

**THE OPTIMIZATION-BASED SYNTHESIS AND DESIGN OF  
WATER/WASTEWATER NETWORK FOR WATER MANAGEMENT IN  
PETROLEUM REFINERY EFFLUENT TREATMENT PLANT**

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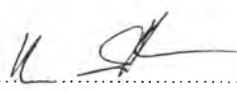
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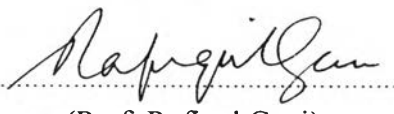
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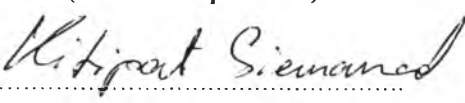
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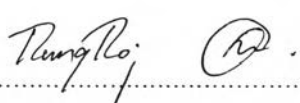
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## ABSTRACT

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Natthapong Suviriyapan: The Optimization-Based Synthesis and Design of Water/Wastewater Network for Water Management in Petroleum Refinery Effluent Treatment Plant.

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The advent of complicated industrial water/wastewater management problems contributes to a determination of effective systematic design for sustainable solution of water balance among conservation, allocation and regeneration. The objective of this work was to extend the research in the area of systematic design of water/wastewater management by developing and modifying a generic model-based synthesis and design of optimized water/wastewater network applying the framework of Quaglia *et al.* (2013). A petroleum refinery effluent treatment plant was implemented in order to formulate different design schemes with two criteria involving with the structure of the treatment system and the requirement of water effluent alternatives that required a sequential solution procedure for different optimization model formulations in two stages. The solution obtained in the case study demonstrated the network design with an improvement in the reduction of a total annualized cost (TAC) and wastewater discharge rate (WWDR) because of a water recycling option. As a consequence, the main key features of developing this approach was to screen and obtain potential optimal networks from a large dimension of problem in an effective time manner, and to provide design flexibility to different scenarios using abovementioned strategic formulations. This developed approach is suitable for all design phases including a new process system, existing process or a retrofit design and is also portable to adapt to be beneficial as preliminary designed pattern for an application in process simulation of further detailed treatment process modelling and design.

## บทคัดย่อ

ณัฐพงศ์ ชื่อวิทยัพันธ์ : การสังเคราะห์และออกแบบเครือข่ายน้ำและน้ำเสียสำหรับการจัดการน้ำในโรงบำบัดน้ำเสียจากโรงกลั่นน้ำมันปิโตรเลียมโดยอาศัยหลักการทางออปติไมเซชัน (The Optimization-Based Synthesis and Design of Water/Wastewater Network for Water Management in Petroleum Refinery Effluent Treatment Plant) อ. ที่ปรึกษา : ดร. อุทัยพร สุริยประภาติลก ศ.ดร. ราฟีก กานี และ ศศ. ดร. กิติพัฒน์ สีมานนท์ 202 หน้า

การมีบทบาทของปัญหากระบวนการจัดการน้ำและน้ำเสียที่มีความซับซ้อนนั้นก่อให้เกิดความมุ่งมั่นในการออกแบบระบบที่มีประสิทธิภาพสำหรับการแก้ปัญหาความสมดุลของน้ำทั้งในเรื่องการอนุรักษ์ การจัดสรร และการนำปรับปรุงฟื้นฟูอย่างยั่งยืน งานวิจัยนี้จึงมีวัตถุประสงค์เพื่อขยายขอบเขตงานวิจัยที่เกี่ยวข้องกับการออกแบบระบบการจัดการน้ำและน้ำเสียโดยการพัฒนาและปรับปรุงแบบจำลอง (โมเดล) ทั่วไปของการสังเคราะห์และออกแบบเครือข่ายการจัดการน้ำและน้ำเสียในสภาวะที่เหมาะสมที่สุด โดยนำไปประยุกต์ผ่านกรอบของกระบวนการในงานวิจัยของ Quaglia และคณะ ปี 2013 ในงานวิจัยนี้ปัญหาทางอุตสาหกรรมของการบำบัดน้ำเสียในโรงกลั่นน้ำมันปิโตรเลียมได้ถูกดำเนินการเพื่อกำหนดแบบแผนการออกแบบในลักษณะที่แตกต่างกันโดยอาศัยสองหลักเกณฑ์ที่เกี่ยวกับ โครงสร้างของระบบการบำบัดและความต้องการของทางเลือกสำหรับน้ำที่ปล่อยออกซึ่งจำเป็นต้องใช้กระบวนการแก้ปัญหาแบบต่อเนื่องสำหรับรูปแบบการจำลองที่เหมาะสมที่สุดที่ถูกกำหนดให้แตกต่างกันภายในสองขั้นตอน ผลเฉลยที่หาได้จากกรณีศึกษาแสดงให้เห็นถึงการออกแบบเครือข่ายที่ถูกปรับปรุงด้วยการลดค่าใช้จ่ายรวมรายปีรวมทั้งลดอัตราการปลดปล่อยน้ำเสีย เนื่องด้วยทางเลือกสำหรับการนำน้ำกลับมาใช้ใหม่ ดังนั้นลักษณะที่สำคัญของหลักของการพัฒนานี้ คือการคัดสรรรูปแบบเครือข่ายที่ดีที่สุดที่มีศักยภาพสำหรับปัญหาขนาดใหญ่ด้วยเวลาอันเหมาะสม และยังสามารถดัดแปลงเพื่อสถานการณ์ที่แตกต่างกันโดยประยุกต์ผ่านรูปแบบการกำหนดเชิงกลยุทธ์ข้างต้น วิธีการพัฒนานี้ยังเหมาะสมสำหรับการออกแบบระบบทุกรูปแบบของกระบวนการใหม่ กระบวนการปัจจุบันและ กระบวนการปรับปรุง และยังเป็นประโยชน์ในการเป็นแบบแผนการออกแบบเบื้องต้นของการประยุกต์ใช้ในการจำลองกระบวนการเพื่อการออกแบบรายละเอียดการสร้างแบบจำลองของกระบวนการบำบัดน้ำเสียต่อไป

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**ABBREVIATIONS**

AirS	= Air stripper
AOC	= Accidentally oil contaminated
API	= American petroleum institute separator
AS	= Activated carbon assisted activated sludge
AsOx	= Arsenic oxidation and precipitation
BFW	= Boiler feed water makeup
BOD	= Biological oxygen demand
BP	= Bypass
CAPEX	= Capital expenditure
CDU	= Crude distillation unit
COD	= Chemical oxygen demand
CPI/PPI	= Corrugated and parallel plate separator
CRS	= Condensate residual splitter
CW	= Cooling water makeup
DAF	= Dissolved air floatation
DNF	= Dissolved nitrogen floatation
DS	= Desalter makeup
ED	= Electrodialysis
EESs	= Environmental effect scores
EIP	= Eco-industrial parks
EL	= Electricity
ETP	= Effluent treatment plant
FFU	= Flocculation and flotation unit
FSS	= Fixed suspended solid
GAC	= Adsorption on granular activated carbon
GAMS	= General algebraic modelling software
IAF	= Induced air floatation
IE	= Ion exchange
LCA	= Life cycle assessment



LPS	= Low pressure steam
MBR	= Membrane biological reactor
MEN	= Mass exchange network
MF/UF	= Microfiltration/ultrafiltration
MILP	= Mixed integer linear programming
MINLP	= Mixed integer non linear programming
MO	= Microorganism
MODWN	= Model for optimal design of water networks
Mogas	= Motor gasoline
MPS	= Medium pressure steam
NF/RO	= Nanofiltration/reverse osmosis
NG	= Natural gas
NLP	= Non linear programming
NS	= NH <sub>3</sub> stripper
O&G	= Oil and grease
OPEX	= Operational expenditure
PACT	= Activated carbon assisted activated sludge
PAC	= Powdered activated carbon
PAHs	= Polyaromatic hydrocarbons
PI	= Process interval
RO	= Reverse osmosis
SWS	= H <sub>2</sub> S stripper
TF	= Trickling filter
TOC	= Total organic carbon
TSS	= Total suspended solids
TWN	= Total water network
UOM	= Unit of measurement
WAO	= Wet air oxidation
WAP	= Water allocation problem
WCA	= Water cascade analysis
WEF	= Water effluent fraction

WNS	= Water network system
WUN	= Water using network
WUTN	= Water usage and treatment network
WWD	= Wastewater discharge
WWDR	= Wastewater discharge rate
WWTN	= Wastewater treatment network
WWTP	= Wastewater treatment plant

## LIST OF SYMBOLS

### Indexes

$i$	= Component
$k$	= Process interval (origin)
$kk$	= Process interval (destination)
$react$	= Key reactant (subset of component)
$rr$	= Reaction

### Parameters

$\alpha_{i,kk}$	= Fraction of the utility $i$ mixed with the stream out of the total utility flow consumed for the interval $kk$
$\gamma_{i,kk,rr}$	= Mass stoichiometry of component $i$
$\theta_{react,kk,rr}$	= Fraction of converted key reagent
$SW_{i,kk}$	= Fraction of component $i$ as disposed waste
$SP_{k,kk}, S_{k,kk}$	= Split factor for separation ( $SP_{k,kk}, S_{k,kk} = 1$ if the process intervals $kk$ and $k$ are connected by the primary or secondary outlet, respectively, $SP_{k,kk}, S_{k,kk} = 0$ otherwise)
$C_{i,sink}^{max}$	= Maximum composition of pollutant
$F_{Sink}^{max}$	= Maximum flow rate
$M$	= A big enough number for activation constraints
$a$	= A coefficient which is chosen depending on the magnitude of the flow rates
$a_{kk}$	= Value of 1 or 0 and determined by the network structure for logical constraints.
$i$	= Interest rate
$n$	= Plant lifetime

$Ac_{kk}, Bc_{kk}$	= Coefficients determined by the cost function relating between flow Rate and capital cost
$Ac'_{kk}, Bc'_{kk}$	= Linear regression of the function in the neighborhood of the flow rate (parameter of y-axis intersection and slope)
$UtilC_{kk}$	= Cost of utilities
$WasteC_{kk}$	= Cost of waste for each process interval $kk$
$C_i$	= Specific cost of utility $i$
$CW_w$	= Specific cost of waste of type $w$
$C_{SinkR}$	= Cost that will be paid if the water user associated to the sink received raw or treated freshwater

### Variables

$F_{i,kk}^M$	= Flow after mixing
$F_{i,kk}^{IN}$	= Inlet flow of component $i$
$R_{i,kk}$	= Utility flow
$F_{i,kk}^R$	= Flow of component $i$ after reaction
$F_{i,kk}^{OUT}$	= Flow after the waste separator
$F_{i,kk}^W$	= Wasted flow of component $i$
$F_{i,kk}^{OUT1}$	= Primary stream
$F_{i,kk}^{OUT2}$	= Secondary stream
$SM1_{k,kk}$	= Fraction of the stream $F_{i,kk,k}^1$
$SM2_{k,kk}$	= Fraction of the stream $F_{i,kk,k}^2$
$F_{i,kk,k}^1$	= Primary stream of element $i$ originated from the separation
$F_{i,kk,k}^2$	= Secondary stream of element $i$ originated from the separation
$F_{i,kk}^{in}$	= Outlet flow rate of a source

- $f_{i,kk}^{in}$  = Inlet flow rate of a sink
- $y_{kk}$  = Selection of process intervals  $k$  (binary)
- $Inv_{kk}$  = Capital cost for process interval  $kk$