Journal of the Taiwan Institute of Chemical Engineers 46 (2015) 132–139

Contents lists available at ScienceDirect

Journal of the Taiwan Institute of Chemical Engineers

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

Practical performance analysis of an industrial-scale ultrafiltration membrane water treatment plant

Chun Ming Chew [a], M.K. Aroua [a,*], M.A. Hussain [a], W.M.Z. Wan Ismail [b]

[a] Department of Chemical Engineering, Faculty of Engineering, University of Malaya, 50603 Kuala Lumpur, Malaysia
[b] Air Kelantan Sdn. Bhd., Bangunan PMBK, Jalan Kuala Krai, 15050 Kota Bahru, Kelantan, Malaysia

ARTICLE INFO

Article history:
Received 30 April 2014
Received in revised form 14 August 2014
Accepted 14 September 2014
Available online 7 October 2014

Keywords:
Ultrafiltration
Water treatment
Design
Operation

ABSTRACT

Common design and operational issues to evaluate the performance of an ultrafiltration (UF) membrane water treatment plant are highlighted with a case study on an industrial-scale drinking water treatment plant located in Malaysia. This treatment plant has been in operation since February 2013 using dead-end polyethersulfone UF membrane filtration system to produce up to 14 million litres a day of drinking water to a small township. Literature solutions are compared with the practised solutions and elucidated with the case study. Gaps between literature solutions which are mainly based on lab-scale research and industry practices are identified. Reducing this gap will have vast implication to improve the design and operation of industrial-scale UF treatment system.

1. Introduction

The demand for high purity drinking water and the descending cost of the membrane raw material has made membrane filtration very feasible for industrial-scale drinking water production. Ultrafiltration (UF) is able to segregate bacteria and viruses from the filtrate to ensure safe drinking water for human consumption [1]. Many countries are adopting membrane technology for drinking water production in large-scale replacing sand filters. The main drawback of using UF membrane compared to sand filtration is the irreversible fouling of the membrane [2].

Ultrafiltration membranes are commonly made from organic (polymers) material such as polyethersulfone or inorganic substances such as ceramics [3]. Polyethersulfone membranes are commonly used because of its good mechanical, chemical and thermal stability [4]. Hollow fibre UF membranes are suitable for drinking water production due to its minimal space requirements. These types of membrane are usually operated in cross-flow or dead-end mode.

Membrane fouling remains the major obstacle for large-scale applications [2]. Arkhangelsky et al. [5] have conducted laboratory-scale experiments to determine the fouling mechanism of a dead-end UF membrane system. In their study, polyethersulfone hollow fibre UF membrane was divided into multiple segments for permeate flux analysis along the membrane capillary. Dead-end filtration is more preferable in UF water treatment plants due to its lower energy consumption per unit of filtrate produced compared to cross-flow filtration. A cost model for drinking water production linking membrane characteristics of permeability, strength and fouling propensity of membrane has been proposed by Pearce [6]. Dead-end membrane filtration has one major drawback which is the high velocity of particle or colloidal deposit at the membrane surface [7]. This drawback has been compensated with its advantage on saving in circulation energy compared to cross-flow filtration in drinking water production. Massé et al. [8] have concluded in their studies that for TMP ranging from 0.2 to 0.8 bar, specific energy consumption for UF in cross-flow mode is always higher than in dead-end mode.

In order to harness the advantages of the ultrafiltration separation process, efficient fouling control is of paramount importance [9]. Stoquart et al. [10] highlighted that hybrid membrane process using activated carbon helps to resolve most of the membrane fouling issues. Nevertheless this hybrid process incurred lots of challenges such as membrane abrasion and other membrane fouling issues that require further research to address. Xiao et al. [11] conducted experiments with advance laboratory analysis equipment and results indicate that cake layer and pores blockage are the main reasons for filtration flux decline. Studies carried out by Sassi and Mujtaba [12] on membrane system have linked input parameters with membrane modules used. The variation of feed water input parameters would incur production cost implications in membrane systems.

* Corresponding author. Tel.: +60 3 7967 4615; fax: +60 3 7967 5206.
E-mail address: mk_aroua@um.edu.my (M.K. Aroua).

http://dx.doi.org/10.1016/j.jtice.2014.09.013
1876-1070/

In this research, actual UF system operation data has been gathered from an industrial-scale UF membrane water treatment plant in Malaysia to evaluate the performance of the plant. The analyses of these data are used to elucidate the root causes of the UF water treatment plant design and operational issues. This is a practical performance analysis where the literature solutions are compared with actual practised solutions in the design and operation of an industrial-scale UF water treatment plant.

2. Background of the industrial-scale UF membrane water treatment plant

The industrial-scale UF membrane water treatment plant which is situated in Kelantan, Malaysia has been commissioned in February 2013. This treatment plant takes raw water from the riverbank filtration intake and channelled to a cascading aerator for natural aeration process. Subsequently the raw water is diverted to an extended aerator for force aeration with bottom air diffusers and air blowers. This aeration process allows further oxidation of the iron and manganese constituent before the filtration process. The aerated water is then fed into pressurized sand filters prior to the UF system. Sodium hypochlorite (NaOCl) or commonly known as liquid chlorine is dosed in the UF filtrate for disinfection before delivery to the main distribution pipeline. A schematic block diagram of the water treatment plant is shown in Fig. 1.

Process control of the treatment plant is carried out using programmable logic controllers (PLC) with touch-screen human machine interface (HMI). All the main control elements (control valves and pumps) and instrumentations (pressure transmitters and flowmeters) are linked to the PLC for data recording and control sequence. This plant is designed to operate automatically 24 h a day with minimal human intervention. The treatment plant operates in automatic mode with all filtration and backwash sequence of the pressurized sand filters and UF system executed automatically upon reaching predetermine conditions. Any abnormality of the system shall trigger an alarm to alert the operator of the plant. This industrial-scale treatment plant is equipped with data acquisition system to record real-time data of important operational parameters such as pressure and flowrate. A water analysis laboratory is also present in the treatment plant to allow for periodic sampling and analysis of the water quality according to the appropriate standards. This plant consists of 120 units of Dizzer XL 0.9 MB 60 W (manufactured by Inge GmbH, Germany) UF membrane modules. There are a total of 7, 200 m^2 of membrane surface area designed to produce up to 14 million litres a day (MLD) of drinking water with a flux rate of 81 l/m^2 h. All the UF membranes are made from modified polyethersulfone (mPES) with 7 capillaries in each fibre operated in dead-end filtration mode. The inside diameter of each capillary is 0.9 mm with pore size of approximately 0.02 μm. The UF membrane modules are installed in 2 racks with each rack consisting of 60 UF modules. Fig. 2 shows the arrangement of the UF membrane modules in the treatment plant.

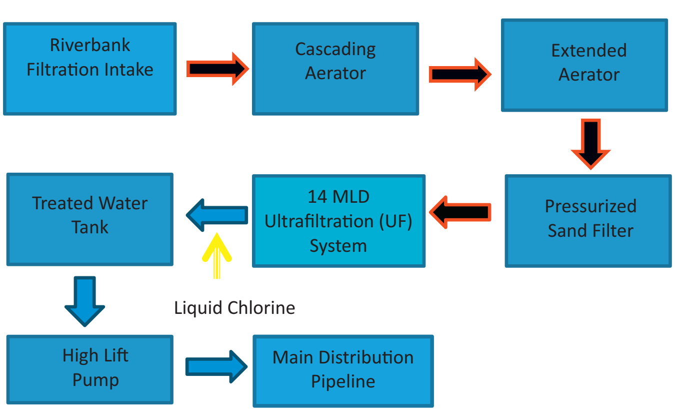

Fig. 1. Schematic block diagram of UF water treatment plant.

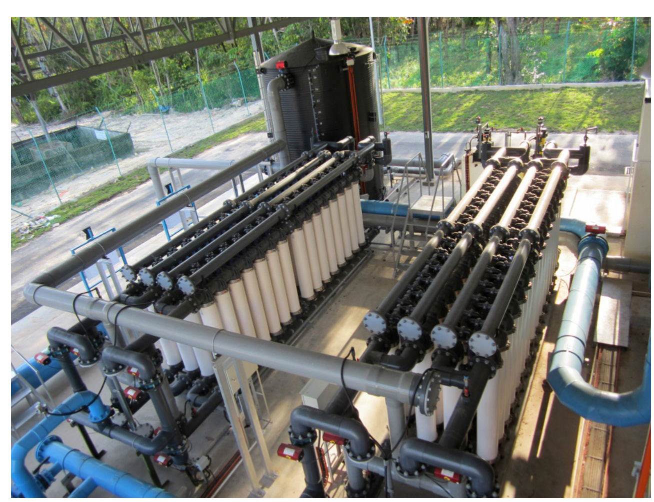

Fig. 2. UF membrane modules.

3. Design considerations of ultrafiltration system

Membrane process designers have tendency to oversize plant capacities due to vague understanding of the fouling mechanism [13]. Plant design and operation are required to fulfil multiple objectives which are often conflicting with each other [14]. Design criteria set during early stage prior to construction of the treatment plant would have direct impact on the operation of the system.

3.1. UF feed water quality and quantity

For the design and sizing of UF system, the concentrations of biopolymer [15], humic acid [16], inorganic salts such as $CaSO_4$, $CaCO_3$, SiO_2, $BaSO_4$ [9], heavy metal content such as Fe and Mn [17] in the feed water are possible required parameters to determine the critical flux of the membrane to reduce the fouling. The selection of suitable UF membrane material (organic or inorganic) is essential to ensure minimal fouling. Due to high degree of uncertainty and interactions between feed water composition and membrane properties, preliminary pilot-scale field experiments are required to determine the system feasibility [18]. In the actual industrial practice, a rigorous pilot-scale study is usually not carried out due to urgency on the water demand and insufficient allocation for pilot studies. During the design, the feed water quality is assumed consistent which is not the case as depicted in Fig. 3 due to reasons such as rain fall events.

Due to the dynamic process of the river flow, existing time series data analysis is usually inaccurate to forecast the minimum water level of the river [19]. Prediction of river water level using artificial intelligence has been proven to yield satisfactory results by Toro et al. [19]. The production from the UF system is forced to be decreased due to the lower yield from the intake source. In the month of September 2013, this treatment plant was expected to produce 7 MLD (292 m^3/h) of drinking water for supply. The incoming raw water flowrate should be maintained at 300–310 m^3/h to sustain the production of the drinking water supply. The flux to the UF systems would have to be adjusted due to the fluctuation of the raw water flowrate as there is fixed membrane