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Towards zero liquid discharge: the use of water auditing to identify water conservation measures

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ABSTRACT

Water is economically cheap, which fails to consider its intrinsic environmental and social value. However, given the uncertain future around the availability of water resources to provide industrial, environmental and social services, water conservation is now of significant concern to industries across the globe. Recently, an extension of water conservation has emerged as zero liquid discharge, whereby no water at all is released from industrial processes, regardless of its quality.

Water auditing is a tool that can be used to identify water conservation strategies, ideally leading to zero liquid discharge. This article discusses a water audit conducted on a sodium cyanide plant, where flows were determined using historical data, proxy data, and known scientific relationships. Water quality throughout the process was defined as contaminated or uncontaminated. From this simple audit, two major water conservation measures were identified and modelled which could reduce inputs and outputs by ~40%. These were the reuse of rain water falling throughout the plant's boundaries instead of demineralised scheme water, and the improvement of the efficiency of one of the cooling towers.

Such a methodology could be easily applied by other industries so as to improve their water conservation. The auditing method may lead to suggestions of conservation techniques for implementation either through retrofitting existing plants or contributing to the design of new ones.

1. Introduction

1.1. Water conservation and auditing

Water is comparatively cheap when considering the myriad of expensive infrastructure, human resources and chemical resources involved in the process industry. However, humanity is facing an uncertain future surrounding the availability of freshwater resources, ranging from pollution concerns to climate change to satisfying the water needs of a growing population (Postel, 2000). Water conservation has become a key item on the agenda of industry, and tools exist to examine how water is being used (and wasted) throughout industrial processes (Klemes et al., 2010).

Water auditing is an analytical tool which quantifies water flows and quality within a predefined boundary (Sturman et al., 2004). The technique can determine where unexpected water losses (or gains) are occurring. This assists auditors and water managers in identifying where water management can be improved within a system (e.g. Agana et al., 2013). The initial step of any water audit is to investigate the known overall water inputs and outputs of the system under examination. Generally an auditor will determine prior to an audit what level of discrepancy between inputs and outputs they are willing to accept. This tolerance is referred to as closure and is calculated from:

$$\text{Closure}: \left(\left(\sum \text{Water Input} - \sum \text{Water Output}\right) / \left(\sum \text{Water Input}\right)\right) < \text{Predetermined Tolerance} \quad \text{Sturman et al., 2004}$$

Often closure cannot be obtained, generally indicating that significant water losses are occurring throughout the system. The method of water auditing then allows for the investigation of where these losses are occurring throughout the system through analysing water volumes utilised by individual process units (Sturman et al., 2004). However, it is important to note that even where closure is obtained, this only indicates the relationship between inputs and outputs of the entire system; it does not immediately indicate that the process is using water optimally. Further investigation into where different source waters flow within the refinery, and where possible, their quality, assist in the

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identification of water reduction measures. The work of Dakwala et al. (2009) and Žbontar Zver and Glavič (2005) detail examples of how this can be implemented in an industrial setting.

Water auditing can thus contribute to sustainable water use, with the ideal outcome of zero liquid discharge (ZLD). This is the concept of closing water cycles so that no water is discharged from a system, meaning that minimal water must be input and then reused and recycled wherever possible (Byers, 1995). Although this may seem like an impossible task, if it is seen as a best practice end goal, it can drive innovation and achievement in water use minimisation (Lens et al., 2002). Wan Alwi et al. (2008) suggest that ZLD is most likely to be achieved by following the water minimisation hierarchy (WMH), where water use should focus on, in decreasing priority;

1. Source elimination: Remove water requirements;
2. Source reduction: Reduce water requirements;
3. Reuse water: Reuse water directly without treatment;
4. Regenerate water: Reuse water following treatment (also known as recycling);
5. Use fresh water: When the use of 'new' water cannot be avoided.

Water auditing can be used in conjunction with the WMH to determine appropriate water conservation measures for a particular system. By considering inputs, outputs, and water quality, ZLD is more likely to be achieved than by focussing on minimising wastewater outputs alone.

1.2. The sodium cyanide production process

Sodium cyanide is used by industries across the globe, primarily in gold extraction, chemical synthesis and metal hardening. It is produced by mixing air, natural gas and ammonia at high temperatures in the presence of a catalyst, resulting in hydrogen cyanide gas. This gas is then mixed with sodium hydroxide, also known as caustic soda, producing sodium cyanide solution. Where solid sodium cyanide is required, excess water is evaporated from this solution and reused or treated prior to disposal. This treatment is generally through the addition of caustic soda to adjust the pH and hydrogen peroxide to destroy chemical contaminants (Rubo et al., 2003). Water is then sent for biological treatment, often in wastewater treatment ponds or wetland systems.

This study investigated the water cycle within a sodium cyanide plant in Western Australia. The plant is relatively new, having been commissioned in 1988, so was not expected to be experiencing any major water losses due to aging infrastructure. Having been built in recent decades, the proposal for the plant itself and each of its subsequent upgrades was subject to intense scrutiny by the Environmental Protection Authority (EPA) and the general public (Environmental Protection Authority, 1987, 1989, 1990a, b, 2001, 2005). During each of these assessments, the EPA highlighted the need for stringent wastewater quality requirements, due to the flow of wastewater to the marine environment (Environmental Protection Authority, 1987, 1989, 1990a, b, 2005). However, only in one instance did the EPA suggest that the volume of such flows could be reduced by recycling or reusing wastewater within the process, and this was not mandated under the license agreement (Environmental Protection Authority, 2001). As such, most of the focus at this site has been on reducing the concentration of contaminants discharged from the plant, with little consideration of the volume of water entering and leaving. The impetus has been heavily placed on compliance with pollution regulation, not on water conservation.

Such a focus has been a common trend in industry until recently, where the emphasis has had to shift to using the WMH to reduce both inputs and outputs of processes, with particular efforts towards reuse and recycling (Byers, 1995). The plant in this study does recycle contaminated water, which reduces overall water inputs and outputs. However, scope may exist to reduce these further, with the ultimate goal of ZLD, and this study aimed to determine the feasibility of this by examining the quantity and quality of flows throughout the plant.

2. Materials and methods

2.1. Audit site

A sodium cyanide plant, part of a larger chemical production facility located in south-west Western Australia, was selected for this study. Sources utilised by the plant during the study period included scheme, rain, bore and demineralised scheme water, as well as water contained within the caustic soda, hydrogen peroxide, sulphuric acid and copper sulphate used in the process. Water used within the plant is sent to onsite wetlands, aerobic treatment units or offsite disposal, lost through evaporation, drift, evapotranspiration or infiltration, or leaves the site in the chemical product.

2.2. Water auditing

The water audit methodology was based upon current industrial best practice (American Water Works Association, 2006; Sturman et al., 2004). A flow diagram of primary water flows across the site was prepared. Diagrams representing the three types of water used in industry; 'process', 'utility' (steam and cooling water) and 'other' (in this case, amenities and emergency response) (Mann and Liu, 1999) were also prepared to identify where flows were directed across the site. A fifth diagram was prepared to investigate flows to the onsite water treatment wetland.

The water audit was conducted using historical data from February 2012 to January 2013. Wherever possible, data from flow meters was analysed, although for several points in the process this was not possible, and flows needed to be estimated using proxy data (for example, rainfall from the nearby weather station) or calculated based upon known relationships (for example, evaporation from the cooling towers). The methods used to determine each flow are detailed in Table 1. All flows were determined on the daily timescale, averaged over a one year period.

Following the collection of flow data, it was determined whether closure could be reached for the site, with closure arbitrarily set at 10% following Sturman et al. (2004).

3. Results

The audit of the primary flows (Fig. 1) indicated a difference between inputs and outputs of 0.7%. This primary audit did not include outputs to offsite disposal as they could not be metered or estimated, although they were anticipated to have accounted for a very small proportion of total water outputs. Evaporation from the cooling towers was the major output from the plant, accounting for 51% of the total.

An investigation of 'process' water flows revealed that all of the water inputs to site contribute to the water used in the sodium cyanide manufacturing process (Fig. 2). However, discussions with site engineers indicated that, in general, scheme, rain and bore water are only included in the process once they become contaminated from contact with process areas (i.e. bunded areas). Instead of treating these streams to improve water quality, it is assumed they contain low concentrations of cyanide, and they are thus included in the process as make-up water.