Towards Sustainable Water Management in Industrial Cities

Sabla Alnouri, Patrick Linke, Mahmoud El-Halwagi

Energy & Water Security Workshop
Hamad Bin Khalifa University, Doha, Qatar
16th February 2015
Two-thirds of the world’s population in 2025 predicted to be under water stressed conditions.

Maplecroft water index identifies Bahrain, Qatar, Kuwait and Saudi Arabia as world’s most water stressed countries.

FRESHWATER RESERVES AND WATER USE BY SECTOR

- **CHINA**: 550 MM m$^3$/y (68% domestic, 26% agricultural, 7% industrial)
- **USA**: 477 MM m$^3$/y (46% domestic, 41% agricultural, 13% industrial)
- **INDIA**: 646 MM m$^3$/y (86% domestic, 8% agricultural, 5% industrial)
- **CANADA**: 45 MM m$^3$/y (20% domestic, 12% agricultural, 69% industrial)
- **RUSSIA**: 79 MM m$^3$/y (63% domestic, 19% agricultural, 18% industrial)

Sources: Natural Land and Water Resources Audit; Ministry of Water Resources China; FAQ aquastat; US Geological Survey
GLOBAL, LOW INCOME & HIGH INCOME COUNTRY WATER USE BY SECTOR

GLOBAL
- Domestic: 70%
- Agricultural: 22%
- Industrial: 8%

LOW INCOME
- Domestic: 82%
- Agricultural: 8%
- Industrial: 10%

HIGH INCOME
- Domestic: 30%
- Agricultural: 11%
- Industrial: 59%

Source: cseindia.org/dte-supplement/industry20040215/agriculture.htm
INDUSTRIAL WATER USE

- Cooling Towers
- Process Operation
- Cleaning and Maintenance
- Boilers
- Office Potable Water
- Fire Fighting
- Irrigation

WATER CONSUMPTION IN INDUSTRY
Industrial Water Use

Fresh Water

Seawater

Desalinated Water

Surface Water

Water Consumption in Industry

Wastewater
Over the past 4 decades various water integration methodologies were developed. Methodologies extended to accommodate water integration across multiple plants.
MACROSCOPIC FRAMEWORK

OPERATION 1
PROCESSING FACILITY
OPERATION 1
OPERATION 3

FRESHWATER

OPERATION 1
PROCESSING FACILITY
OPERATION 2
OPERATION 3

OPERATION 1
PROCESSING FACILITY
OPERATION 3

WASTEWATER
Over the past 5 years:

- Chew et al. (2008)
- Avizo et al. (2010)
- Kim et al. (2010)
- Chew et al. (2010)
- Lim et al. (2010)
- Rubio Castro et al. (2010)
- Boix et al. (2012)

Current Limitations Observed:

- Inability to capture spatial dimensions within a given plot
- Corridors and barriers amongst plants are therefore not accounted for
- Oversimplification of piping and connectivity
- Pressure drop calculations often neglected
MAIN ASPECTS ADDRESSED IN THIS RESEARCH

1. CAPTURING A SPATIAL REPRESENTATION FOR INDUSTRIAL CITIES

2. ADDRESSING INTERCONNECTIVITY IN WATER NETWORK DESIGN (PIPELINE MERGING)

3. INTRODUCING CENTRALIZED & DECENTRALIZED TREATMENT OPTIONS
INDUSTRIAL CITY SPATIAL REPRESENTATION
Spatial Framework

Direct Recycling + Water Treatment

Dijkstra's Algorithm: Used to Extract Shortest Source-to-Sink Distance

START

L(a) = 0
L(others) = infinite

Choose Vertex with least Distance

Is z still in graph?

END

Remove it from graph

Calculate distances between neighbors still in graph

Update all distances choosing lowest
Given source/sink water flowrate data in each plant
FRESH & WASTE FOOTPRINTS

PLANT 1
F= 200 t/h
W= 0 t/h

PLANT 2
F= 0 t/h
W= 200 t/h

PLANT 3
F= 80 t/h
W= 140 t/h

PLANT 4
F= 195 t/h
W= 100 t/h

PLANT 5
F= 220 t/h
W= 0 t/h

PLANT 6
F= 0 t/h
W= 275 t/h

TOTAL FRESH F=695 t/h
TOTAL WASTE W= 715 t/h
PLANT 1
F = 200-21.8 = 178.2 t/h
W = 0 t/h

PLANT 2
F = 0 t/h
W = 200-200 = 0 t/h

PLANT 3
F = 80-31.4 = 48.6 t/h
W = 140-140 = 0 t/h

PLANT 4
F = 195-195 = 0 t/h
W = 100-48.2 = 51.8 t/h

PLANT 5
F = 220-220 = 0 t/h
W = 0 t/h

PLANT 6
F = 0 t/h
W = 275-80 = 195 t/h

TOTAL FRESH F = 695.468.2-220.8 t/h
TOTAL WASTE W = 715.468.2=246.8 t/h
More Details

Clean Technologies and Environmental Policy
December 2014, Volume 16, Issue 8, pp 1637-1659

Date: 19 Mar 2014

Water integration in industrial zones: a spatial representation with direct recycle applications

Sabra Y. Alnouri, Patrick Linke, Mahmoud El-Halwagi
MULTIPLE PIPELINES

SINKS

SOURCES

P1

P2

P3

P4

P5

P6

WASTE MAINS

FRESH MAINS
ADDRESSING PIPELINE INTERCONNECTIVITY
ILLUSTRATIVE CASE EXAMPLE
MULTIPLE PIPELINES

FORWARD BRANCHING ACHIEVED 4.2% SAVINGS

$12,763,003 ----------------------------- $12,011,167
(BEFORE MERGING)                      (AFTER MERGING)
MULTIPLE PIPELINES

BACKWARD BRANCHING ACHIEVED 7.7% SAVINGS

SINKS

SOURCES

FRESH MAINS

WASTE MAINS

$11,211,408 (BEFORE MERGING)

$9,954,339 (AFTER MERGING)
MERGED PIPELINES

SOURCES

SINKS

--- MAINS ---

P1

P2

P3

P4

P5

P6

--- MAINS ---
Optimal interplant water networks for industrial zones: Addressing interconnectivity options through pipeline merging

Sabla Y. Alnouri¹,², Patrick Linke¹,* and Mahmoud El-Halwagi³

Article first published online: 11 JUN 2014
DOI: 10.1002/aic.14516

© 2014 American Institute of Chemical Engineers
INTRODUCING CENTRALIZED & DECENTRALIZED TREATMENT OPTIONS
WASTEWATER TREATMENT

PRE-TREATMENT

- Filtration
- MF/UF
- Clarification
- Ion Exchange
- Softening
- Oil & Grease Removal

VOLATILES REMOVAL

- Stripping
- De-carbonation
- Oxygen Removal

THERMAL & MEMBRANE

- Nanofiltration
- Reverse Osmosis
- Ultrafiltration
- Membrane Distillation
- Multiple Effect Distillation

POST-TREATMENT

- Remineralization
- Chlorination
- Oxidation
- Electrodeionization

WATER TREATMENT IN INDUSTRY
ILLUSTRATIVE CASE EXAMPLE
Given source/sink water flow rate data in each plant.
Given source/sink water contamination data in each plant.
SOURCE & SINK
CONTAMINATION DATA

Given source/sink water contamination data in each plant
CONNECTIVITY SEARCH GRAPH

TYPE 1 CONNECTIVITY CONSTRAINTS
CONNECTIVITY SEARCH GRAPH

SINKS
--- MAINS ---

SOURCES

CTR 1
CTR 2
CTR 3

P1
P2
P3
P4
P5
P6

TYPE 2 CONNECTIVITY CONSTRAINTS
A synthesis approach for industrial city water reuse networks considering central and distributed treatment systems

Sabla Y. Alnouri, Patrick Linke, Mahmoud El-Halwagi

a Department of Chemical Engineering, Texas A&M University at Qatar, P.O Box 23874, Education City, Doha, Qatar
b The Artie McFerrin Department of Chemical Engineering, Texas A&M University, College Station, TX, USA
MULTIPERIOD PLANNING

Multiperiod Planning of Optimal Industrial City Direct Water Reuse Networks

Sumit Kr. Bishnu,‡ Patrick Linke,‡† Sabla Y. Alnouri,† and Mahmoud El-Halwagi‡

†Department of Chemical Engineering, Texas A&M University at Qatar, P.O. Box 23874, Education City, Doha, Qatar
‡The Artie McFerrin Department of Chemical Engineering, Texas A&M University, College Station, Texas 77843-3122, United States
This research was made possible by NPRP grant no. 4-1191-2-468 from the Qatar National Research Fund (a member of Qatar Foundation). The statements made herein are solely the responsibility of the authors.
THANK YOU FOR YOUR ATTENTION