Science of the Total Environment 466–467 (2014) 377–386

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Life cycle and human health risk assessments as tools for decision making in the design and implementation of nanofiltration in drinking water treatment plants

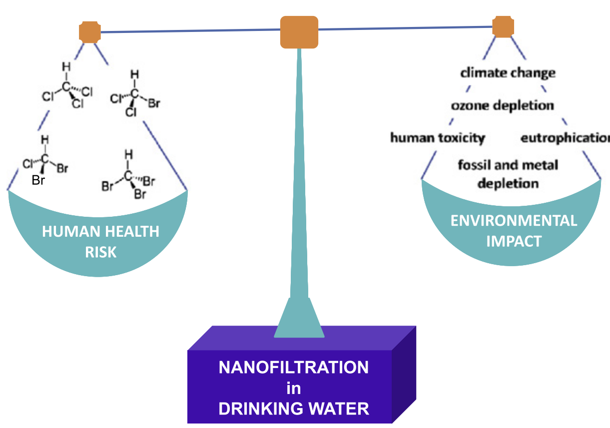
G. Ribera [a,*], F. Clarens [a], X. Martínez-Lladó [a], I. Jubany [a], V. Martí [a,b], M. Rovira [a]

[a] *Fundació CTM Centre Tecnològic, Av. Bases de Manresa, 1, 08242 Manresa, Spain*
[b] *Department of Chemical Engineering, Polytechnic University of Catalonia (UPC), Av. Diagonal 647, 08028 Barcelona, Spain*

HIGHLIGHTS

- An upgrade of a drinking water plant was evaluated by LCA and HHR.
- Several NF scenarios were studied with regards to production capacity and membranes.
- Improvement of drinking water quality increases environmental impact, reducing HHR
- A methodology involving multicriteria aspects was proposed.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 5 February 2013
Received in revised form 21 June 2013
Accepted 21 June 2013
Available online 3 August 2013

Editor: Damia Barcelo

Keywords:
Drinking water
Trihalomethanes
Nanofiltration
Environmental impacts
Carcinogenic risk

ABSTRACT

A combined methodology using life cycle assessment (LCA) and human health risk assessment (HHR) is proposed in order to select the percentage of water in drinking water treatment plants (DWTP) that should be nanofiltered (NF). The methodological approach presented here takes into account environmental and social benefit criteria evaluating the implementation of new processes into conventional ones. The inclusion of NF process improves drinking water quality, reduces HHR but, in turn, increases environmental impacts as a result of energy and material demand. Results from this study lead to balance the increase of the impact in various environmental categories with the reduction in human health risk as a consequence of the respective drinking water production and consumption. From an environmental point of view, the inclusion of NF and recommended pretreatments to produce 43% of the final drinking water means that the environmental impact is nearly doubled in comparison with conventional plant in impact categories severely related with electricity production, like climate change. On the other hand, the carcinogenic risk (HHR) associated to trihalomethane formation potential (THMFP) decreases with the increase in NF percentage use. Results show a reduction of one order of magnitude for the carcinogenic risk index when 100% of drinking water is produced by NF.

* Corresponding author. Tel.: +34 938777373; fax: +34 938777374.
E-mail addresses: gemma.ribera@ctm.com.es (G. Ribera), xavier.martinez@ctm.com.es (X. Martínez-Lladó), miquel.rovira@ctm.com.es (M. Rovira).

0048-9697/$ – see front matter
http://dx.doi.org/10.1016/j.scitotenv.2013.06.085

1. Introduction

Drinking water treatments (DWT) consist of different process steps to supply safe water to the population. The complexity of the process depends on the raw water quality at the intake and on the legislation for each country (75/440/CEE). The risk over human health due to pathogenic microorganisms is reduced by including disinfection techniques in DWT (e.g.: chlorination, ozonation, ultraviolet radiation). Nevertheless, disinfectant agents may react with natural organic matter (NOM) generating harmful disinfection by-products (DBP). Trihalomethanes (THM) are the main group of DBP in chlorinated waters and have been extensively studied as a result of their toxicity (Wang et al., 2007). The four THM are chloroform (TCM), bromodichloromethane (BDCM), dibromochloromethane (DBCM) and bromoform (TBM) and European legislation establishes their maxim concentration in potable water at 100 $\mu g \cdot L^{-1}$, expressed as the total sum of THM (98/83/EC; RD140/2003).

Implementation of new technologies in drinking water treatments plants (DWTP), as nanofiltration (NF), improves quality of potable water (Radjenovic et al., 2008; Verliefde, 2008; Van der Bruggen and Vandecasteele, 2003) and reduces human health risk (HHR) associated to its consumption. Financial, technical and public health aspects are the main factors affecting the selection of one or another technology, although, over the last few years environmental impact has started to play an important role for decision makers. The selection among different water treatment processes based on various criteria is a good practice, especially for water treatment and reuse where social acceptance plays an important role (Chen et al., 2012).

Life cycle assessment (LCA) methodology is able to relate input and output data from a product or process to different environmental concerns, known as impact categories (such as climate change, ozone depletion, eutrophication). LCA has been applied in the last decade to compare the environmental impact among different drinking water treatments (Vince et al., 2008; Friedrich, 2002). These studies provide useful information (system boundaries, specific methodology, inventory data) in order to select the most environmental friendly technology for drinking water production, for example: activated carbon in front of nanofiltration (Sombekke et al., 1997), ultrafiltration (Friedrich, 2002) or reverse osmosis (Mohapatra et al., 2002). Other examples are the comparison between membranes or distillation processes for seawater desalination (Godskesen et al., 2011) or river transfer versus membrane desalination (Raluy et al., 2005). However, results from different studies are difficult to compare due to inherent limitations of LCA methodology: differences in regional location (Comandaru et al., 2012, Bonton et al., 2012; Stokes and Horvath, 2009), lack of agreement for the calculation method (Godskesen et al., 2011; Mohapatra et al., 2002), differences in final water quality (Barrios et al., 2008; Tapia et al., 2008) or different scope and objectives. Currently, LCA studies in water sector are focused on the global urban water cycle, where different stages are evaluated: water abstraction and treatment, distribution, wastewater collection and treatment (Amores et al., 2013).

On the other hand, HHR assessment quantifies the risk for the human health related to the exposure to a chemical toxic, in this case THM present in drinking water. Although, traditionally, most studies only consider ingestion exposure, since 1990 inhalation and dermal absorption are also taken into account (Pardakhti et al., 2011; Lee et al., 2004). Different type of chemicals implies different distribution between exposure phases. As a consequence, the most important exposure pathway varies from one to another compound. In case of THM this is the inhalation pathway (Gan et al., 2013; Basu et al., 2011). The novelty of this paper is to evaluate the relationship between the environmental impact derived from the implementation of NF in a DWTP and the resulting benefit for the human health derived from the decrease in the THM concentration in the drinking water.

The present study aims to evaluate and address the cost/benefit for the environmental impact and the human health when drinking water quality is improved using NF. LCA methodology has been applied for different scenario analysis which will cover different percentages of NF production capacity (25, 43, 50, 75 and 100%) and two different membranes. LCA results are related to those obtained using HHR methodology associated to different drinking water qualities as a function of THM formation potential (THMFP), determined previously in pilot plant tests (Ribera et al, 2013).

2. Description of the drinking water treatment process

This work is focused on the drinking water treatment plant of Manresa (NE, Spain). The production capacity for the current scheme is 23,000 $m^3 \cdot day^{-1}$ and the process consists of a predisinfection step using chlorine gas, a coagulation process using polyaluminum chloride (PAC) followed by sand filtration and, finally, a chlorination step also using chlorine gas. The main goal of prechlorination in this initial step is to decrease the risk of possible algae and microorganism growth in following treatment steps. Finally potable water is distributed to a total population of approximately 130,000 inhabitants.

The present study aims to evaluate the environmental impact and the decrease in the human health risk derived from the implementation of a NF step in the mentioned DWTP. The main objective of implementing a NF stage in the current process is to increase the water quality and to decrease the THM concentration, which, despite the plant complies with current legislation, is still very high. A previous pilot study assessed the impact of several membranes and blending percentages into the final water quality in Manresa DWTP (Ribera et al., 2013).

This NF step would treat part of the sand-filtered water with UF tubular membranes (as necessary NF pretreatment) and NF spiral wound membranes. UF membranes would reduce colloidal and particulate matter (measured as silt density index, SDI) in order to meet the required quality for NF membranes. Furthermore, sodium metabisulphite and scale inhibitor would be added to remove free chlorine (harmful for NF membrane polymers) and reduce inorganic precipitations (in concentrate stream), respectively.

Finally, NF permeate water would be blended with conventional pretreated water from sand filters in order to produce the same volume of drinking water with improved quality for the population.

3. Materials and methods

3.1. Environmental impact

The environmental impact is evaluated following the LCA methodology defined in standardized guidelines under International Organization for Standardization (ISO 14040 and ISO 14044). LCA procedure involves four stages: goal and scope definition, life cycle inventory, impact assessment and, finally, the interpretation of the LCA results. LCA study is implemented using software Simapro v7.3.3.

Environmental impacts for several categories are calculated using the Recipe Midpoint (H) (v.1.06) characterization method (PRéConsultants, 2011) as implemented in Simapro v7.3.3. Results are evaluated for the most relevant impact categories (Table 1) in water processes (Hospido et al., 2008; Lundie et al., 2004).

Firstly, the environmental impact of two main systems is evaluated: the current conventional process and the same treatment including a NF step with a production capacity of 10,000 $m^3 \cdot day^{-1}$ (representing 43% of final drinking water produced by the treatment plant). This capacity is selected from previous results (Ribera et al., 2013) in order to accomplish with legislated levels for the sum of THM, estimated as THMFP, when drastic conditions are occurring (harsh disinfection, dry and warm periods). The system including the NF step has been divided into two sub-scenarios using two different membranes: one including NF270 and another one ESNA1LF2.