CHEMICAL ENGINEERING TRANSACTIONS Volume 18, 2009
Editor Jiří Klemeš
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DOI: 10.3303/CET0918065

Water Reuse Project Selection
A retrofit path to water and energy savings

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A systematic analysis of the water and energy systems in pulp and paper processes reveals interesting opportunities for improvement through their integration. Therefore, when performing a mill retrofit study these interactions have to be considered in the methodology to achieve better process design options and improve overall energy and water efficiency and profitability. More specifically, the selection of retrofit projects to increase water productivity has to account for the limitations imposed by the existing process configuration and utility infrastructure to ensure that all design changes have positive contributions to the mill savings. A novel methodology has been developed to screen process water reduction projects for optimal retrofit of industrial energy and water networks. This methodology is based on analogies with the transhipment model from the operations research literature (Taha, 1982).

1. Introduction

The critical need to reduce industrial water use and identify the best water-saving systems and process retrofits extends across many industries. Water conservation and water supply planning have gained increasing attention due to the high pressure from the environmental regulations and from the economic issues raised around this aspect. An important part of the challenges associated with water management is the interaction with other sub-systems in the process. Improving water use efficiency is an ongoing process that will require sustained attention over the entire industrial facility due to these strong systems interactions between the water system and the energy/utility systems. Successful plant design changes for improved water management will imply retrofit projects that will modify the heat exchanger network for global process benefit. Researchers and engineers have been addressing the water and energy management issues from different angles and have developed a number of methodologies (Savulescu et. al, 2005; Leewongtanawit, 2005; Karuppiah and Grossman, 2008). There is however, a gap between these concepts and their application in practice. It is relatively easy to estimate targets for water/energy reduction and to get guidelines to identify design changes. On the other hand, any changes to the water system have to be evaluated in detail, including all the consequences to the water management system (water tank management, wastewater system) and those in the associated energy systems. The impacts of particular retrofit projects (mainly water reuse projects) have to be identified,

Please cite this article as: Alva-Argaez A. and Savulescu L., (2009), Water reuse project selection – a retrofit path to water and energy savings, Chemical Engineering Transactions, 18, 403-408 DOI: 10.3303/CET0918065

evaluated and adjusted if necessary to ensure the expected global savings. This is often considered in the detailed design and simulation steps.

Presently, the industrial community has access to a vast amount of information about past experience, best practices and lessons learned from numerous case studies reported in the literature. Having a list of projects that have worked elsewhere as a starting point can represent a significant advantage to any plant interested in improving their water management system. The downside of this approach is the time-consuming searching for solutions through such lists of projects to evaluate project compatibility with the specific plant context. The expected water savings reported in many studies should not be taken for granted as global savings until the entire system is checked.

There are a number of questions arising when a water reuse project is considered. Figure 1 illustrates the bleaching section of a pulp and paper process where whitewater (water with some fibre content) is proposed to be reused to replace clean water for washing. This project is common practice in many mills. The implementation of this project calls for a re-evaluation of the warm and hot water production as the heat exchangers producing and supplying the present demand will have to be rebalanced to contribute to the total mill water savings. Also, the new water source has to be sufficient to justify the modification and to limit the impact on the other sinks receiving the whitewater from the same tank. The energy aspects of this water reuse project have to be addressed to ensure that the mill energy efficiency is not going to be negatively impacted. Alternative project options have to be considered too.

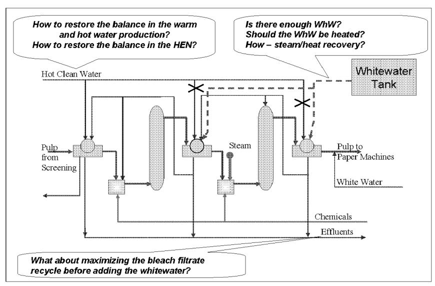


Figure 1- Issues associated with water reuse projects

Therefore, a systematic way of investigating the global process to evaluate the impact of local design changes onto the overall process performance is required. This paper presents an approach that evaluates water projects and helps to screen them based on the global energy and utility response. The algorithm has been developed as part of a combined water and energy optimisation decision support framework dedicated to assist plant engineers to diagnose system inefficiencies in a site specific environment, and to screen and select retrofit design options from a database of project ideas. Following the targeting stage and the identification of opportunities, the impacts of water reuse projects are monitored and tracked as the energy and water are rebalanced in the system through different retrofit water saving paths.

2. Retrofit water saving paths

Many production facilities have been reducing water use by making changes to their production processes implementing water recycle projects based on the quality and quantity of water required by the various operations in a process. Determining the best approach to improve water use efficiency requires a deep understanding of the process

requirements, the complexity of the energy system and the extent of all the implications associated with the process changes in the specific plant context.
In order to select the most promising water reduction projects, the concept of retrofit water-path analysis has been developed. A retrofit water path is determined by the connections between a water source such as fresh water and the water process demand such as a process operation. Consequently, a water path is built by a number of segments connecting sources and sinks along the water network. This concept is used to track the water use through the process. Figure 2 illustrates a simple water-energy network example where fresh water is supplied to two operations through a set of connections passing through a heat exchanger and a tank.

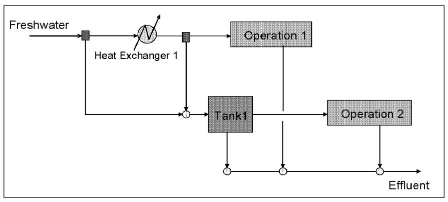


Figure 2 – A simple water-energy network example

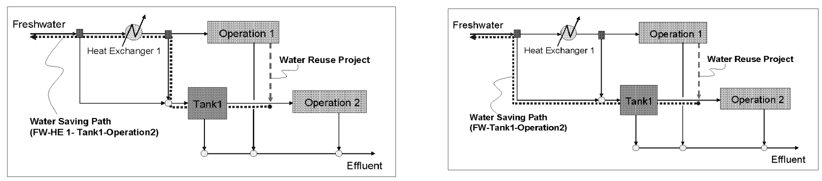
In association with the retrofit water-path concept, a source-sink matrix is introduced to explore different aspects related to the paths such as: path structural configuration, flowrate distribution, flow limitations and energy requirements. The source-sink matrix is a numerical representation of the network where all the source-sink pairs are identified. This matrix includes all the water paths. The structure of the network in Figure 2 is presented in Table 1 (in this matrix 1- connection present, 0- no connection). Project options can also be represented in the matrix as additional cells.

Table 1 – Source-Sink Water System Connectivity Matrix

Source/Sink	FW	HE 1	Tank 1	Operation 1	Operation 2	Effluent
FW	0	1	1	0	0	0
HE1	0	0	1	1	0	0
Tank 1	0	0	0	0	1	1
Operation 1	0	0	0	0	0	1
Operation 2	0	0	0	0	0	1

Let us consider a water reduction project for this simple case by introducing direct reuse between operations 1 and 2. When water from operation 1 is reused in operation 2 (water reuse project – Figure 3) there are two potential ways/paths to cut the water sent to operation 2. One option is to reuse water from operation 1 into operation 2 and to push water back to the source of interest (fresh water - FW) through the FW-Tank1-Operation 2 path as shown in Figure 3a. Alternatively, water can be saved by pushing it back to the source of interest through the FW-Heat Exchanger 1- Tank 1- Operation 2 path. Each of these retrofit water saving paths will have its own limits set by the components/segments of the path. Therefore, a water saving path evaluation has to be performed for each path to acknowledge the restrictions on minimum water flow for water using operations, and heat exchangers according with the cooling demands (hot streams). A "no restrictions" assumption has been considered for the water tanks although limits on minimum water flow may be imposed. The flow rate requirements on each segment may be energy-dependent (when the amount of water is imposed by heat transfer requirements, in particular the hot streams), or it may be process-dependent (when the water requirement is subject to the process demands for water) or it could have a dual-dependency.

Each segment can impose a limit on the amount of water that may be saved through that particular path and the lowest value in the path will dictate the water reduction potential of the path. By exploring the “savings capacity” of all paths in the water network it is possible to identify the most promising reuse projects to evaluate. The water savings retrofit paths that have the largest capacity would be the most promising links to water savings; any water reuse project that has the potential to exploit this potential will be a high priority candidate. By performing energy-response targeting [Alva-Argaez, et. al, 2008] after the water reuse projects have been identified, a project selection may be accomplished using both water and energy criteria in an integrated manner.



(a) (b)

Figure 3- Retrofit water saving paths

3. Methodology

A water-based energy assessment is applied first to evaluate the energy-based water and energy targets of the base case and to identify inefficiencies (Alva-Argaez et al, 2008). Also, a review of the water source-sink network could lead to the identification of areas of opportunity for improving the water efficiency through reuse/recycle. Based on project past experience numerous recommendations for water management improvement can be suggested however, each has to be evaluated in detail. The following methodology steps have been proposed for the evaluation of water projects to ensure water and energy global plant savings and are illustrated with the example shown in Figure 4.

- **Step 1 – Building the flow matrix for the existing water-energy network**

  The water and energy network illustrated in Figure 4 is translated into the source-sink matrix format as described in the previous section

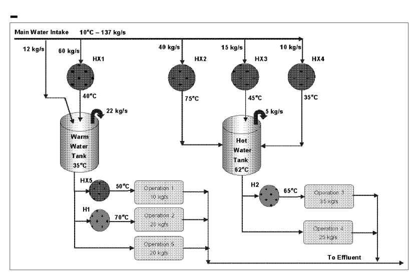


Figure 4 – Water Energy network - Case Study

- **Step 2 – Identify and integrate in the flow matrix the existing network constraints along water saving paths**

  Evaluate the minimum water flow required for each connection along water savings path. Links that involve heat exchangers will feature a minimum water flow that depends on the hot stream and a driving force (assumed to be 10 C in the illustration).

- **Step 3 – Check the list of water reduction projects and include them in the matrix (Figure 5)**
  - Establish the water reduction strategies by comparing the current network with project options; introduce the new potential connections in the matrix
  - Set limits on the projects based on the minimum flow between the water sources and sinks associated with the project
  - Process water-using operations can 100% replace the present water source (FW in the example) with alternative sources if available (initial assumption)
  - The matrix in Figure 5 illustrates the flowrates that set the limits for each individual source-sink pairs in the water paths

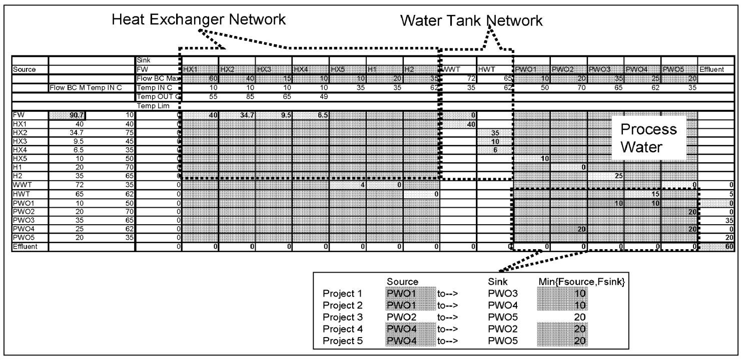


Figure 5 – Case Study Flowrate Matrix Limiting Values

- **Step 4 – Check all the water current paths in the network and evaluate their minimum flow (Figure 6)**
  - The difference between the current flow rates and the flow rate limits on each path will determine the water savings capacity of each one.
  - Evaluate the potential for savings on all water paths in existing network
- **Step 5 – Identify water reuse projects that lie on the most promising water saving path**
- **Step 6 - Estimate the energy response for each path**
- **Step 7– Project ranking and water energy-efficient project selection (Figure 7)-** For the purposes of illustrating the procedure we compare two project options each following a different water savings path.

In Figure 7 Path #2 represents a water reuse project that takes the effluent from operation 4 and takes it directly into operation 2; water savings of 20 kg/s are achieved as indicated by the limit on Path #2 in Figure 6. Path # 4 represents a project to eliminate the 22 kg/s overflow from the warm water tank; however and as indicated in Figure 6 and 7 the best that can be achieved is a reduction of 20 kg/s due to the constraints of the water saving path. In terms of water savings both options are equivalent; it is necessary to perform the energy-response targeting for both options to identify the energy implications and provide further decision criteria for project selection. Figure 7 presents the results of the approach in terms of the cooling load of the overall system and the water savings achieved. The reuse project achieves significant water savings however it incurs an energy penalty as an additional cooling load is required. Reducing the tank overflow produces the same water savings and a reduction in cooling duty thus making it a more interesting option

#NR Path	Current Paths (CP)						Min Flow
1	FW	HX1	WWT	HX5	**PWO1**	Effluent	
	20	20	6	6	10	10	6
2	FW	HX1	WWT	H1	**PWO2**	Effluent	
	20	20	20	20	20	20	20
3	FW	HX1	WWT	**PWO5**	Effluent		
	20	20	20	20	20		20
4	FW	HX1	WWT	Effluent			
	20	20	22	22			20
5	FW	HX2	HWT	H2	**PWO3**	Effluent	
	5.3	5.3	35	35	**10**	10	5.3
6	FW	HX2	HWT	**PWO4**	Effluent		
	5.3	5.3	10	**10**	10		5.3
7	FW	HX3	HWT	H2	**PWO3**	Effluent	
	5.5	5.5	35	35	**10**	10	5.5
8	FW	HX3	HWT	**PWO4**	Effluent		
	5.3	5	10	**10**	10		5.3
9	FW	HX4	HWT	H2	**PWO3**	Effluent	
	3.5	3.5	10	10	**10**	10	3.5
10	FW	HX4	HWT	**PWO4**	Effluent		
	3.5	3.5	10	**10**	10		3.5
11	FW	WWT	HX5	**PWO1**	Effluent		
	12	**6**	**0**	**0**	0		0
12	FW	WWT	H1	**PWO2**	Effluent		
	12	20	20	20	20		12
13	FW	WWT	**PWO5**	Effluent			
	12	20	**20**	20			12
14	FW	WWT	Effluent				
	12	22	22				12
14							

Figure 6 – Case Study Water Saving Paths

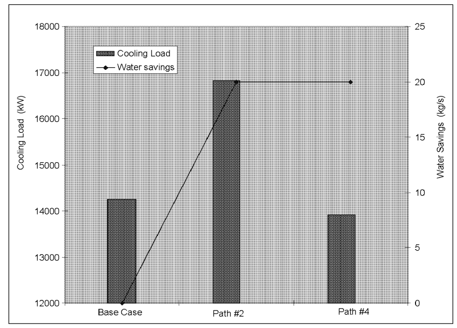


Figure 7 –- Water paths comparison

The result is as expected for this simple example and it illustrates that before implementing any reuse opportunities; the overflow issue must be resolved. Notice that given the capacity of the associated water saving paths; once we reduce the overflow by 20 kg/s, the reuse project can no longer be implemented since the reduction potential has been exhausted for these paths.

4. Conclusion

Water and energy are closely interrelated and their interactions can be complex and difficult to evaluate. A systematic procedure to identify the most promising water savings options that considers directly the energy implications of such modifications has been presented. In general the method may be used to explore the potential trade-offs between saving water and saving energy although, as illustrated in the simple example, both may be achieved simultaneously. The set of linear equations defined by the source-sink matrix could also in principle be solved by applying Linear Programming techniques and identify those new connections that would bring about the maximum reduction in freshwater demand; however a heuristic-based search was selected in order to enable a deep understanding of the constraints at play and provide a better understanding of the options for process changes.

References

Alva-Argaez A, Savulescu L. and Cripps H. R., 2008, Water-based energy assessment. A conceptual approach to retrofit systems with strong energy-water interactions, 11th PRES Conference 24-28 August 2008, Prague - Czech Republic

Karuppiah, R and Grossman, I. E. 2008, Global optimization of multiscenario mixed integer nonlinear programming models arising in the synthesis of integrated water networks under uncertainty. Comp Chem Eng (32) 145-160

Leewongtanawit, B. 2005, Heat-integrated water system design. PhD thesis, The University of Manchester

Savulescu, L; Kim, J.K and Smith, R, 2005, Studies on simultaneous energy and water minimisation—Part II: Systems with maximum re-use of water. Chem. Eng Sci (60) 3291-3308

Taha, H.A 1982, Operations Research. 3rd Edition Collier-MacMillan