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Research article

Wastewater reuse in a cascade based system of a petrochemical industry for the replacement of losses in cooling towers

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ABSTRACT

This article discusses the mapping of opportunities for the water reuse in a cascade based system in a petrochemical industry in southern Brazil. This industrial sector has a large demand for water for its operation. In the studied industry, for example, approximately 24 million cubic meters of water were collected directly from the source in 2014. The objective of this study was to evaluate the implementation of the reuse of water in cascade in a petrochemical industry, focusing on the reuse of aqueous streams to replenish losses in the cooling towers. This is an industrial scale case study with real data collected during the years 2014 and 2015. Water reuse was performed using heuristic approach based on the exploitation of knowledge acquired during the search process. The methodology of work consisted of the construction of a process map identifying the stages of production and water consumption, as well as the characterization of the aqueous streams involved in the process. For the application of the industrial water reuse as cooling water, mass balances were carried out considering the maximum concentration levels of turbidity, pH, conductivity, alkalinity, calcium hardness, chlorides, sulfates, silica, chemical oxygen demand and suspended solids as parameters turbidity, pH, conductivity, alkalinity, calcium hardness, chlorides, sulfates, silica, chemical oxygen demand and suspended solids as parameters. The adopted guideline was the fulfillment of the water quality criteria for each application in the industrial process. The study showed the feasibility for the reuse of internal streams as makeup water in cooling towers, and the implementation of the reuse presented in this paper totaled savings of 385,440 m^3/year of water, which means a sufficient volume to supply 6350 inhabitants for a period of one year, considering the average water consumption per capita in Brazil; in addition to 201,480 m^3/year of wastewater that would no longer be generated.

1. Introduction

The shortage of water is an increasing concern throughout the world. According to UNICEF (The United Nations Children's Fund), one billion two hundred million people lack access to clean water, and one billion eight hundred million people do not count with adequate sanitation services (Sistema, 2014; CETESB, 2014). In Brazil, water shortages in metropolitan and industrial areas has occurred due to the degradation of rivers by various sources of pollution and rising demand for many activities, such as supply for the population, industry and agriculture (Matsumura and Mierzwa, 2008). Faced with these shortage problems, there is a need to develop strategies to improve the management of water use in its different applications (Gutterres et al., 2010).

In the chemical and petrochemical industries, water is a key resource for the operation of the production process. Distillation, liquid-liquid extraction, washing operations, and cooling systems are some of the various processes in these industries where water is used intensively. Petroleum production and processing units, for example, use about six barrels of water per barrel of oil processed (Bagajewicz, 2000; Tom, 2005).

Cooling towers are among the biggest consumers of water in industrial processes due to the use of large volumes of fresh water as makeup water in the system, which owes to losses through evaporation, splashing and purges (Wang et al., 2014a, 2014b) Some authors have studied alternatives to reduce water consumption in cooling towers. Altman et al. (2012) used reverse osmosis for the treatment of a recirculating stream of a cooling tower, achieving a 16% reduction in water replacement and 49% in effluent purge (Altman et al., 2012). Limpt and Wal (2014) treated the make up

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stream and achieved savings of up to 85% of chemical inputs, 28% of make up water and 48% of discharged effluent (van Limpt and van der Wal, 2014). Chien et al. (2012) evaluated the use of treated municipal wastewater for losses reposition in cooling towers (Chien et al., 2012) and Santos et al. (2015) used industrial treated wastewater to replenish losses in the cooling tower of a refinery in Brazil (Santos et al., 2015). Durante et al. (2015) also used conventional treated effluent as make up water in a cooling tower in an agribusiness industry (Durante et al., 2015). The shortage scenario and the studies presented above show that the adoption of water reuse is an important and strategic step for achieving sustainable development, particularly in the viewpoint of the possible environmental, economic, and social benefits that can be achieved (cost reduction, increased productivity, minimizing environmental impacts of uncontrolled use of water, etc.) (Gutterres et al., 2010; Cleary et al., 2014).

In this context, this study aims to carry out a mapping of water reuse opportunities in the cooling towers of a petrochemical industry, which could save large volumes of water withdrawn directly from the water sources. This is an industrial scale case study and the relevance of the work is distinguished by the application of a heuristic approach based on the exploitation of knowledge acquired during the search process and by real data obtained from field research. Results of water consume and characterization of water streams in a petrochemical process obtained in this work are relevant for future studies on this area, once real data from industrial activities are usually not available.

2. Methodology

The methodology of this study consists of a survey to check the water consumption in the various processes of the assessed industry, followed by the characterization of the aqueous streams of interest and application of mass balances to evaluate the use of the effluents as makeup water sources in cooling towers.

A process map was designed for the survey of water consumption in industrial processes, identifying the stages of production and water consumption. From this map a survey was carried out to check all existing flow meters through a data management software (Aspen Process Explorer version 8.4, 2013). Having identified the meters of interest, the average flow rates of 2014 have been compiled.

A characterization of aqueous streams was carried out in 2014. The evaluated parameters were: turbidity, pH, conductivity, alkalinity, calcium hardness, chlorides, sulfates, silica, chemical oxygen demand and suspended solids. Mass balances were used to calculate the maximum flow rates of reuse water in each case, always considering the quality required for each application of water in the manufacturing process according to the parameters set by the industry under study.

To calculate the possible reuse of water flow in cooling towers the following mass balance equations were used:

Global mass balance

$$A = P + E + R \quad (1)$$

Where:

A – makeup water for compensation of losses of the system (t/h);
P – purge to limit the salt concentration in the water due to its evaporation (t/h);
E – water evaporation, used to promote the lowering of the cooling water temperature (t/h);
S – splash-outs resulting from steam and air (t/h).

Mass balance by component

$$A*WC = P*PC + E*EC + R*SC \quad (2)$$

Where:

WC – Makeup water concentration parameter (mg/L);
PC – Purge water concentration parameter (mg/L);
EC – Evaporation water concentration parameter (mg/L), considered equal to zero;
SC – Splash-out water concentration parameter (mg/L).

Mass balance by component (Equation (2)) considered all the evaluated parameters (turbidity, conductivity, alkalinity, calcium hardness, chlorides, sulfates, silica, chemical oxygen demand and suspended solids). The most restrictive parameter had been used to define the water reuse flow that fulfilled the water quality criteria for each application.

2.1. Calculating the maximum water flow for reuse in cooling towers

The maximum flow rate for reuse in the cooling towers of the industry was obtained by equaling the concentration of cooling water (purging and splashing out) to the maximum concentration levels of each parameter. By bringing the tower to the maximum concentration levels, it is possible to obtain the maximum concentration of the makeup water. Considering also that the solutes are not leaving the system during the evaporation, the mass balance results in Equation (3).

$$A*CAmax = P*Clim + R*Clim \quad (3)$$

Where:

CAmax – Makeup water maximum concentration parameter (mg/L);
Clim – Maximum concentration level for the operation of the cooling tower (mg/L).

Equation (4) is obtained by highlighting the maximum concentration term in the makeup water.

$$C_{Amáx} = \frac{(P + R)*C_{lim}}{A} \quad (4)$$

In order to obtain the makeup water flow, the equation which is used is the one that represents the mixture of the clarified water streams (usually used as makeup water of the cooling towers) and the reuse water equation (Equation (5)).

$$A*C_{Amáx} = AC*C_{AC} + RW*C_{RW} \quad (5)$$

Where:

RW – reuse water used as makeup water (t/h);
CRW – Reuse water concentration parameter (mg/L).

Highlighting the water flow term for reuse, the maximum water flow possible for reuse in the cooling tower is obtained (Equation (6)).

$$RW = \frac{A*(C_{Amáx} - C_{AC})}{(C_{RW} - C_{AC})} \quad (6)$$

The following conditions must be applied to the equations in order to interpret the results: