hydroperoxide ions to form hydroxyl radicals. The radicals will decompose the organic compounds. Another process called Fenton involves oxidation process using Fenton reagent which H_2O_2 used as oxidizing agent and Fe^{2+} as catalyst which also involves hydroxyl radical ($OH^{\bullet}$). In this process, H_2O_2 will react with Fe^{2+} to form $OH^{\bullet}$[21, 22]. The reaction as followed:

$$H_2O_2 + Fe^{2+} \rightleftharpoons Fe^{3+} + OH^{-} + OH^{\bullet} \tag{1}$$

Category	Emerging Contaminants	Technology	% Removal
EDCs	Nonylphenol	MBR	98.7
	Testosterone		99
	Bisphenol A		94.2
	Androstenedione		99
PCPs	Propyl parabene	MBR	100
	Salicylic acid		97.8
	Benzophenon		
Antibiotic	Ofloxacin		90
	Sulfamethaxazole		95.2
	Erythromycin		79
High strength wastewater	Textile	AOP	88.3
		MBR	97
	Fruit processing	Combined anaerobic-aerobic	97.5
	Palm oil Mill Effluent (POME)	Integrated anaerobic-aerobic	85
	Coffee processing	AOP	95

Table 1: Summary of removal methods for high strength wastewater and emerging contaminants.

$$OH^{\bullet} + H_2O_2 \rightarrow HO_2^{\bullet} + H_2O \tag{2}$$

$$OH^{\bullet} + Fe^{2+} \rightarrow Fe^{3+} + OH^{-} \tag{3}$$

$$Fe^{3+} + H_2O_2 \rightarrow Fe^{2+} + H^{+} + HO_2^{\bullet} \tag{4}$$

$$Fe^{3+} + HO_2^{\bullet} \rightarrow O_2 + Fe^{2+} + H^{+} \tag{5}$$

Those radicals will decompose the organic compounds. Hybrid method which combined electrocoagulation and fenton will give a high performance effluent which can remove both TSS and high COD [23]. Our research showed that a hybrid method of electrocoagulation-fenton can reduce the COD of high strength of wastewater up to 88.3 % COD removal and 88.5 % color removal [24].

A Photo-Fenton process is a development of classical Fenton process, is widely used for the removal of Emerging Contaminants such as antibiotics around 90 % to 100 % removal [18], EDCs around 85 %. The process has been carried out for coffee processing wastewater and the COD can be removed around 95 % [23]. Table 1 shows the summary of removal high strength wastewater and emerging contaminants using hybrid treatment system [18, 19]

4. Conclusion

Water sustainability is a critical issue in the future which needs an integrated approach to manage, as we know water and energy are always unavoidable linked. Hence, some technologies have been developed to consider water-energy link. As many emerging contaminants go to water stream, there are also a need for emerging trend for water management. All method used in treating emerging contaminants and high strength wastewater have considered to reduce the use of land and energy. Integrated and Combine systems and compact size of treatment has been introduced. MBR has been found to be highly effective in the removal of EDCs, PCPs and antibiotic. On the other hand, AOPs have been found to be best process for removal of high strength wastewater especially textile and colored wastewater. Hybrid biological system is also better for high strength wastewater treatment.

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