Generating Efficient Wastewater Treatment Networks

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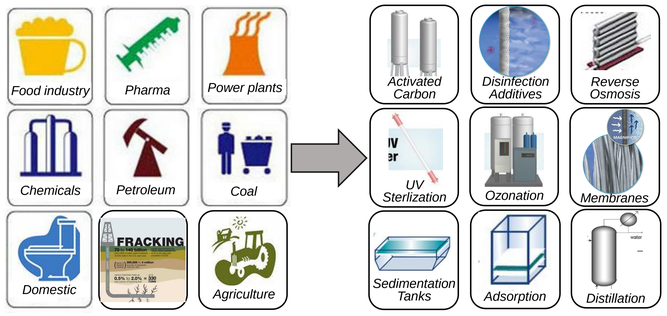
Background & Motivation

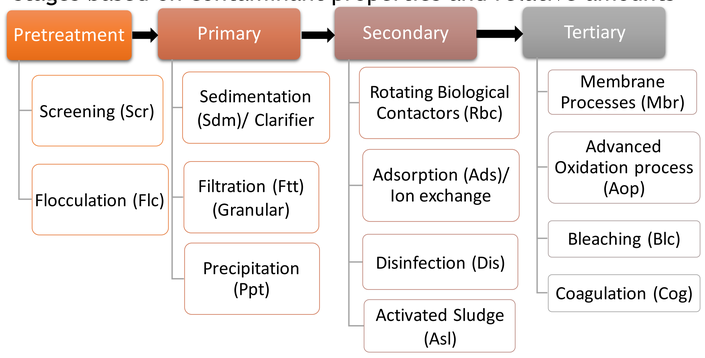
- Irresponsible use of water resources and wastes released from domestic, agricultural and industrial sectors in natural water bodies has exacerbated the challenges relating to availability, quality, and purity of water resources
- Thus, wastewater treatment, reuse and safe disposal are crucial for sustainable existence



Wastewater Treatment Selection: a Systems Engineering Problem

Treatment Stages & Technologies

Wastewater treatment is most effective when conducted in stages based on contaminant properties and relative amounts



Framework for Design & Evaluation

- Provide input wastewater composition and define output purity specifications
- Construct the wastewater treatment network design as an optimization model
  - ✓ Mass and energy balances
  - ✓ Design equations, costing, utility and labor requirements
  - ✓ Integer variables to select technologies by holding a (0,1) value
- Methods: 1. GAMS (General Algebraic Modeling Software); MINLP solver (BARON)
  2. P-Graph Studio (Graph Theory based Process Synthesis); MILP solver

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Page, 1996. Use of Reclaimed Water and Sludge in Food Crop Production.

Case Study: Municipal Wastewater Treatment

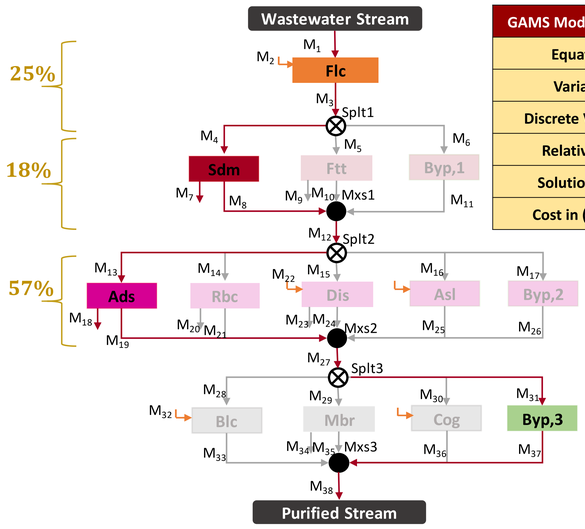
Table 1: Municipal wastewater contaminant concentrations and purity levels

Contaminant	Inlet Amount	Outlet Amount	Units
Acids/Chlorides	5000	300	mg/L
COD (Inorganic)	2000	70	mg/L
BOD (Organic)	1100	25	mg/L
Settable solids	200000	500	mg/L
Metals (Pb, Cu, Ni, Zn)	1340	5	µg/L

Source: Page et.al., 1996 "Use of Reclaimed Water and Sludge in Food Crop Production", The National Academy Press for publications in Sciences, Engineering and Medicine.

Approach#1: GAMS – MINLP formulation

- A superstructure optimization model is built to contain all technologies and determine the suitable technologies in each stage depending on the inlet and outlet specifications
- GAMS Model selected flocculation, sedimentation, adsorption in the first 3 stages and bypassed the tertiary stage



GAMS Model Statistics	Values
Equations	267
Variables	199
Discrete Variables	12
Relative Gap	0.00000005
Solution Time	0.390 seconds
Cost in (USD/h)	6252.27

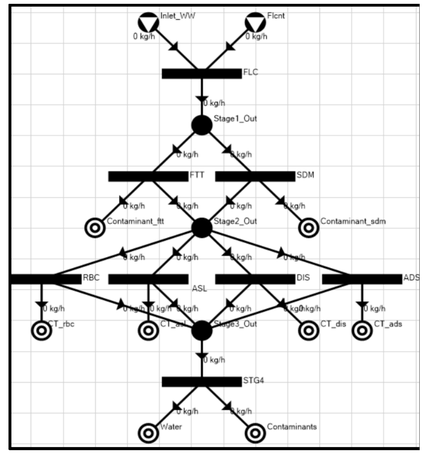
Approach#2: P-graph methodology

- P-graph (process graph) studio uses vertices and nodes to represent materials & operating units connected by arcs represent streams
- Includes two types of nodes
  - ✓ M-type: Materials
    raw materials ▼ ; products ◎ & intermediates ●
  - ✓ O-type: Operating units ▬
- Based on axioms for structurally feasible process networks
- Algorithms available:
  - ✓ MSG (Maximal Structure Generator): generates the maximal structure
  - ✓ SSG (Solution-Structure Generator): generates all the structurally feasible process networks
  - ✓ ABB (Accelerated Branch and Bound): generates the optimal or n-best feasible networks

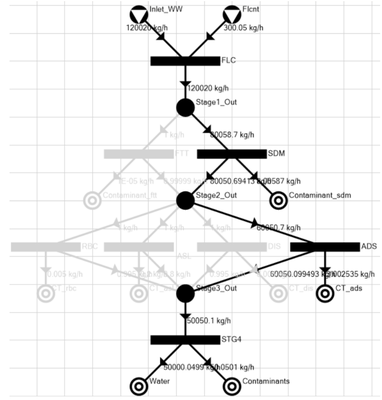
Friedler, F., Tarján, K., Huang, Y.W., Fan, L.T., 1992. Graph-theoretic approach to process synthesis: axioms and theorems. Chem. Eng. Sci. 47, 1973-1988.
Heckl, I., Friedler, F., Fan, L.T., 2010. Solution of separation-network synthesis problems by the P-graph methodology. Comput. Chem. Eng., Selected Paper of Symposium ESCAPE 19, June 14-17, 2009, Krakow, Poland 34, 700-706.

Solutions from P-Graph formulation

Original Problem

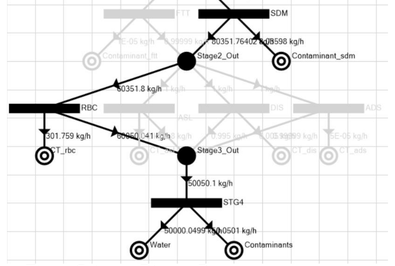


Feasible Structure#3



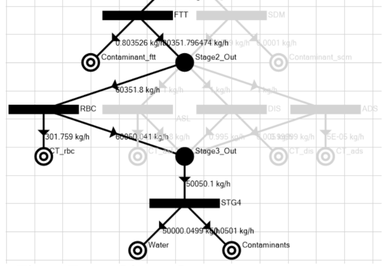
- Flc - Sdm - Ads - Byp (same as GAMS)
- Cost: 6219.14 USD/h

Feasible Structure#1



- Flc - Sdm - Rbc - Byp
- Cost: 3056.10 USD/h

Feasible Structure#2



- Flc - Ftt - Rbc - Byp
- Cost: 4312.12 USD/h

Total six feasible structures are predicted and ranked in P-graph studio

Summary

- An integrated approach involving design and optimization for generation of cost-effective wastewater treatment networks is presented
- In addition to GAMS, P-graph approach has been used which provides a ranked list of networks with detailed costs and also provides insights into non-intuitive solutions
- Future aim is to extend this approach to study more complex wastewater treatment structures and includes sustainability evaluations for the ranked list of optimal networks

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Sustainable Design and Systems Medicine Lab Website: https://yenkiekm.com/

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