BENCHMARKING WATER UTILISATION USING MINIMUM WATER NETWORK TECHNIQUE

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ABSTRACT

This paper describes a procedure to establish the minimum utility targets, which relates to the maximum potential utility savings for a manufacturing plant. The focus is on setting the best achievable, or the minimum water and wastewater benchmark targets for a semiconductor plant using a new procedure known as the minimum water network (MWN) technique (Manan and Wan Alwi, 2006). The procedure involves detailed analysis of a plant configuration, material and energy balances, design and thermodynamic constraints. The minimum water network (MWN) technique can help a company realize its' best achievable water savings target and assess its true potential for continuous improvement as part of its quality management requirement. Application of MWN technique on a semiconductor plant in Malaysia showed that savings of up to 85.5% fresh water and 97.8% waste water were achievable with an estimated payback period of less than half-a-year. The proposed detailed improvement schemes and targets provided a useful guideline for the semiconductor plant short and long term water-saving program.

Keywords: Minimum water network, maximum water recovery, water pinch analysis, semiconductor, benchmarking

1 INTRODUCTION

Manufacturing companies with large utility bills usually set annual targets for utility savings in order to continuously reduce operating costs. Many companies conduct a combination of *inter-company* and *intra-company* benchmarking as basis to set realistic utility savings targets. In the former, companies refer to achievements of other companies in the same business while in the latter, it refers to its own past performance. Inter-company and intra-company benchmarkings are usually part of a company's total quality management program that calls for the relevant department to set annual targets for continuous improvement. In order to meet the quality management requirements, a conservative utility savings target of, for example, 5% a year is usually randomly specified. This target is typically set quite separate from considerations of technical potentials and limitations, design and thermodynamic constraints of a plant. Hence, the true potential of a plant can be missed.

The advent of water pinch analysis (WPA) as a tool for the design of a maximum water recovery (MWR) network enables a process plant to assess its inherent potential for saving utilities and benchmark its performance based on the structure, operating conditions, design and thermodynamic characteristics that are unique to the plant. Since its introduction by Wang and Smith (1994), various noteworthy WPA developments on targeting, design, optimization and improvement of an MWR network have emerged. Most authors claimed that their methods lead to the minimum fresh water and wastewater targets.

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 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. This article describes a procedure to establish the minimum utility targets, which relates to the maximum potential utility savings for a manufacturing plant. The focus is on setting the best achievable, or the minimum water and wastewater benchmark targets for a plant using a new technique known as the minimum water network (MWN) technique (Manan *et al.*, 2006). The procedure involves detailed analysis of a plant configuration and design, material and energy balances, design and thermodynamic constraints. The MWN technique strives to achieve maximum water reduction, and hence, maximum savings holistically after considering not only reuse and recycling, but all conceivable options to reduce water usage through elimination, reduction, reuse, outsourcing and regeneration. We demonstrate how the true water-saving potential of a plant can be realized through application of the MWN technique on a semiconductor plant

2 METHODOLOGY

The MWN procedure is a holistic framework for water management. A key feature of the holistic framework is the water management hierarchy (WMH) as a guide to prioritise process changes qualitatively as well as quantitatively. The WMH consists of five levels, namely (1) source elimination, (2) source reduction, (3) direct reuse/outsourcing of external water, (4) regeneration, and (5) use of fresh water. The levels are arranged in order of preference, from the most preferred option at the top of the hierarchy (level 1) to the least preferred at the bottom (level 5) as in Figure 1 (Manan and Wan Alwi, 2006). Water minimisation is concerned with the first to the fourth level of the hierarchy. The key steps to establish the MWN benchmark targets are illustrated in Figure 2 and are described next.

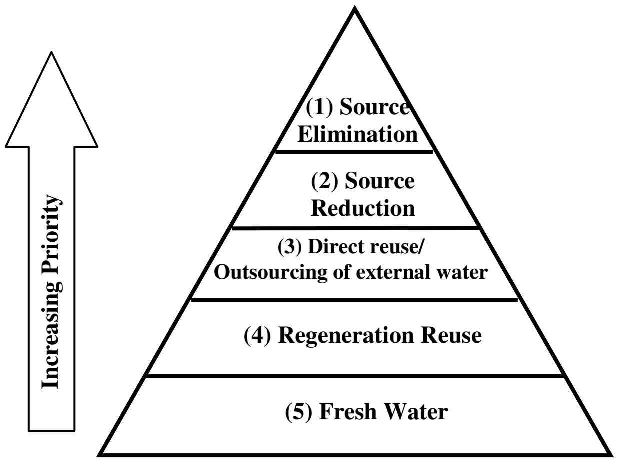

FIGURE 1. The water management hierarchy (Manan and Wan Alwi, 2006).

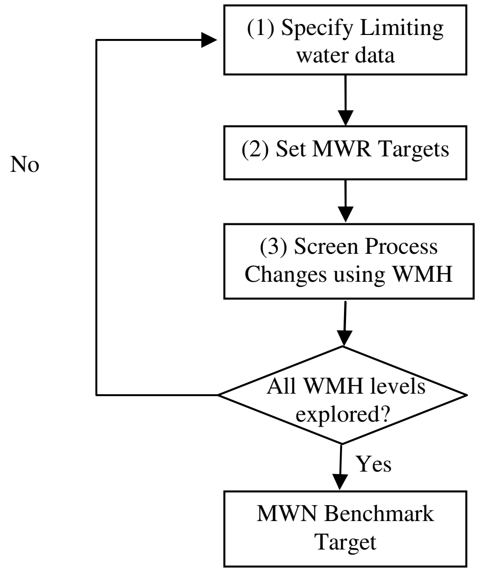

FIGURE 2. A holistic framework for establishing the MWN benchmark target

2.1 STEP 1: SPECIFY THE LIMITING WATER DATA

The first step was to specify the limiting water data. This involved process line-tracing, establishing process material balances and isolating the appropriate water sources (outlet streams with potential to be recycled) and water "demands" (inlet streams representing process water requirements) having potential for integration. The water sources and demands were listed in terms of quantity (flowrate) and quality (contaminant concentration

2.2 STEP 2: DETERMINE THE MWR TARGETS

The second step was to establish the *base-case* MWR targets, i.e. the overall fresh water requirement and wastewater generation for the process. Note that the *base-case* MWR targets exclude other levels of WMH except re-use and recycling of available water sources and mixing of water sources with freshwater to satisfy water demands. Established graphical and numerical techniques for setting the MWR targets are widely available such as the source and sink composite curves (SSCC) technique by El-Halwagi *et al.* (2003) and water cascade analysis (WCA) technique by Manan *et al.* (2004).

2.3 STEP 3: SCREEN PROCESS CHANGES USING WMH

Changes can be made to the flowrates and concentrations of water sources and demands to reduce the MWR targets and ultimately achieve the MWN benchmark. This was done by observing the basic pinch rules for process changes and by prioritising as well as assessing all possible process changes options according to the WM hierarchy.

It is vital to note that implementation of each process change option will yield new pinch points and MWR targets. In addition, interactions and "knock-on effects" between the process change options should also be carefully considered. It is therefore important that each process change be systematically prioritized and assessed with reference to the revised pinch points instead of the original pinch point so as to obey the fundamental rules for process changes listed previously and to guarantee that the MWN benchmark is attained. Bearing in mind these constraints, the core of step 3 was the level-wise hierarchical screening and prioritisation of process changes options using the water management hierarchy (WMH) and the following three new option-screening heuristics which was sequentially applied to prioritise process changes.

Heuristic 1: *Begin process changes at the core of a process*

Heuristic 2: *Successively reduce all available demands with concentration lower than the pinch point, beginning from the cleanest demand.*

Heuristic 3*: Successively reduce the demands starting from the one giving the biggest flowrate reduction if several demands exist at the same concentration.*

Heuristic 1 strictly applies to the process change options at levels 1 and 2 of WMH. Applying heuristic 1 to various source elimination options at level 1 of the WMH will lead to new targets and pinch points. For mutually exclusive options, the one giving the lowest revised MWR targets was selected. Heuristic 1 was repeated to reduce water at WMH level 2 once all elimination options were explored. If a few demands exist at the same concentration, to achieve the biggest savings, begin by reducing the demand that yields the most flowrate reduction. Proceed to reduce the remaining demands that exist at concentration lower than the revised pinch concentration, as stated in heuristic 3.

The revised MWR targets as well as the new option-screening heuristics were used as process selection criteria. The screening and selection procedure was hierarchically repeated down the WMH levels to establish the maximum scope for water savings.

3 RESULTS AND DISCUSSION

The technique for setting the MWN targets introduced by (Manan *et al.*, 2006) was successfully applied on a semiconductor company in Malaysia (MySem). MySem which involved a combination of domestic and process water usages represented an ideal application of the MWN benchmarking technique for both urban and industrial sectors. Water demands in MySem included DI water production, domestic uses (toilet flushing, office cleaning, wash basin, toilet pipes and ablution) and non-process uses such as abatement, scrubber, cooling tower and wet bench cooling. The estimated total fresh water consumption for MySem was 34, 618 m^3/month for the month of October to produce 118 unit of wafer Water supply is obtained from Jabatan Bekalan Air (JBA) Selangor with a tariff of \$0.51 per m^3. MySem have its own industrial wastewater treatment (IWT) plant that cost \$0.04 per m^3 of IWT treated. The domestic wastewater is sent to sewer system which is not charged.

Implementation of the MWN yielded the best achievable benchmark targets for fresh water flowrate of 5.797 m^3/hr and IWT flowrate of 0.7492 m^3/hr. This represented 85.5% fresh water and 97.8% IWT reduction. Hence, these were the best performance benchmark targets (Figure 3) that MySem needed to achieve. Manan and Wan Alwi (2006) have shown that application of total reuse only using water pinch analysis (WPA) method yielded a lower water savings potentials of 72.4% fresh water and 83.4% wastewater reduction with a 0.59 year payback period (MySem, 2005). November 2005 water bills had shown that all the conventional water reductions strategies applied by MySem had only managed to reduce fresh water usage from 42.6 m^3/hr to 40.24 m^3/hr representing a savings of \$ 880 per month. An estimated total savings of \$194,242 per year was predicted with the implementation of MWN method. A preliminary cost estimate indicated that this best performance required an investment of approximately \$ 75,018 with a payback period of 0.39 years.

Once the best performance benchmark was established through MWN method, the predicted maximum savings was then compared with the international benchmark. The International Technology Roadmap for Semiconductor (ITRS 2001) had aimed to reduce high purity water (HPW) consumption from the current rate of 6-8 m^3 in 2005 to 4-6 m^3 per wafer by 2007 (Wu *et al.*, 2004). After cost-effective MWN analysis, MySem had potential to use 4.06 m^3 of DI water per wafer for Fab 1 and 13.73 m^3 of DI water per wafer from Fab 2, down from its previous consumption of 6.3 and 72.4 m^3 of DI water per wafer respectively. Fab 1 had potential to meet the ITRS 2001 target. Fab 2 however was far from this ITRS target due to its wafer production rate of well below the design capacity.

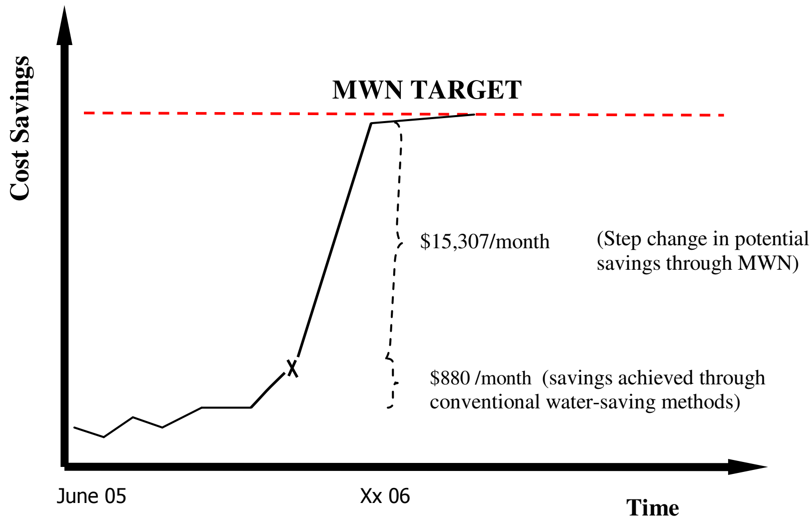

FIGURE 3. Savings achieved by MySem in comparison to savings predicted through MWN technique.

4 CONCLUSION

The minimum water network (MWN) technique can help a company realize its' best achievable water savings target and assess its true potential for continuous improvement to fulfill its quality management requirement. Application of MWN technique on a semiconductor plant showed that savings of up to 85.5 % fresh water and 97.8% industrial waste water were achievable with an estimated payback period of 4.6 month. The proposed detailed improvement schemes and targets provided a useful guideline for short and long term water-saving programme that is generally applicable to any plant. Various approaches for benchmarking such as maximum water recovery (MWR) technique based on pinch analysis technique which considers plant design and thermodynamic constraints could also help a company realize its potential for conservation of resources beyond water, including material and utility heat, power and gases.

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