Eco Industrial Parks for Water and Heat Management

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Abstract

An EIP is a cluster of several processes that are not necessarily part of the same company, that share common infrastructure designed and operated to induce integration of materials exchange, discharge and waste treatment. Here three companies are concerned and the EIP is related to the management of fresh and waste water and the energy consumption. First each company is optimized alone according to fresh water and waste treatment, number of connections between processes, number of heat exchangers and energy consumption. Then the energy consumption of the EIP is minimized according to bounds on fresh water and wastewater treatment, the problem being parameterized by the number of heat exchangers and the number of connections. An example adapted from the literature is solved, showing the potentiality of the method for providing pertinent answers for reducing energy consumption, fresh water demand and wastewater treatment. The proposed methodology presents a real economic interest, with together a significant ecological impact.

Keywords: Eco industrial park, Multiobjective optimization, Water, Energy.

1. Introduction

The world concern of sustainable development gave birth to Industrial Ecology. Industrial Ecology has been defined by Allenby (2006) as “a systems-based, multidisciplinary discourse that seeks to understand emergent behavior of complex integrated human/natural systems”. In most of the researches in Industrial Ecology the common guideline is that natural systems do not have waste in them, so our systems should be modeled from natural ones if we want them to be sustainable. Many difficult societal and/or industrial problems appear under the generic term on Industrial Ecology. This is the case for eco-industrial parks (EIP) concerned by this study. An EIP is a cluster of several processes that are not necessarily part of the same company, that share common infrastructure designed and operated to induce integration of materials exchange, discharge and waste treatment. A basic condition for an EIP to be economically viable is to demonstrate that the sum of benefits achieved by working as collective is higher than working as a stand-alone facility.

2. IEP for managing water and energy

2.1. Problem formulation

After having demonstrated that an adequate organization of water fluxes in an industrial process (Boix et al., 2010) could provide significant gains, this study is now dedicated to an EIP where the collaboration between different companies is related both to water and energy fluxes management. Several successful examples of EIPs located all around the world particularly in North America (Heeres et al., 2004), Western Europe (Baas and Boons, 2004) and Australia (Van Berkel, 2007). EIP problems for managing industrial water were solved by mathematical programming either by using NLP, MILP or MINLP procedures (Chew et al., 2008, Lovelady and El-Halwagi, 2009).

Table 1 Data for the EIP

Process	Company	Pollutant Flow-rate ($kg.h^{-1}$)	Maximal inlet concentration (ppm)	Maximal inlet concentration (ppm)	Outlet temperature (°C)
1	**A**	2	0	100	40
2		2	50	80	100
3		5	50	100	80
4		30	80	800	60
5		4	400	800	50
6	**B**	2	0	100	90
7		2	50	80	70
8		5	80	400	50
9		30	100	800	40
10		4	400	1000	100
11	**C**	2	0	100	80
12		2	25	50	60
13		5	25	125	50
14		30	50	800	90
15		15	100	150	70

In this paper, the EIP design is illustrated by the example proposed by Olesen and Polley (1996) for managing water (see the first five columns of Table 1). When considering energy, an outlet temperature has to be provided for each process (last column of Table 1). The industrial pool involves three companies, each one including five processes. The three companies decide to constitute an EIP for managing their energy under a constraint related to fresh water consumption limitation. In the EIP, a heat exchanger (heater or cooler) can be associated with each process of a given company. So the aim is to minimize the energy consumption, while minimizing also the number of heat exchangers and the number of connections between processes of each company. The number of connections reflects the complexity of the network representing the EIP, but has also a significant impact on the plant cost.

2.2. Preliminary study

A preliminary study was carried out a good to find the initial flowsheet for each company before solving the EIP problem. The problem was to identify the best solution giving a minimal Global Equivalent Cost (GEC) in water and also minimal energy consumption, while minimizing the number of heat exchangers and the number of connections between processes of the company. All these objectives represent both the economical performance and the environmental impact of the company. The GEC in water is defined as:

$$GEC = F_f + F_w \quad (1)$$

where F_f is the fresh water flow-rate (T/h) and F_w is the contribution of waste water flow-rate (T/h). In terms of cost, according to Bagajewicz and Faria (2009) it comes:

$$F_w = 5.625 \times F_f \quad (2)$$

As far as it is a question only of determining an initial estimate, the solution of this four-objective optimization problem was approximated by using the following unrefined procedure. For a given value of the heat exchanger number, the connection number was fixed, and the energy consumption as well as the GEC were minimized. For minimizing the energy consumption and the GEC, a ε-constraint strategy has been implemented. At an upper level, several numerical trials were carried out on the connection and heat exchanger numbers. The obtained solutions for each company are listed in Table 2.

Table 2. Initial solutions for each company

Company	Number of connections	Number of heat exchangers	Fresh water flow-rate (T/h)	GEC (T/h)	Energy consumption (MW)
A	7	3	111.8	740.7	740.9
B	8	3	63.1	418	418.2
C	7	5	195	1291.9	1291.9
A+B+C	22	11	369.9	2450.6	2451

2.3. Strategies for the EIP

Two major scenarios are considered for constituting the EIP, where the relative energetic gain is imposed to be the same for each company, and the GEC for the whole EIP must be less then the global GEC(2451 T/h) for the initial case displayed in Table 2. Concerning the heat exchanger number two scenarios are studied: Case I - EIP involving 11 exchangers and Case II – EIP involving 10 exchangers.

3. Problem solution

For a given number of heat exchangers (10 or 11), the problem consists in minimizing the energy consumption under a constraint on the GEC, parameterized by the number of connections between processes of the EIP. The problem was solved by means of CPLEX GAMS.

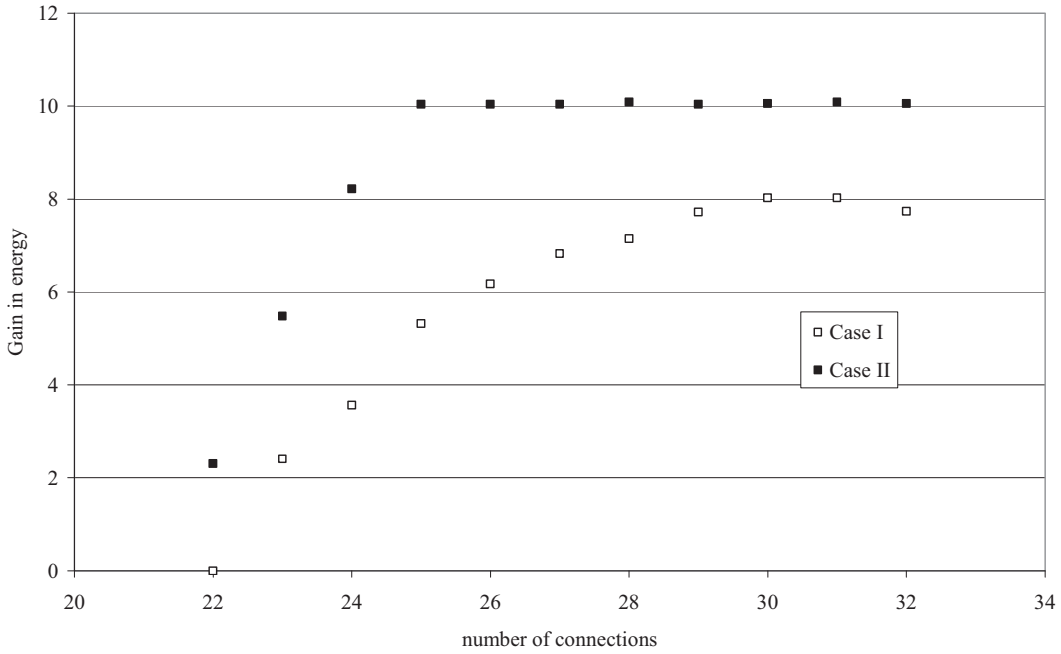

Fig. 1 Gains in energy vs. he number of connections in the EIP for cases I and II.

For the both cases, the results are plotted in Fig. 1. From the Figure, the choice of the best solution is not a trivial task that is why supplementary information is displayed in Tables 3 and 4, where the relatives gains computed from the initial estimate are listed. It can be noted that the gains in GEC is slightly negative for companies B and C, but as imposed by the constraint, the global gain remains positive.

Taking into account the poor gains in GEC and also the respective cost of energy and fresh water, it seems obvious that the three companies will privilege their energy consumption rather than their fresh water needs. So case II is the most efficient one on all the objectives, excepted the GEC, but the difference in GEC between the two scenarios is very slight.

Table 3 Optimal solution for the EIP for Case I

Company	Connection number	Heat exchanger number	Fresh water flow-rate(T/h)	GEC (T/h)	Energy consumption (MW)
A	11	3	79.6	527.4	681.2
Gain (%)				0.28	0.08
B	9	3	65.6	434.6	384.5
Gain (%)				-0.04	0.08
C	10	5	199.3	1320.4	1187.7
Gain (%)				-0.02	0.08
A+B+C	30	11	344.5	2282.2	2253.4
Gain (%)				0.07	0.08

4. Conclusion

The previously developed approach (Boix et al., 2010) implemented for designing water networks in industrial problems, is now extended to the case of several companies constituting an EIP, by considering both energy consumption and water needs and discharge. An example adapted from the literature is solved, showing the potentiality of the method for providing pertinent answers for reducing energy consumption, fresh water demand and wastewater treatment through a new indicator: the global equivalent cost in fresh water. The proposed methodology presents an evident economic impact, but has also an ecological connotation.

Table 4 Optimal solution for the EIP for case II

Company	Connection number	Heat exchanger number	Fresh water flow-rate(T/h)	GEC (T/h)	Energy consumption (MW)
A Gain (%)	9	3	66	437.3 0.41	666.5 0.10
B Gain (%)	8	2	66.1	437.9 -0.05	376.2 0.10
C Gain (%)	8	5	206.2	1366.1 -0.06	1162.2 0.10
A+B+C Gain (%)	25	10	338.3	2241.3 0.09	2204.9 0.10

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