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Topological impact of regeneration unit constraints upon water and wastewater network

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Abstract

Optimization of water use/reuse gained an increasing attention during the last years based on four major driving forces: higher water demands, supply water cost increase, such as the wastewater treatment cost and more stringent regulatory limits for the disposal of the used water. This means a drastic reduction of the contaminants level of wastewater discharge, which itself has to be reduced continuously. A significant decrease of water disposal can be achieved rising internal water reuse/recycle through regeneration; the concept of "zero discharge" being the limit, although economic considerations are a major impediment in its full application. The topological impact of regeneration unit upon water and wastewater network is studied for three cases: critical component regeneration, partial regeneration and total regeneration (zero discharge concept). Every case is compared against the optimal water network topology obtained using as objective function the total supply water flow rate.

Keywords: water network topology, regeneration, zero discharge, genetic algorithm, critical component regeneration

1. Introduction

There are three possible ways to reduce the supply water (equivalently, the wastewater discharge to treatment) for a water network: simple reuse, reuse after regeneration and regeneration recycle. The first strategy means using con-

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taminated water from one unit operation to other unit operations provided that the later comply with the contaminant restrictions. The second strategy means treating the contaminated water which attended a threshold concentration to make it suitable for use in other unit operations. The third strategy means returning the regenerated water in the same unit operation, although this might be the worst economic solution. The studies for optimal design or retrofit of water systems with or without taking into account the regeneration reuse have been made using graphical techniques, mathematical programming tools or evolutionary/direct search methods as solving procedures. Although recognized as handy and intuitive, graphical techniques have some severe limitations: multiple contaminants are difficult to handle, and so are the piping and sewer costs or multiple treatment processes and retrofit. Ultimately, graphical procedures remained confined to single contaminant cases, for which useful results have been derived for partial or total regeneration [1, 2]. The two later methodologies were used mainly in conjunction with the superstructure concept, the objective function being the distinct characteristic serving to prune an initial assembly of complex configurations. In last years, an increased attention is given to another approach: the optimization of the mathematical model of the water and wastewater network, with or without regeneration, with or without recycling, using a convenient objective function, from the fresh to the regenerated water flow rate [3, 4, 5], from the investments and operating costs to the total cost of a wastewater reuse system with either wastewater regeneration reuse or wastewater treatment reuse [6]. The concept of total regeneration or zero discharge emerged [5, 6] but this is only a false solution to the problem of environmentally friendly systems.

This paper will present the influence of regeneration type upon the optimal water network topology. Regeneration can be classified into several types: critical component regeneration, partial regeneration (with sub-types: limited or unlimited treatment) and total regeneration (zero discharge opportunity). Every network topology and performance obtained using one of the aforementioned regeneration type is compared against the optimal water network topology resulted from minimizing the overall supply water flow rate.

2. Design strategy: concept and implications

Critical component regeneration. This concept applies when a particular component has a major influence on either the supply water consumption or some internal flows, due to the a number of mass transfer bottleneckings, or it attends during the early stages a threshold concentration, which prevents internal water of being reused. To comply with this challenge, a targeted regeneration unit could be used, to clean-up all the internal streams reaching a concentration in the critical component higher than a convenient upper limit.

Partial regeneration. Partial regeneration of internal flows can be done either using some heuristic criteria or a thorough analysis and optimization concerning the threshold concentrations beyond which the stream is cleaned-up to a certain level. In our opinion, the regeneration exit level should be an economic compromise or, when this is not feasible, it should correspond to the minimum allowable input restrictions for all units, except those with contaminant free input. This way, the regenerated water can be easily supplied to all units in the network. The same criterion could be applied to the threshold concentrations, but this time considering the output restrictions. So, the input into the regeneration unit will have a reasonable low contaminants concentration. The regeneration would happen more often, leading to an overall increase in the mass transfer driving force at the network level; this will diminish the supply water demand. The *unlimited regeneration* means that all streams are decontaminated, while limited regeneration means that there could be streams, later in the network, which cannot be regenerated, due to the unit limited regeneration capacity.

Total regeneration (zero discharge approach). The *zero discharge concept*, environmentally appealing, represents an ideal isolated systems, supposed to be harmless to the environment; no supply water is needed, except for the fresh water used to compensate the technological losses, no aggression against environment is done, since no water is discharged into the nature. In fact, the *zero discharge concept* hinders the problem of pollutants/contaminants disposal (see Fig. 1 for details) through the redistribution of the treatment network. A mass flow rate $\Delta\dot{m}$ of pollutants/contaminants enters the system through the water network and should leave the system, either transformed or in very concentrate states. According to the *ideal zero discharge concept*, water is a simple carrier, claiming that the pollution is reduced or even solved since no water is released into the environment. Still, the waste is there and should be disposed of, even if a part of the initial $\Delta\dot{m}$ flow rate could be converted during the treatment into environmentally harmless compounds. However, the main advantage of the *zero discharge concept* is the reduction of the operating and treatment costs, since less water should be fully treated to be disposed into the environment.

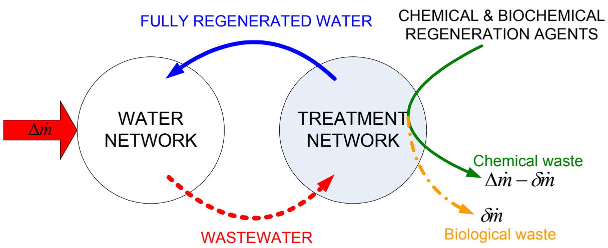

Fig. 1 Zero discharge concept

3. Mathematical model of the water network

The water network is seen as an oriented graph, where unit operations are ordered according either to their maximum load or supply water needs [4]. The model includes overall and contaminant mass balances around units, inlet and outlet constraints for each unit and regeneration unit type and characteristics.

Solving strategy. The mathematical model is solved using an improved variant of genetic algorithms, as detailed elsewhere [4]. The internal flows compose the chromosome and the overall supply water is the objective function which should be minimized.

4. Case study

A synthetic water network with six processes and four contaminants is considered for optimization of supply water, in order to prove the topological impact of the regeneration occurrence and type; the data are presented in Table 1.

Table 1 Case study - limiting data (*threshold limits arbitrary chosen)

Contaminant	PROCESS UNITS												REGENERATION UNITS	
	Inlet maximum concentration (ppm)						Outlet maximum concentration (ppm)						Inlet* (ppm)	Outlet (ppm)
	1	2	3	4	5	6	1	2	3	4	5	6		
1	0	**10**	15	14	12	20	35	63	81	80	75	100	*50*	**10**
2	0	**8**	12	18	10	23	38	49	73	78	70	95	*40*	**8**
3	0	12	18	20	**10**	25	27	39	87	95	100	120	*30*	**10**
4	0	15	16	15	**13**	20	32	80	102	105	110	150	*50*	**13**

Table 2. Results for *partial* and *total regeneration* (Allow/Neglect flows under 1 t/h)

Flow rate (t/h)			NO REGENERATION		(PARTIAL) REGENERATION	
			Allow	Neglect	Allow	Neglect
Normal discharge	**FF**	Fresh water	20.43	20.40	12.39	12.65
		Regenerated water	N.A.		***11.04***	***10.09***
	L	Fresh water	20.29	20.40	15.70	19.14
		Regenerated water	N.A.		***5.88***	***2.18***
Zero discharge	**FF**	Fresh water	20.43	20.40	***9.47***	***9.47***
		Regenerated water	N.A.		***12.26***	***12.56***
	L	Fresh water	20.29	20.40	***9.60***	***9.47***
		Regenerated water	N.A.		***15.56***	***16.32***
	NO	Fresh water	20.43	20.40	***9.47***	***9.47***
		Regenerated water	N.A.		***18.28***	***15.43***

(FF- network ordered by Freshwater Flow rate; L - network ordered by Load; NO- network not ordered, N.A.-not applicable)

5. Results& discussions

The results obtained for the optimization of the water network whose restrictions are given in Table 1 are presented in Table 2, for *partial* and *zero dis-*

charged regeneration, and in Table 3 for *critical component regeneration*. When threshold concentrations for all contaminants are considered, the flow rate of freshwater decreases and some regenerated water can be reused in other process unit (Table 2). If regeneration is done for only one contaminant, the difference of supply water flow rate is under 1 t/h, against the base case (Table 3).

Table 3 Results for *critical component regeneration* (Allow/Neglect flows under 1 t/h)

Fresh water (t/h)		CRITICAL COMPONENT REGENERATION							
		1st of 4		2nd of 4		3rd of 4		4th of 4	
		Allow	Neglect	Allow	Neglect	Allow	Neglect	Allow	Neglect
Normal dis-charge	**FF**	19.48	19.70	19.73	20.03	20.30	20.40	20.42	20.40
	L	19.08	19.58	19.73	20.03	20.20	20.41	20.41	20.40

(FF- network ordered by Freshwater Flow rate; L - network ordered by Load)

A new graphical representation was proposed for water network topology representation (see Fig. 2).

Fig. 2 Representation of water streams: a) wastewater stream b) regenerated water stream

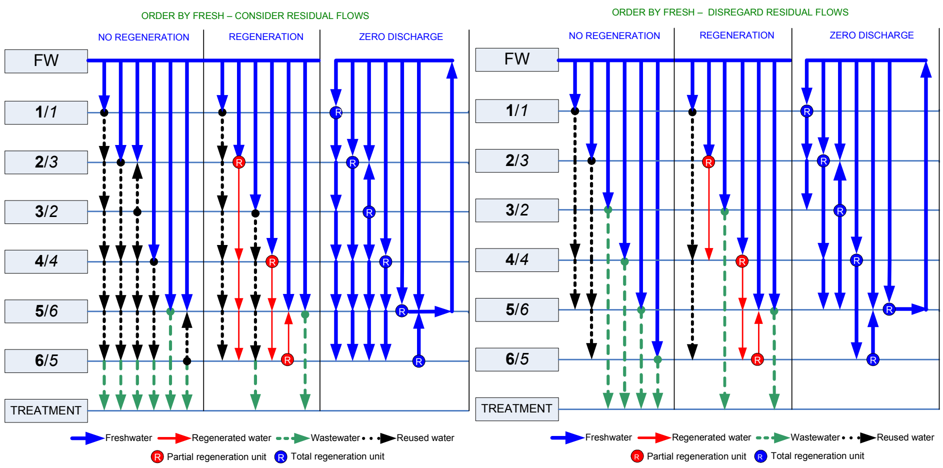

Fig. 3 Water network topology oriented by freshwater flow rate. left - all flow are considered, right - flow rates under 1 t/h are neglected (*italics* – the ordered sequence)

The water stream is an arrow coming from a source and ending in multiple sinks. When a source is not linked with a sink, no arrow points to that sink. A circle with an R is a source followed by regeneration.

The optimal water network topologies are depicted in Fig. 3, when ordering is done by the maximum freshwater needs for three scenarios: no regeneration, regeneration and zero discharge. The same scenarios, but when the ordering is done by maximum load, gave the optimal water network topologies shown in Fig. 4. Analyzing the data from Table 2 we observe that the sum of the internal regeneration flows is higher than the saved supply water.

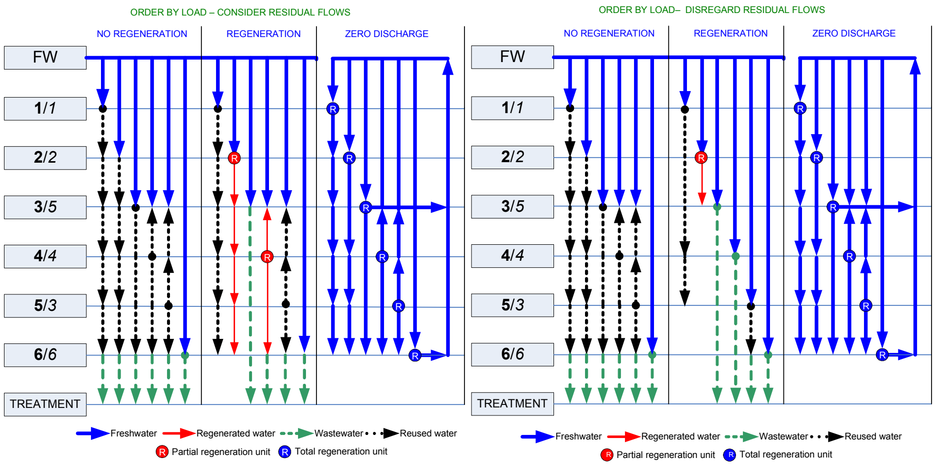

Fig. 4 Water network topology oriented by contaminant mass load. left - all flow rates are considered, right - flow rates under 1 t/h are neglected (*italics* – the ordered sequence)

The same observation is valid when the network is designed using the zero discharge concept. The sum of all the flows which enter total regeneration unit (here enters the supply water too, which comes also from regeneration) is greater than the initial supply water demand (see the values under the heading "no regeneration"). This would render the benefits of using regeneration rather problematic, due to the higher costs of regenerated water against supply water. In fact, there are cases in which regeneration is economically attractive, knowing that the contaminated water exiting the network under normal discharge conditions should go to treatment, in order to be released into environment.

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