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Evaluating the impact of ambient benzene vapor concentrations on product water from Condensation Water From Air technology

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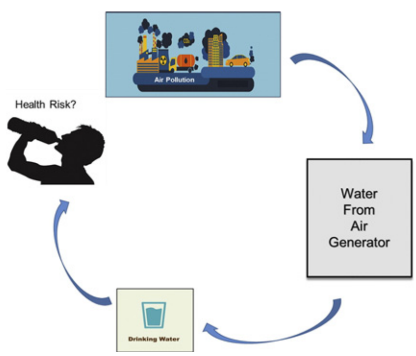
HIGHLIGHTS

- Potential for air contaminants to enter drinking water and impact human health
- Environmental chamber tests compared benzene concentrations in air and product water
- Temperature and air quality influence the product water quality of CWFA technology
- Poor air quality may result in product water not meeting drinking water standards.

GRAPHICAL ABSTRACT



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ABSTRACT

Globally, drinking water resources are diminishing in both quantity and quality. This situation has renewed interest in Condensation Water From Air (CWFA) technology, which utilizes water vapor in the air to produce water for both potable and non-potable purposes. However, there are currently insufficient data available to determine the relationship between air contaminants and the rate at which they are transferred from the air into CWFA untreated product water. This study implemented a novel experimental method utilizing an environmental test chamber to evaluate how air quality and temperature affects CWFA untreated product water quality in order to collect data that will inform the type of water treatment required to protect human health. This study found that temperature and benzene air concentration affected the untreated product water from a CWFA system. Benzene vapor concentrations representing a polluted outdoor environment resulted in benzene product water concentrations between 15% and 23% of the USEPA drinking water limit of 5 μg/l. In contrast, product water benzene concentrations representing an indoor industrial environment were between 1.4 and 2.4 times higher than the drinking water limit. Lower condenser coil temperatures were correlated with an increased concentration of benzene in the product water. Environmental health professionals and engineers can integrate the results of this assessment to predict benzene concentrations in the product water and take appropriate health protective measures.

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1. Introduction

Globally, drinking water resources are diminishing in both quantity and quality. Growing concerns about water scarcity and drinking water shortages have renewed interest in alternate methods of obtaining water, which includes Water From Air (WFA) technology. Currently, this technology generates water from atmospheric moisture in military, commercial, industrial, and residential applications. For example, the United States Army is interested in developing WFA technology to improve logistical efficiencies that reduce reliance on intermediate staging bases and sustainment logistics in remote, austere environments. The ideal WFA technology would improve the Army's ability to conduct military operations by bringing water production and purification closer to the point of need and thereby improve unit self-sufficiency (Army Capabilities Integration Center, 2014). Past studies have investigated the efficiency of CWFA systems (Peters et al., 2013; Walhgren, 2001). Current CWFA systems have a high-energy requirement that make the technology attractive only in situations in which water is expensive to procure or not readily available due to source or infrastructure limitations. However, given growing global concerns about water scarcity and drinking water shortages, interest in this technology has grown and improvements to energy efficiency for WFA technology is being sought by industry. Between 2015 and 2022, the global WFA market is expected to grow 37.4%, with drinking water programs in Japan and India investigating policies for this use of this technology (GlobeNewsWire, 2016). In the United States, the Monterey Peninsula Water Management District Board of Directors recently approved the use of WFA technology as the sole water source option for businesses or secondary buildings (Whittaker, 2014). WFA technology is receiving greater interest and its increased efficiency is making it a more practicable option for water production. Therefore, it is important to determine how airborne contaminants impact the product water quality of WFA technology in order to select the most appropriate water treatment technologies that maximize technology efficiencies while protecting health.

Potential applications of WFA technology include worldwide use in outdoor and indoor environments. Of the outdoor environments, megacities may be the most significant. Megacities are dense urban environments comprised of populations >10 million. By 2030 60% of the world's population is projected to live in urban environments that may be congested and highly polluted (Department of the Army, 2014). Since megacities are mostly emerging in low-income countries in which drinking water resources may be inadequate, WFA technology may become an appealing possibility to local governments and nongovernment organizations for residential and commercial applications (Chittaranjan-Tembhekar, 2013). WFA technology applications in indoor settings are also important because industrial processes such as automotive repair and painting operations can create air quality that has the potential to be extremely poor. Currently, there are limited regulatory or manufacturer specific guidelines or special considerations for the prolonged operation and maintenance of the WFA water treatment systems in either indoor or outdoor settings. Thus, it is important to characterize the quality of drinking water produced from WFA technology when used in highly polluted environments.

The WFA systems extract water from the air for both potable and non-potable purposes. The WFA technology concept is not new, with feasibility experiments dating back >45 years (Hellström, 1969). The two most common types of these systems utilize either condensation or desiccant technology. Condensation Water From Air (CWFA) systems operate by condensing water vapor on an evaporator coil to form liquid droplets. CWFA systems accomplish the phase change from a vapor to liquid by cooling air to the saturation temperature. Often the saturation temperature is lower than the ambient air temperature and depends on the amount of humidity in the atmosphere. The compressor, condenser, evaporator, and a liquid medium in the CWFA systems are the primary components essential to the vapor compression cycle and process airflow that drive the cooling process for the CWFA system, which is very similar to an in-home dehumidifier. It is important to note that not all condensation systems are the same. Condensation systems vary in design for improvements in energy efficiency, coil design, fan speed, and water treatment. Nevertheless, the core process is very similar in most condensation technologies.

In the United States, CWFA system product water intended for drinking water purposes is not required to meet the EPA drinking water standards (USEPA, 2009). As a drinking water source, there is a necessity to determine how product water quality from CWFA systems compares to EPA drinking water standards to characterize health risk. However, there are currently insufficient data available to determine the rate of transfer between air contaminants and CWFA product water. Also absent is a method to predict the transfer of air contaminants into the product water under specified environmental conditions (air temperature, humidity and contaminant concentrations). Although most WFA systems incorporate treatment modules to remove water contaminants, there is uncertainty regarding the appropriate level and maintenance interval of water treatment modules required to minimize the health risk of ingesting product water from CWFA systems given such a wide array of potential environments with different and fluctuating air quality compositions. Walhgren's (2001) review on WFA technology indicated that water produced from the atmosphere may not be safe to drink without treatment. Gandhidasan and Abualhamayel (2010) specified that in polluted urban and industrial environments, water quality of desiccant WFA systems may be compromised and should be monitored. Although neither the aforementioned articles indicated the type of contaminants that may be a health concern, volatile organic compounds (VOC), such as benzene, are common contaminants in those environments.

Benzene (C_6H_6) is a colorless aromatic liquid at room temperature, but evaporates quickly into the atmosphere and is present at low levels in the ambient air around the world (ATSDR, 2007). According to the ATSDR (2007), the most significant health effect of benzene is that it is a carcinogen with chronic exposures having the greatest effect on the immune and hematopoietic system due to benzene metabolite effects on the bone marrow. While no human studies have investigated the potential for carcinogenicity due to benzene ingestion, several animal studies have found evidence of benzene acting as a multiple site carcinogen (Huff et al., 1989; Maltoni et al., 1983). Benzene's physical characteristics, likelihood of presence in both indoor industrial and outdoor urban environments, and potential adverse health effects made it the optimal VOC contaminant of concern for this study.

Previous studies have tested the water quality of WFA systems (Bautista-Olivas et al., 2014; Gandhidasan and Abualhamayel, 2010; U.S. Army Institute of Public Health (USAIPH), 2011; Walhgren, 2001). However, no studies have quantified the relationship of temperature with air quality data and its impact on WFA product water quality. Thus, airborne benzene in polluted environments may be a significant concern since it is expected to transfer from the air to the product water of CWFA systems. Accordingly, there is a need for research to determine the best method to predict the transfer of VOCs in the air to CWFA system product water. Henry's Law provides a simple, but potentially useful, method to predict the concentration of water contaminants using only the partial pressure of the gas and the Henry's Law constant (K_H), which is contaminant and temperature dependent (Supplementary materials). Air temperature is the easiest to measure in field settings; however, CWFA coil temperature may be a better predictor of benzene concentrations in product water. Saturation temperature can be used as a predictor for CWFA system coil temperature by means of both relative humidity (RH) and air temperature.

A literature search of global ambient benzene concentrations in outdoor urban as well as indoor industrial environments resulted in the selection of appropriate benzene vapor concentrations to be used in experimental testing. The literature indicated that outdoor urban and indoor industrial concentrations of benzene vary significantly across