Towards water integration in Eco-Industrial Park: An overview of water recovery from industries

S F Sa’ad, R Zailan, S R Wan Alwi*, J S Lim and Z A Manan

Process Systems Engineering Centre (PROSPECT), Research Institute for Sustainable Environment (RISE), School of Chemical and Energy Engineering, Faculty of Engineering, Universiti Teknologi Malaysia, 81310 Skudai, Johor, Malaysia

*E-mail: syarifah@utm.my

Abstract. Water integration among different industries in Eco-Industrial Park brings a promising opportunity in reducing freshwater consumption by implementing industrial symbiosis concept. Mixing of wastewater from industries might be cost-effective, however, it is not the best option for water reuse since different reuse option requires different water qualities and treatment. Thus, wastewater segregation based on the wastewater source and quality is required. This paper reviews the potential wastewater source from the industry and wastewater recovery prior to be reused. The review is based on the literature survey from the industries, suppliers and guidelines. From the survey, wastewater sources that can be recovered for reuse option are water generated as by-product, wastewater from the cleaning operation and utility operation. These wastewater sources cannot be mixed because each source has different types of contaminant content. Appropriate water quality can be achieved through primary, secondary and tertiary treatment. Advance technology such as membranes are efficient to remove non-desirable compounds from wastewater. The treated wastewater can provide a viable solution as an alternative water source to ease water-related stress and wastewater segregation can reduce the burden of the treatment.

1. Introduction

Freshwater is used vigorously in industries yet the scarcity of freshwater has become a severe global issue recently with increasing of competition and climate change [1]. According to Connor [2], the water demand from the manufacturing sector will increase to 400% by 2030. The growing of water reuse in the industry could help to solve the issues. Water exchange between industries is one of the synergies besides waste and energy intended to minimize freshwater consumption in the Eco-Industrial Park (EIP) [1]. Such a strategy could assist companies through water efficiency and water recycling initiatives within the EIP to save industrial water demand [3-4]. EIP is designed and implemented on the basis of mutual collaboration between multiple industries in the same industrial site to achieve sustainable industries by applying industrial symbiosis concept [5-6]. Industrial symbiosis represents a cyclic flow of wastes from one industry to the other industry as new resources [1]. The option of water reuse in the industry described by the water produced after undergoing necessary treatment with appropriate quality suits with the process requirement. The objectives of water reuse are primarily to fulfil industrial water demand, reduce pressure on freshwater consumption, reduce the cost of energy use and environmental protection. From the environmental view, water reuse also helps to reduce greenhouse gas emissions and prevent wastewater penetration into water bodies.

European Union (EU) water policy and EU policy on resource efficiency in 2015 have embraced safe and cost-effective water reuse as an alternative source of water in the planning for water scarcity
Water reuse also contributes to the United Nations 2030 Sustainable Development Agenda through its objective of significantly increasing the effectiveness of water use and improve water quality across all sectors by the year 2030. Previous studies have presented an overview of the wastewater management related to EIP development globally. Piadeh et al. [8] have studied the industrial estates in Iran towards the EIP development and stated that reusing of wastewater for industrial consumption through the installation of advanced treatment units in Iran is successful. Through a recent case study by Jia et al. [9], highly efficient water utilization, as well as economic and environmental benefits, were achieved by implementing industrial symbiosis concept for coal chemical industry in Erdos, China. Whereas, in order to develop reuse of industrial water in Port Melbourne, a cost-effectiveness study of five water treatments and industrial reuse options in Port Melbourne’s Fishermans Bend industrial area has been done. The research identified that further pilot testing of the quality of input water requires strong financial and continuous stakeholder involvement [3].

Various industries in the EIP like the power plant, oil refinery, and chemical plant require water reuse for different purposes such as cooling, processing, aggregate washing, concrete manufacturing, soil compaction, and dust control [7]. The typical source of wastewater for the water integration is mixed wastewater either from the urban wastewater or secondary effluent of wastewater treatment plant (WWTP). Mixing of wastewater from industries might be cost-effective, however, it is not the best option for water reuse [10]. This is due to the different reuse option requires different types of water quality as well as the level of treatment. Rubio-Castro et al. [11] have proposed the water integration model with wastewater source segregation into two different stages of treatment. However, the types of potential wastewater source that can be recovered are not being addressed. Furthermore, the wastewater segregation based on the regeneration unit and not based on the specific wastewater quality. In the real case, there are many types of wastewater with different contaminant content. These wastewaters need to be collected separately and if possible, at each point of the source. In this paper, the potential wastewater sources that can be recovered for reuse option are presented which give an overview to the designers and developers to develop water integration between different industries. Each wastewater source needs to be segregated based on the quality, then recovered based on the reuse option requirement. Different qualities of water reuse will be sold to the industries based on the plant’s requirement. Figure 1 shows the illustration of the water integration process between industries that will be presented in the next section of this paper.

![Water integration process between industries](image)

**Figure 1.** Water integration process between industries.

2. Existing of water integration

The section reviews several existing successful water integrations in the established EIP globally. The most interesting and successful EIP is the Kalundborg, Denmark, which has practised water exchange between tenants, i.e., Asnaes Power Station and Statoil refinery [7]. The power station receives 700,000 m³ of cooling water each year from Statoil as boiler feed water and the cooling water becomes steam that is returned to Statoil. Furthermore, the power station also utilizes approximately 200,000 m³ of Statoil’s treated wastewater each year for cleaning. The savings recorded about 3 million m³ of groundwater and 1 million m³ of surface water per year [7, 12]. One of profitable EIP is the Kwinana...
Industrial Area (KIA) in Western Australia, the largest EIP in the world managed to minimize about 6 Gl/year scheme water for the industrial process by replacing it with recycled water. At the Kwinana Water Reclamation Plant (KWRP), about 24 ml/day of secondary treated wastewater from the WWTP at Woodman Point undergoes microfiltration/reverse osmosis to generate high-quality industrial-grade water. Subsequently, about 17 ml/day of recycled water is supplied to Kwinana industrial sites including cogeneration plant [13].

The formation of Chinese EIP had begun since China launched the national EIP demonstration program in 2000 [4]. Tianjin Economic-technological Development Area (TEDA) was instated as one of the National Demonstration EIPs in 2008. The EIP was certified with ISO14001 and adopted its primary principles for decreasing wastewater discharge to the water scarcity problem during the year 2000. According to Yu et al. [14], TEDA was committed to employing the following water integration initiatives:

i. Operated the first wastewater reclamation plant and preceded with two measures: the sewage disposal fee exemption in 2000 and encouragement of the use of alternative water sources in 2002.
ii. In order to encourage companies to enhance their wastewater treatment and use recycled water, the price of recycled water was set 20% cheaper than tap water.
iii. In 2007, TEDA has come out with the regional water cycle system by integrating in-situ regeneration of wastewater, WWTP, recycled water and ecological landscape restoration to provide high-quality water to the EIP tenants.
iv. Almost 25.29% of discharged water was recycled by 2009.

In addition, Shanghai Chemical Industrial Park (SCIP) was endorsed as a national demonstration EIP in 2013. EIP is enthusiastic to reduce pressure on freshwater consumption for its industrial process by downgrading the high water-intensive to less water-intensive sectors (i.e. from oil refinery and raw chemical production to fine chemicals) and practicing water reuse option among EIP tenants. The WWTP accentuated on the quality of wastewater and separated it into four classifications which are organic, inorganic, rainwater and municipal wastewater instead of mixing them together. Furthermore, SCIP also commissioned an artificial wetland experiment to further the treatment of WWTP effluent to be reused before final discharge to Hangzhou bay [15].

3. Potential industries and equipment
The water reuse in industrial sectors can help to minimize the use of potable water and maximize the return on investment. High consumption of water also means a high potential to generate a high quantity of wastewater. As most water will become wastewater except those being consumed by the process, evaporated or lost. Most of the water in the industry is used for cooling purposes and the major water consumption is chemical, steel, and pulp and paper industrial sectors [16]. Water reuse can be used for different types of options according to the requirements of the industries such as cooling, heating, product cleaning, irrigating, washing and others. The potential uses of reused water for industrial sectors are cooling tower make-up water, boiler feed water, stack gas scrubbers, process waters, and construction [17]. Figure 2 shows the global application of water reuse after treatment.
Figure 2. Global application of water reuse after treatment [18].

Landscaping can accept water reuse with a high concentration of nitrogen and phosphorus [10]. Most plants cannot survive the irrigation water with high total dissolved solids (TDS) level of 1000 ppm and the recommended value is 500 ppm [19]. The continual use of high TDS water will cause the minerals and salts to build-up in the soils, which will greatly impair the root growth of plants. Water reuse option for cooling purposes requires lower water quality compared to the other industrial water and it needs the removal of residual organics, suspended solids, ammonia, phosphorus, calcium, magnesium, iron and silica [10]. Meanwhile, boiler, process and cleaning water require the removal of heavy metals and water softening [10]. Table 1 shows the recycled water quality requirement for irrigation and cooling tower. Table 2 shows the recommended water quality standards of boiler feed water for low and medium pressure boiler from American Water Works Association (AWWA), British Standards Specification (BSS) and US Environmental Protection Agency (USEPA) as a benchmark.

| Parameter                        | Irrigation          | Cooling Tower |
|----------------------------------|---------------------|---------------|
| Total suspended solids (TSS)     | < 5-35 mg/l         | 30 mg/l       |
| Biochemical oxygen demand (BOD)  | < 5-45 mg/l         | 30 mg/l       |
| Chemical oxygen demand (COD)     | < 20-200 mg/l       | -             |
| TDS                              | < 450-4000 mg/l     | -             |
| Heavy metals                     | < 0.001 mg Hg/l     | -             |
| Chlorine residual                | < 0.01 mg Cd/l      | -             |
| Nitrogen                         | < 0.02-0.1 mg Ni/l  | -             |
| Phosphorus                       | 0.5-5 mg Cl/l       | 1 mg Cl/l     |
|                                  | 10-15 mg N/l        | -             |
|                                  | 0.1-2 mg P/l        | -             |

| Parameter   | AWWA | BSS | USEPA |
|-------------|------|-----|-------|
| TSS (mg/l)  | 300-600 | 100-1500 |   10  |
| TDS (mg/l)  | 3000-5000 | 3000 | 700 |
| Hardness (mg/l) | 0-10 | 10 | 0.3 |
| Alkalinity (mg/l) | 700 | 700 | 350 |
| COD (mg/l)  | -    | -   | 5    |
Reused/Recycled water can be alternative sources of raw water if the requirements are met. Water quality for boiler feed water depends on the pressure of the boiler, where higher pressure requires higher quality water. Since 2000, several Los Angeles refineries have been using recycled water as the main source of boiler feed water [18].

4. Potential wastewater source

According to Rossiter and Rutkowski [22], there are three types of potential sources of wastewater from industries that can be recovered for reuse option. Firstly, wastewater from the cleaning operation to remove impurities such as desalting in oil refining, brown stock washing in pulp mills, solvent extraction and others. Secondly, wastewater generated as a by-product from the process operation such as decanted water from crude oil or water generated by reaction processes. Water as a by-product of crude oil or natural gas extraction is commonly defined as produced water. This produced water contains high saline concentration, TDS and hydrocarbons, which requires high treatment technology [18]. However, the quality of produced water varies widely depending on the geographical location, source of geological formation and type of hydrocarbon. For example, the coalbed methane production has low TDS water sources and this produced water can be reused with very little treatment. The treatment technologies for produced water include oil-water separator, dissolved gas flotation, adsorption and filtration [18].

The third potential wastewater source is wastewater generated by the utility operation such as blowdown from boilers and cooling tower. The blowdown of the boiler is mainly used to regulate dissolved solids in boiler water and to remove loose scale contaminants and sediments. The blowdown frequency depends on the type of boiler, operating conditions of the system and the feed water contaminant levels [20]. The blowdown water could have high TSS, TDS, hardness, alkalinity, bacteria, oil and grease, chemical additives, heavy metals and others [20]. At equilibrium, the quantities of TDS removed by boiler blowdown exactly equal the quantities of TDS present in boiler feed water [23]. Blowdown water from the cooling tower could have high TDS range from 500 to 1300 ppm, depending on the feed water and the operation of the cooling system [19]. The treatment of cooling tower blowdown can optimize the cooling tower consumption, reduce operational costs and water footprint [20]. Table 3 shows the sources of wastewater and contaminants content from different industries. Table 4 shows the blowdown water characteristics of the cooling tower.

| Industry            | Operation                  | Wastewater content                      |
|---------------------|----------------------------|----------------------------------------|
| Discrete parts      | Cleaning system            | Metals and oily water                  |
|                     | Mop water                  | Heavy metals                           |
| Textiles (assembly) | Compressor operation       | Oily water                              |
| Automobile parts    | Metal plating and cleaning | Heavy metals                           |
| Power plant         | Cooling system             | Heavy metals                           |
| Seafood processing  | Cleaning system            | Heavy metals, gypsum, fly ash          |
| plant               |                            |                                        |
| Oil refinery        | Cooling system             | Solid particles, nitrogen and phosphorus |
|                     | Spent soda streams         | Heavy metals                           |
|                     | Main commingled effluent   | Phenols, oil and gases                 |
|                     |                            | Oily water                             |
| Chemical plant      | Cooling system             | Heavy metals                           |

All of these three potential sources of wastewater cannot be mixed before treatment and reuse because each wastewater source has different types of contaminant content. Thus, wastewater sources need to be channelled separately to the centralised recovery system by using water header collectors, which transport different quality of wastewater. The segregation of wastewater not only improve the water reuse quality but also reduce the burden of treatment.
Table 4. The blowdown water properties of the cooling tower [24].

| Parameter                        | Range       | Average  |
|----------------------------------|-------------|----------|
| pH                               | 6-9         | 7.93     |
| Conductivity (µS/cm)             | 0.4-7940    | 1977.12  |
| Alkalinity (ppm CaCO3)           | 19.2-800    | 208.42   |
| Hardness (ppm CaCO3)             | 14.4-1000   | 426      |
| SO4 (ppm)                        | 200-1400    | 763.5    |
| Silica (ppm)                     | 25-800      | 132.5    |
| Chlorine (ppm)                   | 0.5-2102    | 381.13   |
| Iron (ppm)                       | 0.03-3      | 1.14     |

5. Potential wastewatertreatment

As water shortages have increased and environmental policies have introduced more stringent blowdown wastewater laws, high technologies for water treatment have been continually created to satisfy the requirements of the industry. The regenerator is used to remove contaminants in the contaminated water so that the water is suitable to be reused [22]. There are three levels of treatment for water recovery which are physical and/or chemical treatment, biological treatment and treatment for removal of nutrient and pathogen [7]. The choice for the specific treatment option depends on the quality requirement. In the United States, all wastewater is required to be treated to secondary levels, at a minimum [18]. Table 5 shows the treatment phase and application for water recovery.

Table 5. Treatment phase and application for water recovery [25].

| Classification | Treatment                        | Application                                      |
|----------------|----------------------------------|--------------------------------------------------|
| Preliminary    | Equalization                     | Wastewaters with high variability                |
|                | Neutralization                   | Wastewaters with extreme pH values               |
|                | Temperature adjustment           | Wastewaters with extreme temperatures             |
|                | Screening                        | Wastewaters containing large solids              |
|                | Grit removal                     | Wastewaters containing significant amount of large and heavy solids |
| Primary        | Sedimentation                    | Wastewaters containing suspended solids          |
|                | Dissolved-air floation (DAF)     | Wastewaters containing oils, fats, suspended solids |
| Secondary      | Activated sludge                 | Biologically treatable organic wastes            |
|                | Aerated pond                     | Biologically treatable organic wastes            |
|                | Trickling filter                 | Biologically treatable organic wastes            |
|                | Pressure filtration              | Wastewaters high in suspended solids             |
|                |                                  | 80-90% of BOD and suspended solids removal       |
|                |                                  | 80-90% of BOD removal                            |
|                |                                  | 80-90% of BOD removal                            |
|                |                                  | Lower operating costs than activated sludge     |
|                |                                  | 90-95% solids removal                            |

Sedimentation is the primary step to reduce 50-70% of TSS and 25-40% of BOD [26]. Flocculation/DAF system is used to remove suspended solids and oil [10]. Water treatment technologies are usually focused on the secondary treatment in which the biodegradable organic matter and suspended solids are being biologically removed [27]. Activated sludge (AS) is an aerobic slurry to remove soluble organic matters [26]. Organic matters are converted to biomass in a suspended growth reactor by the microorganism in the wastewater. The aerated pond is used for biological treatment and water from this treatment can be used for once-through cooling [10]. Trickling filter (TF) is an attached-growth process of a circular packed bed of media with a biological film of microorganisms, used to remove organic
matters [26]. The removal rate is depending on the surface area and the contact time of the stream with the surface.

Filtration and disinfection provide additional removal of pathogens and nutrients [18]. Filtration removes pathogen by physical adsorption or entrapment. Biological filtration is a granular media filter to remove biodegradable constituents such as total organic content (TOC). On the other hand, granular activated carbon (GAC) filtration uses physical and biological processes for contaminant removal. Besides, GAC has adsorption property and can accumulate more microbial biomass on activated carbon media [18]. Disinfection processes kills many classes of microorganisms through the chemical or biophysical method [18]. The most common disinfection method is chlorination. The effectiveness of chlorine disinfection relies on the temperature of the water, pH, degree of mixing, contact time, the presence of interference substances, chlorinating species concentration and form, and concentration of the organisms to be destroyed [18]. In general, bacteria are less chlorine resistant than viruses. Meanwhile, UV disinfection is increasing in use due to energy efficient and low-cost UV technologies. However, UV disinfection performance and efficiency are highly impacted by the presence of particle-associated microorganisms and the UV transmittance (UVT) of the wastewater [18]. Thus, wastewater needs to undergo filtration to remove particles prior to UV disinfection.

Membranes are one of the most widely used technology for the treatment of water and have the ability to remove non-desirable compounds from wastewater [28]. Membrane filtration has high removal capacity and recovery of 50-90% for brackish water [29]. The main disadvantages of the membrane are high cost causing by fouling, chemical demand and high energy consumption [27, 28]. The concept of membrane filtration is the implementation of a semi-permeable filter that allows the water to permeate due to pressure differences and removes certain suspended or dissolved contents. The membrane filtration consists of microfiltration (MF), ultrafiltration (UF), nanofiltration (NF) and reverse osmosis (RO). UF is commonly used for the pre-treatment of RO by providing solid-free feed for the subsequent treatment step [27]. UF can remove TSS, sediment, algae, viruses and bacteria [26]. UF reduces water turbidity up to lower than 0.35 NTU, TSS up to lower than 0.6 mg/l, and TOC and COD up to 30% [27]. However, UF is not an effective barrier for dissolved solids, pH, conductivity, and hardness. Table 6 shows the composition of water before and after the treatment of UF.

| Parameter       | Units | Average UF feed | Average UF filtrate |
|-----------------|------|-----------------|---------------------|
| Turbidity       | NTU  | 2.5-6           | 0.18-0.25           |
| TSS             | mg/l | 8               | 0.3-0.4             |
| BOD             | mg/l | 7               |                     |
| COD             | mg/l | 44              | 32-40               |
| TOC             | mg/l | 18              | 13.4-23             |
| Ammonia         | mg/l | 6.31            | 4-6                 |
| TDS             | mg/l | 899             | same                |
| Hardness (CaCO3)| mg/l | 343             | same                |
| Calcium         | mg/l | 85              | same                |
| Magnesium       | mg/l | 32              | same                |
| Chloride        | mg/l | 314             | same                |

On the other hand, NF is used to separate solutes with low molecular weight and effective in reducing hardness, dye and heavy metal [30]. NF has been used to remove monovalent and divalent ions in olive mill effluent, pulp and paper wastewater treatment, and oily wastewater treatment [30]. NF is efficient to remove BOD and conductivity up to 80%, calcium and magnesium up to 85%, COD up to 90%, TOC up to 60%, and TDS up to 70% [31, 32, 33]. However, NF membranes do not remove soluble gases such as CO₂ and permethane has low pH resulting from the alkalinity removal from the water [34]. NF has low operating pressure, low energy consumption and higher permeate flux that can replace RO. Besides, NF has high rejection compared to UF for wastewater treatment. NF performance is affected by the operating conditions, feed properties and membrane characteristics. NF characteristics are between UF
and RO which is very innovative, economical and environmentally friendly due to low energy consumption and better selectivity. Table 7 shows the application of NF in the industry.

**Table 7. Application of NF in the industry [30].**

| Application     | Membrane performance                        | Wastewater reuse                     |
|-----------------|---------------------------------------------|--------------------------------------|
| Rubber industry | COD removal up to 95%                       | Permeate can be reused as boiler feed water |
|                 | Water recovery up to 80-90%                 |                                      |
|                 | Energy cost decrease up to 55%              |                                      |
| Dairy industry  | COD removal up to 99%                       | Permeate can be reused as water in boiler and cooling tower |
|                 | Solids removal up to 93%                    |                                      |
| Coking industry | COD, hardness, conductivity, fluoride and chlorine removal | Industrial reuse |

RO membrane is a dense polymer layer which is used for removal of dissolved compounds and microorganisms in the water with rejection rates higher than 96% [27]. It is very crucial to decrease the particulate matter in the feed water of RO by using UF to prevent the blockage of RO components and fouling. The second RO pass can be used to further treat the RO permeate for the application as cooling water or boilers. Figure 3 shows the comparison of the membrane process based on the types of materials rejected and pore sizes. The recovery rate for the membrane process depends on the quality of the water source, fouling feed rate, operating pressure and the membrane type. Table 8 shows the typical rates of recovery and concentrate flowrates of the feed water for the membrane process.

**Figure 3. Membrane process comparison [34].**

**Table 8. Rates of recovery for the membrane process [34].**

| Process          | Recovery rate (%) | Concentrate flow (%) |
|------------------|-------------------|----------------------|
| Microfiltration  | 85 - 98           | 2 - 15               |
| Ultrafiltration  | 85 - 98           | 2 - 15               |
| Nanofiltration   | 75 - 90           | 10 - 25              |
| Brackish water RO| 60 - 85           | 15 - 40              |
| Seawater RO      | 20 - 50           | 50 - 80              |

Ion exchange (IX) is a reversible process in which the exchange of the charged ion in solution with the charged ion attached to the immobile solid particle [26]. The stream has to pass through the cationic and anionic resins for complete removal. The cooling tower of Gaojing Power Plant in China used the multimedia filter (MMF) as a pre-treatment to remove TSS and turbidity, followed by UF and RO [24].
For the application as boiler make-up water, the permeate of the first stage RO was degasified and pH was increased before the second stage RO. The blowdown water requires pre-treatment including filtration, softening, pH adjustment and/or IX [20]. For example, the cooling tower blowdown reuse in Switzerland required MMF, UF, GAC, and IX. The last step, water is demineralized with use of a high recovery close circuit RO. The treated water is used as make-up water for cooling tower.

6. Conclusion
The demand for water in Malaysia and Southeast Asia continues to grow and the natural resources are being impacted by climate change and pollution. Finding alternative and environmental-friendly sources is currently becoming a necessity to arrest challenges of water security. The benefits of wastewater recovery as a second water source cannot be denied. Wastewater emitted from different sources has high potential to be recovered and reused for many purposes in order to reduce freshwater consumption. Wastewater segregation is required before treatment in order to reduce the burden of water treatment as well as to improve the quality of water reuse. Water treatments require adequate technology to produce water that is suitable to be reused. Different reuse option requires different water quality and treatment. Appropriate water quality can be achieved through primary, secondary and tertiary treatment. Advance technology such as membranes treatment are efficient to remove non-desirable compounds from wastewater.

Acknowledgement
The authors would like to thank Universiti Teknologi Malaysia (UTM) for providing the research fund for this project under Vote Number Q. J130000.2509.19H34 and Q. J130000.3509.05G96.

References
[1] Aviso K B 2014 Design of robust water exchange networks for eco-industrial symbiosis Process Saf. Environ. Prot. 92 160-70
[2] Connor R 2015 The United Nations world water development report 2015: water for a sustainable world (France: UNESCO)
[3] Giurco D, Bossilkov A, Patterson J and Kazaglis A 2011 Developing industrial water reuse synergies in Port Melbourne: cost effectiveness, barriers and opportunities J. Clean. Prod. 19 867-76
[4] Shi H, Chertow M and Song Y 2010 Developing country experience with eco-industrial parks: a case study of the Tianjin Economic-Technological Development Area in China J. Clean. Prod. 18 191-99
[5] Lowe E A 2001 Eco-Industrial Park Handbook for Asian Developing Countries (Oakland: Indigo Development)
[6] Afshari H, Farel R, Gourlia J P and Peng Q 2016 Energy symbioses in Eco-Industrial Parks: models and perspectives Proc. ASME 2016 Int. Design Engineering Technical Conf. and Computers and Information in Engineering Conf. (North Carolina: ASME) pp 1-10
[7] EU Water Directors 2016 Guidelines on Integrating Water Reuse into Water Planning and Management in the context of the Water Framework Directive (Amsterdam)
[8] Piadeh F, Moghadam M R A and Mardan S 2014 Present situation of wastewater treatment in the Iranian industrial estates: Recycle and reuse as a solution for achieving goals of eco-industrial parks Resour. Conserv. Recycl. 92 172-78
[9] Jia S, Zhuang H, Han H and Wang F 2016 Application of industrial ecology in water utilization of coal chemical industry: A case study in Erdos, China J. Clean. Prod. 135 20-29
[10] Martin S A, Weitz K A, Cushman R A, Sharma A and Lindrooth R C 1996 Eco-Industrial Park: A case study and analysis of economic, environmental, technical, and regulatory issues (Oakland: Indigo Development)
[11] Rubio-Castro E, Ponce-Ortega J M, El-Halwagi M M, Serna-Gonzales M and Jimenez-Gutierrez A 2011 Synthesis of water integration networks in eco-industrial parks 21st European Symposium on Computer Aided Process Engineering (Greece: Elsevier) pp 1170-74
[12] Harris S, Van Berkel R and Kurup B 2008 Fostering industrial symbiosis for regional sustainable
development outcomes CRRC 2008 (UK: Queen’s University Belfast) pp 1-21

[13] Rosano M and Schianetz K 2014 Measuring sustainability performance in Industrial parks: A Case Study of the Kwinana Industrial Area Int. J. Sustain. Dev. 17 261-80

[14] Yu C, de Jong M and Dijkema G P J 2014 Process analysis of eco-industrial park development—the case of Tianjin China J. Clean. Prod. 64 464-77

[15] Yune J H, Tian J, Liu W, Chen L and Descamps-Large C 2016 Greening Chinese chemical industrial park by implementing industrial ecology strategies: A case study Resour. Conserv. Recycl. 112 54-64

[16] Magara Y 2017 (cited 7 Nov 2018) Industrial Water Available from: https://www.eolss.net/sample-chapters/c07/E2-19-02-04.pdf

[17] Rimer A E 2018 Planning for the Distribution of Reclaimed Water (United States: American Water Works Association)

[18] United States Environmental Protection Agency 2012 Guidelines for Water Reuse (Washington: U.S. Agency for International Development)

[19] Alliance for Water Efficiency (cited 21 July 2019) Blow-Down Water Introduction Available from: http://www.allianceforwaterefficiency.org/blow_down_water_introduction.aspx

[20] Lenntech 2019 (cited 14 June 2019) Water treatment and purification Available from: https://www.lenntech.com/

[21] Jami M S, Amosa M K, Alkhatab M F R, Jimat D N and Muyibi S A 2013 Boiler-Feed and Process Water Reclamation from Biotreated Palm Oil Mill Effluent (BPOME): A Developmental Review Chem. Biochem. Eng. Q. 27 477-89

[22] Rossiter A P and Rutkowski M A (cited 13 Feb 2019) Process integration for wastewater minimization Available from: https://pdfs.semanticscholar.org/b48c/947a19b595e638b89cda379d87ee9274c0e6.pdf

[23] KLM Technology Group 2011 (cited 24 July 2019) Process Design of Water Systems Available from: https://www.klmtechgroup.com/PDF/ess/PROJECT_STANDARDS_AND_SPECIFICATIONS _design_of_water_systems_Rev01.pdf

[24] Olariu R 2015 Treatment of cooling tower blowdown water-The effect of biodispersant on the ultrafiltration membrane (Netherlands: Delft University of Technology)

[25] Eludoyin A O 2016 Sustainability and Water Reclamation Urban Water Reuse Handbook (Florida: CRC Press Taylor and Francis)

[26] Yang L, Salcedo-Diaz R and Grossmann I E 2014 Water network optimization with wastewater regeneration models Ind. Eng. Chem. Res. 53 17680-695

[27] Niewersch C, Arias A, Gilron J, Sukopova M, Vila S, Gilabert G, Pi J R, Guell I J, Svoijtka J and Martinez X 2016 Report on innovative membrane technologies and schemes for water reuse (Spain: DEMOWARE)

[28] Martinez X, Hochstrat R, Miehe U, Casado F, Frijsn J, Bortoli J, Denieul M P, Orsoni J, Alcalde L and Jeffrey P 2017 Final Publishable Summary Report (Spain: DEMOWARE)

[29] Altmann S J, Jensen P R, Cappello M A, Sanchez A L, Everett R L, Anderson Jr H L and McGrath L K 2012 Membrane treatment of side-stream cooling tower water for reduction of water usage Desalination 285 177-83

[30] Mulyanti R and Susanto H 2018 Wastewater treatment by nanofiltration membranes IOP Conf. Ser.: Earth Environ. Sci. 142 012017

[31] Zulaikha S, Lau W J, Ismail A F and Jaafar J 2014 Treatment of restaurant wastewater using ultrafiltration and nanofiltration membranes J. Water Process Eng. 2 58-62

[32] Bodzek M, Tomaszewskas B and Rajca M 2017 Nanofiltration renovation of mineral water Arch. Environ. Prot. 43 51-59

[33] Naidu L D, Saravanan S, Chidambaram M, Goel M, Das A and Babu J S C 2015 Nanofiltration in Transforming Surface Water into Healthy Water: Comparison with Reverse Osmosis J. Chem. 1-6

[34] Davis M L 2010 Water and Wastewater Engineering (New York: McGraw Hill)