# CHAPTER I
# INTRODUCTION

Water is intensively used in many industrial processes; therefore, the balance among conservation, allocation and regeneration has to be significantly taken into account for issues regarding sustainability of water resources (Takama *et al.*, 1980, Hashim *et al.*, 2009). The upward fresh water consumption along with the wastewater treatment cost, and more stringent environmental regulations have also pushed many industries from a conventional end-of-pipe treatment towards a more sustainable solution (Foo, D.C.Y., 2008, Jeżowski, 2010).

Selectively reuse and/or recycling of treated wastewater is one of the best practice alternatives not only to minimize the amount of using fresh water but also to minimize the amount of water discharge simultaneously. However, in the more realistic industry, the wastewater of the process involves a wide variety of contaminants that depend on such characteristic of the process. Also, there are many rigorous limitations on environmental and economic specification. Consequently, the type and sequence of treatment technologies have to be considered prudently to overcome their restriction toward the most effective water/wastewater minimization as well as water/wastewater management in terms of both release and recycle.

A purpose of a wastewater treatment is to reduce the pollutants in an industrial wastewater so as to meet a limitation of the environmental regulations or any specification of water stream required, allowing discharge of the water effluent or recycle to a water user process. Generally, wastewater treatment processes are composed of three stages (Tchobanoglous *et al.*, 2003): a primary treatment that involves physical operations to remove free oil and suspended solid; a secondary treatment that involves chemical or biological operation for removal of dissolved contaminants as well as organic compounds; and a tertiary treatment that is needed to remove the residual contaminants or refractory compound or even heavy metals. A wastewater treatment plant usually includes a wide variety of technologies commonly implemented in an industrial process, which is considered and organized sequentially on the basis of the pollutants to remove on treatment principle. A comprehensive overview of individual technologies regarding wastewater treatment operation is presented in Tchobanoglous *et al.* (2003).

Accordingly, in order to focus on the best water management design for industrial practice, water system design problem was considered and represented as network design through process systems engineering. Typically, there are two major systematic approaches to design the water/wastewater network synthesis: the conceptual graphical design (Water pinch techniques) and the mathematical programming techniques. However, the water pinch techniques are cumbersome to be applied with a large number of contaminants and have limitation to address the complex problem (Bagajewicz, 2000, Moodley, 2001, Yoo *et al.*, 2007). The nother approach is to use mathematical optimization which is more effective to serve as a useful synthesis tool and a suitable approach for optimizing complex systems with different complex constraints for both grassroots and retrofit applications (Huang *et al.*, 1999, Yoo *et al.*, 2007, Hashim *et al.*, 2009).

In the past, seminal work associated with the problem of water network design in industrial process in both water-using and water treatment processes was studied by Takama *et al.* (1980) and many authors have widely attended to study a water management system through water network design since then. In the aspect of wastewater minimization and treatment system, these design problems evolved successively (Gupta *et al.*, 1994, Wang, Y.-P. *et al.*, 1994, Wang, Y. *et al.*, 1994, Kuo *et al.*, 1997, Alva-Argaez *et al.*, 1998, Galan *et al.*, 1998, Kuo *et al.*, 1998, Poplewski *et al.*, 2007, Faria *et al.*, 2008, Statyukha *et al.*, 2008, Dzhygyrey *et al.*, 2009, Galán *et al.*, 2011). However, recycling and reusing issues have been more interested in an effective water/wastewater management. Furthermore, a number of recent efforts have also been increasing toward a systematic design of integrated water network of the re-using and re-routing the water streams in order to minimize the consumption of fresh water in the system, and the amount of wastewater treated and disposed into the environment (Hamad *et al.*, 2003, Gabriel *et al.*, 2005, Karuppiah *et al.*, 2006, Bandyopadhyay *et al.*, 2008, Feng *et al.*, 2008, Nápoles-Rivera *et al.*, 2010, Ponce-Ortega *et al.*, 2010, Khor *et al.*, 2011, Ponce-Ortega *et al.*, 2011, Nápoles-Rivera *et al.*, 2012, Pennati, 2012, Quaglia *et al.*, 2013). Thus, the research in the area of integrated wastewater management is quite mindful for simultaneous effective water/wastewater minimization.

However, recent development of those works has been rather concentrated on the optimization-based method design because it is appropriate with more complex design problem and still emphasized on both the design tool and the model development with new solution-techniques for the global solution. Although the works on wastewater network design have been continuously advanced, such wastewater network problems are still based on a simple and small problem of water treatment design (with respect to treatment process option, number of streams and wastewater composition) that is difficult to be applied in more challenged problems with its complexity based on real industrial practice. Thus, in order to manage with this limitation, a good computer-aided framework system of processing network synthesis is needed to generate.

Lately, Quaglia et al. (2012) have proposed the integrated solutions framework for a synthesis and design of processing networks in recent years. Such an approach relies on the integration of methods and tools in a computer-aided framework. Through the framework, the complexity associated with the definition, mathematical formulation and solution of the industrial process problems has been managed through a systematic approach. Such an approach can be managed and solved effectively the complexity of the problem through the method and tool for a problem definition, formulation as MINLP optimization and solution. Hence, this is the one of appropriate systematic method associated with mathematical optimization techniques to be applied in water/wastewater network synthesis and design in a good way that recently proposed by Quaglia *et al.* (2013).

Their framework has systemically generated for any wastewater treatment plant. Thus, it can be effectively applied with real industrial problems that have complicated in treatment process model as well as a high number of streams and contaminants. To address such a complex problem, the framework will be adopted to develop a model for synthesis and design of water/wastewater networks with a large dimension of an industrial problem. Hence, it is expected that this beneficial tool based on the framework will be used for the new application on water network design in different scenarios. At the same time, this model will be also flexible to perform in both grassroots (new system) and retrofit design of water/wastewater system in an effective time manner.

In this contribution, we aimed at extending the above mentioned body of research in the area of systematic design of water management system by developing a generic model-based synthesis for optimization of water/wastewater networks through a Mixed Integer Non Linear Programming (MINLP) model. The systematic methods and computer aided tools were designed to manage the complexity of the water/wastewater network superstructure by focusing the reduction of the amount of fresh process water through the recycle of treated wastewater via different scenario designs. The design of an optimal water/wastewater network superstructure for a real industrial case dealing with effluent treatment system of petroleum refinery plant was studied. The economic benefit and process specification together with environmental impact improvement were evaluated by comparing the cases of existing process, retrofit design and grassroots systems and the optimal network of each case was analyzed.