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A Systematic Technique for Design of Minimum Water Network

Sharifah Rafidah Wan Alwi and Zainuddin Abdul Manan*

Chemical Engineering Department, Faculty of Chemical and Natural Resources Engineering,
Universiti Teknologi Malaysia, 81310 Skudai, Johor, Malaysia.

Abstract

Until today, the idea of minimum water design was unknown for *urban system* even though there has been extensive work on the design and improvement of industrial processes for maximum water recovery. The development of novel systematic techniques to maximise water efficiency in *urban buildings* represents a shift in the global traditional process engineering paradigm to allow maximum water recovery beyond the frontiers of process industry, into the realm of urban sector. This paper describes the *Systematic Hierarchical Approach for Resilient Process Screening* (SHARPS) as a new cost-screening tool for design and retrofit of a minimum water network. Guided by the water management hierarchy, *SHARPS* offers a quick and efficient means to guide and screen inferior process changes and to predict the potential maximum fresh water savings within a desirable investment limits ahead of design. Application of SHARPS technique on Sultan Ismail Mosque in UTM demonstrates substantial water savings potential to satisfy the investment criteria set by the mosque authority with freshwater and wastewater reduction of 97% and 61% respectively for grassroots designs and 71% and 86% respectively for retrofit designs.

Keywords: Pinch Analysis-minimum water network-urban systems-water management hierarchy-cost-screening

1.0 Introduction

Over the past decade, the advent of water pinch analysis (WPA) as a tool for the design of a maximum water recovery (MWR) network has been one of the most significant advances in the area of water minimisation. Since its introduction by Wang and Smith [1], various noteworthy WPA developments on targeting, design and improvement of an MWR network have emerged. Most authors claim that their methods lead to the minimum fresh water and wastewater targets. These include works on processes with fixed flowrate and fixed concentration [2-5], regeneration targeting [6-7], numerical water targeting [5], network design to achieve water targets [1, 4, 7-11], problems with multiple contaminants [12-16], water network retrofit [17] and water targeting for batch systems [18-20]. Wan Alwi *et al.* [21] had recently made the first attempt to implement WPA on urban system by using their *Water Cascade Analysis* (WCA) technique to establish water targets and design an MWR network for a mosque. Most authors claim that their methods lead to the minimum fresh water and wastewater targets.

Manan and Wan Alwi [22] pointed out that MWR which relates to maximum reuse, recycling and regeneration has two limitations. Firstly, it only addresses water minimisation problem partly since crucial water minimisation options such as elimination and reduction are

*Corresponding author: Tel: +607-5535512, Fax: +607-5581463, Email: zain@fkkksa.utm.my

neglected. Secondly, since MWR focuses on water reuse and regeneration, strictly speaking, it does not lead to the *minimum water targets* as widely claimed by researchers over the years. To overcome these limitations, Manan and Wan Alwi [22] suggested the use of water management hierarchy (WMH) together with pinch analysis in order to achieve the minimum water network (MWN) and maximise savings for industry and urban water systems. They proposed a holistic framework to design the MWN by considering not only reuse and recycling, but all conceivable methods to holistically reduce water through elimination, reduction, reuse/outsourcing and regeneration. The framework comprises of four main steps, i.e. (1) Water data specifications, (2) Water targeting, (3) WMH-guided process changes, and (4) Network design (see Figure 1).

Even though the holistic framework proposed by Manan and Wan Alwi [22] led to significant water reductions, however, some costly process changes may not be attractive for most plant owners due to the long investment payback period. Hence, we propose to incorporate a new short-cut cost-screening technique within the holistic framework proposed by Manan and Wan Alwi [22]. Figure 1 shows a modified holistic framework that involves economic evaluation of the water network design using a new technique to screen inferior design options. Note that steps 1 to 3 will be repeated until an economical water network design is achieved. This paper presents the development of the *Systematic Hierarchical Approach for Resilient Process Screening* (SHARPS) as a new cost-screening tool for design and retrofit of minimum water network. SHARPS is used to screen various water management options prior to design based on the cost estimates for network investment and savings subject to the desired payback period set by a designer.

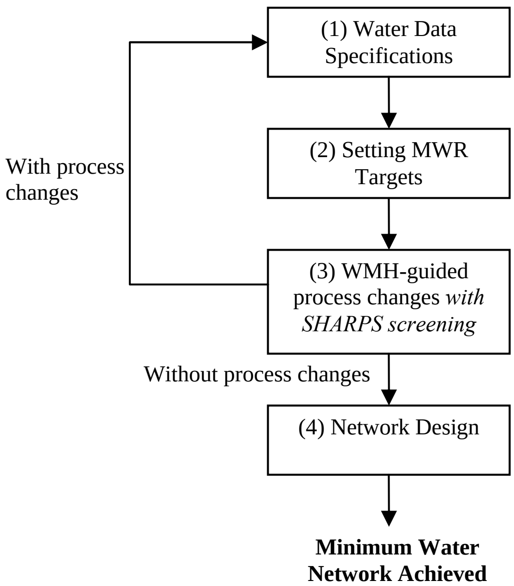

Figure 1 A modified holistic framework for minimum water-network design.

2.0 Materials & Method

2.1 Sharps Technique

In order to obtain the optimum process changes as well as water savings to satisfy a desired payback period, the new SHARPS technique is implemented as follows:

Step 1: Set the desired payback period, PP_{set}.

Step 2: Use WCA method by Manan *et al.*, [5] to calculate the maximum potential fresh water and wastewater savings for each process change. Favor the scheme at the top level of the WM hierarchy before going to the next level.

Step 3: Generate an investment vs. annual savings (IAS) plot for each level of the WM-hierarchy. The gradient of the graph gives the payback period for each process change. The steepest positive gradient yields the highest investment per unit of savings, thus represents the most costly scheme. On the other hand, a negative slope indicates that the new equipment requires lower investment as compared to the base case equipment. Note that a linear cost line is very unlikely for most cases as most equipment cost is of an exponential value to the capacity. Hence, if the line is a curve line, a few points can be taken to plot the curve line for each process changes. Similarly to the linear line, a curve moving upward signifies that more investment is needed and a curve moving downward signifies less investment is needed as annual savings increases.

Step 4: Draw a straight line connecting the starting point and the end point of the IAS plot. The gradient of this line is a preliminary cost estimate of the total payback period (*TPP*) for implementing all process changes in line with the WM hierarchy as explained in previous section. The TPP estimate provides a useful guide to screen process changes ahead of design.

Step 5: Compare the TPP_{BS} (the total payback period before SHARPS) with the PP_{set} (the desired payback period set by a designer). The TPP_{BS} should match the maximum desired payback period set (PP_{set}) by a designer. Thus, it is possible to tailor the minimum water network as per the requirement of a plant/building owner.

If $TPP_{BS} \leq PP_{set}$, proceed with network design.
If $TPP_{BS} > PP_{set}$, two strategies may be implemented.

Strategy 1: The first strategy is to consider replacing the equipment that results in the steepest positive gradient (except reuse line) with equipment that gives a less steep gradient. For example, a stainless steel storage tank may be changed to a plastic barrel that could store the same amount of water but at a much cheaper price.

Strategy 2: The second strategy is to reduce the length of the steepest positive gradient (except reuse line) until *TPP* is equal to PP_{set}. This means that instead of completely applying each process change, one can consider eliminating or partially applying the process change that gives the steepest positive gradient, and hence, a small annual savings compared to the amount of investment. For example, instead of changing all water taps to infrared-type, only 50% of the water taps are changed. If *TPP* is still more than the PP_{set} even after adjusting the steepest gradient, then the length for the next steepest gradient will be reduced until *TPP* is equal to PP_{set}.

Note that *Strategy 1* which involves equipment replacement is more desirable compared to *Strategy 2*. However, *Strategy 1* and *2* can also be applied simultaneously. Note also that the lines after the line that is changed either via *Strategy 1* or *2* might not be similar to the original lines before the implementation of SHARPS strategies.

The overall procedure for SHARPS is summarized in Figure 2. The SHARPS technique provides clear quantitative and tangible insights to screen process changes. By applying the SHARPS technique in accordance with the water management hierarchy, it is possible to decide the schemes to partially apply or completely eliminate in order to satisfy a desired payback period, thereby allowing a designer to estimate the maximum potential annual savings ahead of design. SHARPS is a novel cost-screening technique that enables a designer to generate the minimum water network design as per the requirement of a plant or building owner.

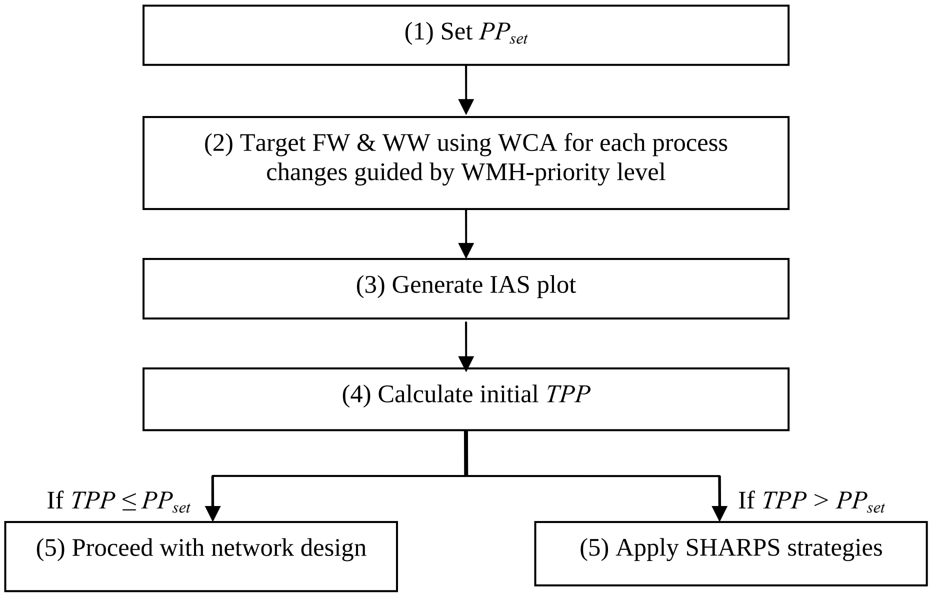

Figure 2 The overall procedure for SHARPS steps.

3.0 Results and Discussion

3.1 Application Of Sharps Into Sultan Ismail Mosque (Sim), Utm

Considering the example data of a mosque used by Manan and Wan Alwi [22], the initial water demand and source data of the mosque is as in Table 1. Now, this data will be implemented into the SHARPS steps mentioned in Figure 2. The designer had set that PP_{set} as 2 years for both grassroot and retrofit designs for the SIM case study. Figure 3 shows the summary of each process changes effect on the targeted new freshwater flowrate and pinch point by using WMH-guided process changes suggested by Manan and Wan Alwi [22]. The *NCI* and the *NAS* for the grassroots and retrofit systems were determined and IAS plot was generated. The total payback period before SHARPS (TPP_{BS}) calculated for grassroots design is 2.1 years and for retrofit design is 9.7 years. Since, both the initial total payback period is more than the total payback period set by the designer i.e. 2 years, hence SHARPS strategies should then be applied for both cases to calculate the most cost-effective process changes for the mosque to achieve PP_{set}. Figures 4 and 5 shows the total payback period before (TPP_{BS}) and after (TPP_{AS}) SHARPS strategies application for grassroots and retrofit design respectively. For grassroots design, a total payback period of approximately 2 years can be achieved by eliminating only 1.52 t/day of D8, i.e. changing only 29 unit of the 12 l toilet flush to composting toilet instead of 30 unit. Instead, for retrofit design, a total payback period of 2 years are possible to be achieved without considering elimination and only harvesting 6.6 t/day of rainwater.

Table 1 Summary of water demands and water sources for Sultan Ismail Mosque [23].

Process	Demand	*F* (*t/day*)	*C* (*ppm*)	Source	*F* (*t/day*)	*C* (*ppm*)
Kitchen	1	0.03	0	1	0.03	536
Ablution	2	25.03	10	2	25.03	23
Wash basin	3	0.14	10	3	0.14	23
Showering	4	0.14	10	4	0.14	216
Mosque cleaning	5	0.29	10	5	0.29	472
Irrigation	6	1.46	10			
Toilet pipes	7	0.44	10			
Flushing toilet	8	1.57	10			

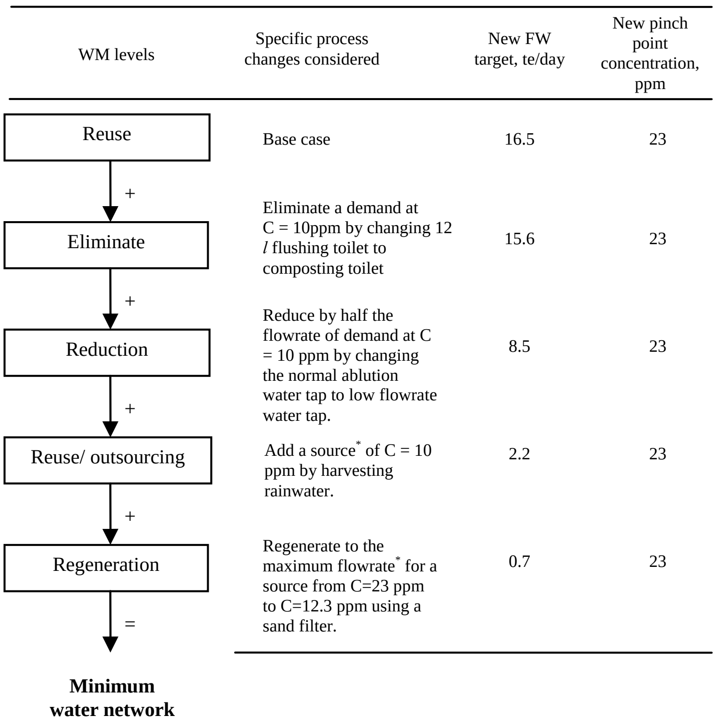

Figure 3 The effects of WMH-guided process changes on water targets and pinch location [22].

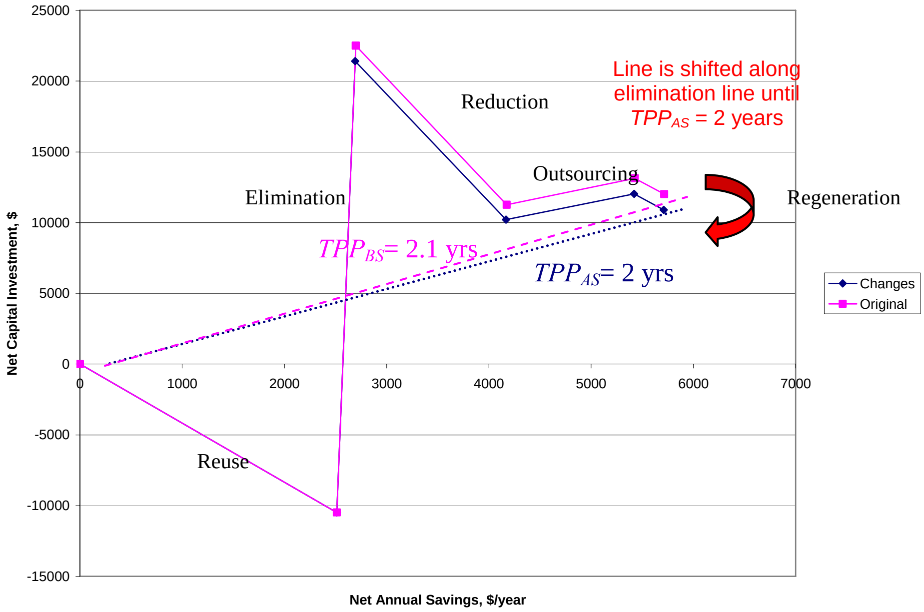

Figure 4 Investment versus annual savings for SIM grassroots design – achieving a total payback period of 2 years.

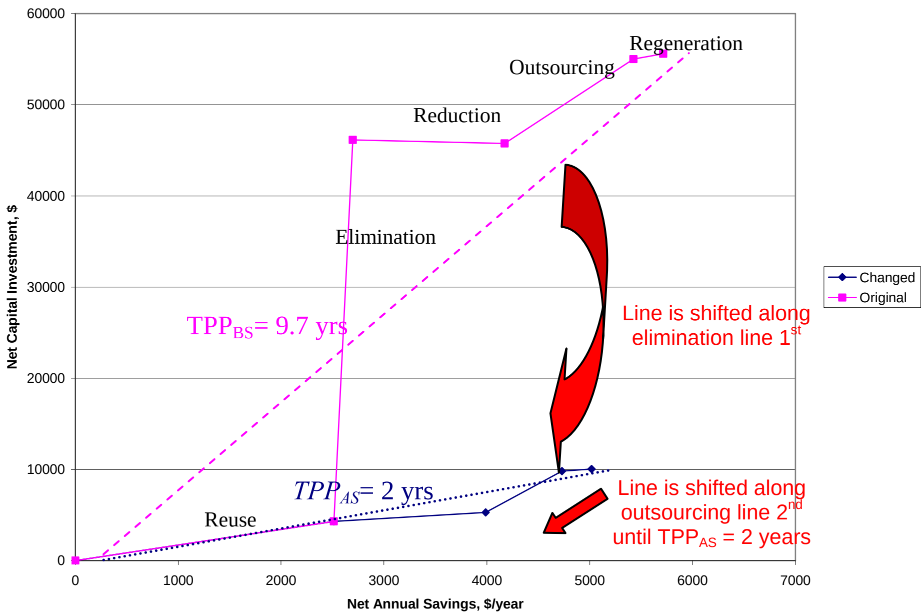

Figure 5 Investment versus annual savings for SIM retrofit design – achieving a total payback period of 2 years.

4.0 Comparison Study

Table 2 shows the difference in the savings between conventional pinch method, before SHARPS implementation and after SHARPS implementation for the WMH-guided process changes method for retrofit and grassroots cases. Note that the conventional maximum water recovery technique gives a much smaller payback period compared to the MWN method by

Manan and Wan Alwi [22]. However, if a designer has set a limit that the maximum payback period for the new installed water saving system is 2 years, then the most minimum water network that achieve this limit should be sought. The cost-effective MWN method involves the consideration of all water conservation strategies and after SHARPS implementation, enables a designer to choose the most cost-effective water management options. A case study on Sultan Ismail Mosque in UTM has shown that a potential freshwater and wastewater reduction of 97% and 61% respectively for grassroots designs and 71% and 86% respectively for retrofit designs are achievable with a payback period of within two years.

Table 2 Difference in savings between conventional pinch method, before SHARPS implementation and after SHARPS implementation for the WMH-guided process changes method for retrofit and grassroots cases.

Type of building	Method used	Freshwater savings, %	Wastewater reduction, %	Net Capital Investment, $	Net Annual Savings, $/yr	Total Payback period, yrs
Grassroots	Conventional pinch method	43%	49%	-10481	2513	-4.2
	Before SHARPS	97%	61%	12015	5715	2.1
	After SHARPS	97%	61%	10899	5709	1.9
Retrofit	Conventional pinch method	43%	49%	4308	2512	1.7
	Before SHARPS	97%	61%	55585	5715	9.7
	After SHARPS	71%	86%	10057	5019	2.0

5.0 Conclusion

A cost-effective minimum water network in urban and industrial sector can be achieved by using the new *Systematic Hierarchical Approach for Resilient Process Screening* (SHARPS) technique. *SHARPS* can provide a quick and efficient means to guide and screen inferior process changes and predicts the potential maximum fresh water savings and the desirable investment limits during the early design stage. A case study on Sultan Ismail Mosque in UTM has shown that a potential maximum freshwater and wastewater reduction of 97% and 61% respectively for grassroots and 71% and 86% respectively for retrofit are achievable for a payback period of within two years. This is a very encouraging result in terms of water savings and meeting designers' requirements.

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