Desalination 263 (2010) 271–278

Contents lists available at ScienceDirect

Desalination

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

Pilot study of drinking water treatment with GAC, O_3/BAC and membrane processes in Kinmen Island, Taiwan

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ARTICLE INFO

Article history:
Received 25 February 2010
Received in revised form 11 June 2010
Accepted 29 June 2010
Available online 7 August 2010

Keywords:
2-MIB
Biological activated carbon
Nanofiltration
THMFP

ABSTRACT

A study on advanced treatment of drinking water was conducted in a pilot scale plant in Tai Lake, Kinmen, Taiwan. The raw water contains a high concentration of disinfection by-product (DBP) precursors and causes serious odor problems. Chlorination of the raw water produced higher haloacetic acid formation potential (HAAFP) than trihalomethane formation potential (THMFP). Therefore, the high concentration of NOMs, which is the major source of DBP precursors, and the removal efficiencies of non-purgeable dissolved organic carbon (NPDOC), UV_{254}, THMFP, HAAFP, 2-methylisoborneol (2-MIB), and trans-1, 10-dimethyl-trans-9-decalol (geosmin) were evaluated for both conventional and advanced water treatment processes. 2-MIB and geosmin can be removed efficiently by the GAC and O_3/BAC process, but bromo-THMs cannot. In addition, the removal efficiency of HAAFP was higher than that of THMFP by the GAC or O_3/BAC process. The ultrafiltration (UF)-nanofiltration (NF) combined process showed removal efficiencies for NPDOC, UV_{254}, THMFP, HAAFP of 88.7%, 94%, 84.3% and 97.5%, respectively. This study found that the GAC or O_3/BAC process is a promising way to treat odor problems, and the UF–NF membrane process was one of the best available ways to remove NOMs and DBP formation potential.

1. Introduction

The main sources of drinking water in Kinmen Island are both ground and surface waters, which contribute 49% of the water supply in the west and 51% in the east of the island, respectively. In Kinmen Island, the surface waters are polluted by agricultural activities, domestic wastewater discharges and livestock effluents, which result in eutrophication and cause blooming of algae in the reservoirs. Organic matters in natural water can cause odor, taste, color, and bacterial regrowth problems. Chlorine disinfection is a widely used process for eliminating pathogenic microorganisms in drinking water and preventing water-born diseases. NOMs in raw water react with chlorine to form disinfection by-products (DBPs), which is potentially carcinogenic or mutagenic to animals in laboratory test [1].

The drinking water in Kinmen Island suffers from problems of toxins, metabolite of algae, taste and odor (2-MIB and geosmin), trihalomethanes (THMs) and haloacetic acids (HAAs), which are difficult to remove by conventional treatment processes. In the meantime, the seawater intrusion causes a rising bromide concentration in the groundwater and surface waters. Chlorination of the water with bromide will shift the chlorinated DBPs to brominated DBPs, which increases the total DBPs yield and more easily exceeds the drinking water standard [2]. In order to reduce the production of DBPs, it is better to remove the dissolved organic precursors in the raw water before disinfection. However, the conventional water treatment processes cannot remove the DBPs precursors or the metabolite of algae effectively. The concentration of THMs in drinking water sometimes exceeded 0.1 mg/L in some places in Kinmen Island. Wang et al. [3] indicated that people living in Kinmen Island were threatened with a higher carcinogenic risk of THMs compared with other districts of Taiwan (7.77×10^{-5} and 7.88×10^{-5} for male and female, respectively). The water treatment in Kinmen Island is getting more and more stringent and upgrading the conventional to advanced water treatment process is urgent in the near future.

The available technologies recommended for the control of DBPs are NOMs removal or applying suitable disinfectants [4,5]. Enhanced coagulation, granular activated carbon (GAC), ozonation followed by biological activated carbon (O_3/BAC), and membrane treatment processes are available to remove NOMs [6–8]. The GAC process can remove organic matters such as dissolved organic carbon (DOC),

Abbreviations: AOC, assimilable organic carbon; BAC, biological granular activated carbon; DBAA, dibromoacetic acid; DBP, disinfection by-product; DCAA, dichloroacetic acid; EBCT, empty bed contact time; EDC, endocrine disrupting compounds; GAC, granular activated carbon; HAA, haloacetic acid; HAAFP, haloacetic acid formation potential; MBAA, monobromoacetic acid; MCAA, monochloroacetic acid; MWCO, molecular weight cutoff; NF, nanofiltration; NOM, natural organic matter; NPDOC, non-purgeable dissolved organic carbon; SUVA, specific ultraviolet absorbance; TCAA, trichloroacetic acid; THM, trihalomethane; THMFP, trihalomethane formation potential; UF, ultrafiltration.

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doi:10.1016/j.desal.2010.06.069

DBPs, 2-MIB, geosmin, and pesticides. Ozonation can shift a higher molecular weight compound into smaller ones. In this way, the aromatic or hydrophobic organic compounds can be converted to more hydrophilic, biodegradable organic compounds, such as aldehydes, carboxylic acids, ketones and other organic acids [9,10], which can also be further removed in a subsequent biological activated carbon (BAC) process [7,11,12]. Many studies found that NF membranes were effective in removing assimilable organic carbon (AOC), THMs, HAAs, microcystin and endocrine disrupting compounds (EDCs) [13–16]. The UF–NF combined membrane process had better removal efficiency of NOMs compared with other treatment processes, and is found to be the best available way to remove NOMs [13,17]. The main objectives of this paper are to evaluate the removal efficiency of organic matter, THMFP, HAAFP, 2-MIB, geosmin in each treatment unit, and the performance of three advanced treatment processes.

2. Materials and methods

2.1. Pilot plant

The pilot plant for this study was built at the Tai Lake water works in Kinmen Island using the source water from Tai Lake and Ron Lake with a mixing ratio of 1:1. The pilot scale plant conventional treatment process was composed of coagulation, flocculation, dissolved air flotation, sedimentation, and rapid sand filtration. The treatment was divided into three treatment processes, A, B and C. Process A was conventional treatment followed by O_3/BAC, Process B was Process A followed by UF–NF, and Process C was conventional treatment followed by GAC and UF–NF. Fig. 1 shows the schematic process of the pilot scale plant. The ozone contactor was 2.5 m in height and 0.3 m in inner diameter (ID), which was made of stainless steel. Ozone was produced by an ozone generator, using air as the feed gas. Ozone gas was bubbled into the contactor continuously and used counter flow to increase ozone concentration. The GAC column (height 3 m, ID 0.4 m) was filled with 1.5 m of GAC and 0.3 m silica sand. Filtration velocity was 159 m/day and empty bed contact time (EBCT) was 27.1 min. The BAC column (height 3 m, ID 0.48 m) was filled with 1.33 m of GAC and 0.3 m of silica sand. The filtration velocity was 111 m/day and EBCT was 39.1 min. Both GAC and BAC columns were filled with GAC (Pt. Tanso Putra Asia, Indonesia). The type of UF membrane used was PES-UF made by Koch Membrane Systems (USA). The length and diameter of the module were 1016 mm and 101.6 mm, respectively. The effective surface area of the UF module was 7.5 m^2 and the molecular weight cutoff (MWCO) of the membrane was 10,000. The NF membrane was made of polyamide (Hydranautics, USA). The length and diameter of the module were 1016 and 100.3 mm, respectively. The NF module nominal membrane area was 7.87 m^2. Table 1 shows the operating parameters of each unit in the pilot plant.

The capacity of the pilot plant was about 30 m^3/day. Aluminum sulfate was used as a coagulant with feed concentration about 80–100 mg/L depending on the result of the jar test. Backwashing of both rapid sand filtration and the GAC column were practiced twice a day. UF and NF membranes were cleaned on site every 3 months, or when the operating pressure exceeded the designed value (UF>150 psi and NF>600 psi).

2.2. Analytical methods

Water samples were taken weekly from each of the sample sites from April to September, 2006, and transferred directly to the laboratory. NPDOC, UV_{254}, THMFP, HAAFP were analyzed weekly, and 2-MIB and geosmin were analyzed once per month.

The dissolved organic matter content of the water was quantified by NPDOC, which was measured by the combustion-infrared method using a total organic carbon analyzer (TOC-5000, Shimadzu, Japan). UV_{254} was used to obtain a representation of the aromatic characteristic of the organic matter. It was measured at a wavelength of 254 nm (U-1100, Hitachi, Japan).

THMFP was measured by the purge and trap packed-column gas chromatographic method using a GC (3400, Varian, USA) equipped with an electron capture detector (ECD). An adequate amount of sodium hypochlorite (NaOCl) was injected into the sample to ensure that at least 1 mg/L free chlorine residual existed at the end of the 7-

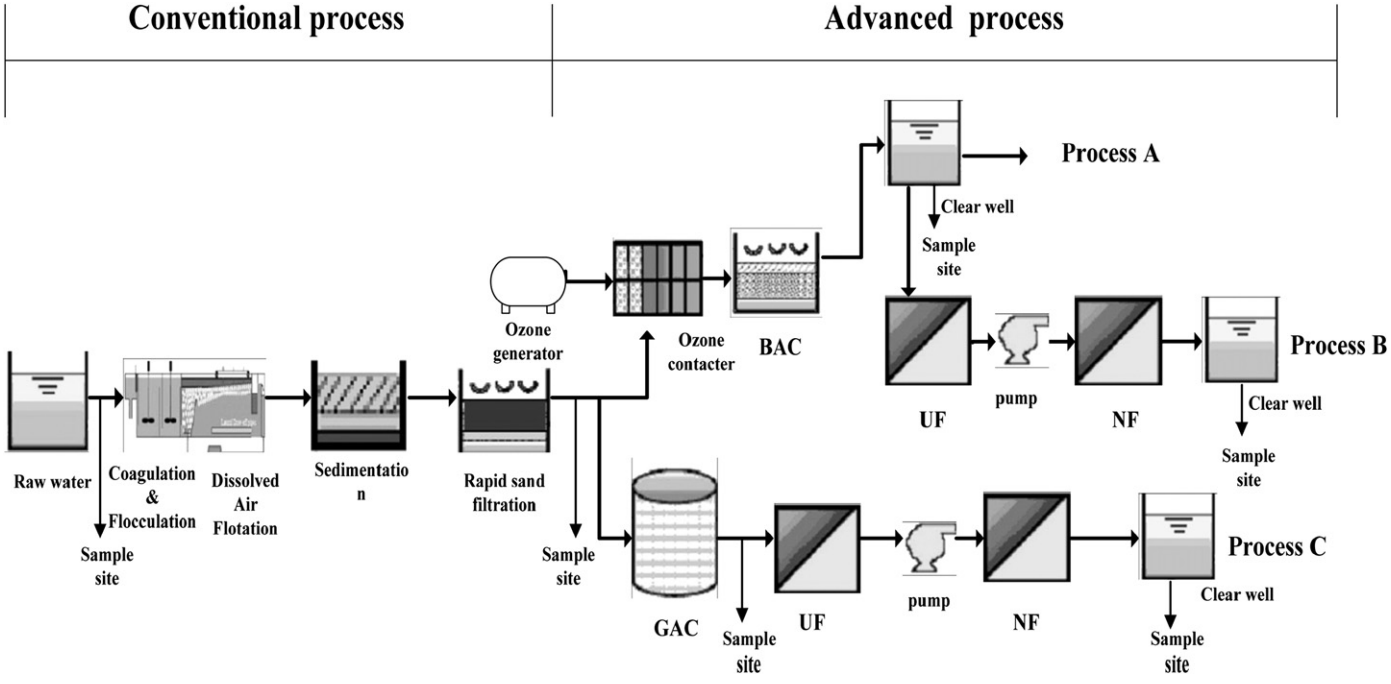

Fig. 1. Schematic diagram of the pilot plant.