A Prototype Design and Experimentation of Reverse Osmosis (RO) Based Wastewater Treatment

Mohammad Younas*, Wajid Ali, Muhammad Zaheer

Department of Chemical Engineering, University of Engineering and Technology, Peshawar, Pakistan

* Corresponding Author, engr_unas@nwfpuet.edu.pk, u4unas@gmial.com

Abstract

In the past few years, the commercialization of small scale reverse osmosis (RO) plant for low total dissolved solids (TDS) brackish and contaminated groundwater water desalination offered an alternative solution to obtain drinking water with TDS lower than 500 mg/L. Due to rapid development in membrane technology the technical and economical usefulness of RO process has been improved. In the current research work, a prototype Reverse Osmosis (RO) wastewater treatmentplant has been developed and its performance was evaluated to produce the safe and drinkable water at local small community.Salt rejection and permeatewater flowrate are the key performance parameters. These performance parameters are influenced by other variable parameters such as applied feed pressure, temperature, recovery and feed water salinity.The RO plant performance has been evaluated through testing different water quality parameters; including physical, chemical and biological analysis of the treated sample. The plant was operated by varying feed water pressures and feed water salinity which indicated that the product water has the highest quality and maximum permeateflow rate at 25 bar of applied feed water pressure for feed water salinity upto 4000 mg/L. The water quality results indicate that permeate obtained after treatment has excellent quality free physical and microbial contaminants.

Keywords: Reverse Osmosis; Membrane; Wastewater treatment; Pressure; TDS

Introduction

Water, a colorless, odorless and tasteless liquid, is an important entity for life, plants and animals to survive. The significance of drinking water is increasing day by day due to the rapid growth in world's population and decrease in natural resources. However, huge water resources are available in various parts of the world but are contaminated. On the hand scarcity of water sources has been noted in certain parts of the world despite the availability of clean drinking water. Contaminated water sources have direct and indirect effect on human health. There are numerous diseases like diarrhea, cholera, typhoid fever are transmitted through the polluted water [1, 2].

Water availability in Pakistan is decreasing day by day due to drastic increase in population and misuse of water resources. At the time of independence per capita availability of water was 5000m^3/year which is now reduced to 1000 m^3/(ca.year). Data from the Pakistani federal government's Planning and Development Division shows that the overall water availability in Pakistan has decreased from 1,299 m^3/ ca in 1996-97 to 1,101 m^3/ ca in 2004-05 [3]. A survey has conducted which shows that about 36% of Pakistan's groundwater is highly saline [4].In rural areas, groundwater is mostly used. In areas with saline groundwater, the main source of domestic water is irrigation canals [5]. Salinity level of water samples of Peshawar region is in the range of 400-100 mg/L [6]. However water salinity increases upto in thousands of mg/L to in Brackish water or where the water is inundated with flood and run-off. In the worst situation like in earth quack and flood, river and inundated water channels need attention to be treated and to make it drinkable.

In a study conducted by Bachaet al. [6] ninety (90) drinking water samples from the urban and rural areas of district Peshawar were analyzed. It was found that Total Coliform was ranged from 0.00-150.00 with mean value of37.79 and E. coli was present in 26 % samples and absent in 74% drinking water samples.

Membrane filtration technology offers an advanced alternative for conventional water treatment technology by producing water free of biological contamination. Especially, Reverse Osmosis (RO) and Nano filtration (NF) technologies, mainly because of their small pore sizes, have a great potential to remove biodegradable organic substances from source water and consequently reduce the potential for bacterial growth in the distribution system [7]. However, pilot scale studies have not been found in the literature to treat the raw water including physical and biological wastewater characteristics in one step.

High quality of potable water can be produced if reverse osmosis (RO) technology can be applied to the brackish ground and surface water situated near to rivers running in Khyber Pakhtunkhwa (Pakistan). Such implementation would yield enough quantity of good quality water that is free from turbidity, high salinity, viruses, bacteria and other micro-organisms.

RO is one of the finest levels of filtration available and is the most widely used technology for the effective and economical brackish as well as seawater treatment. It has been used to remove salts and impurities from water to improve water quality. Design consideration of reverse osmosis system depends on total dissolved solids, organics, suspended solids and desired water product quality. The RO membrane does not allow dissolved salts, organic and inorganic micro molecules to pass through it, while the water molecules, on the other hand, pass freely through the membrane producing pure drinking water[8, 9].

The key objective of this research work is to determine the optimum operational conditions i-e pressure in RO process for the removal of coliform bacteria, pathogens, TDS from brackish groundwater inundated by flood or river water in worst situation like during earthquake and flood which may be used for drinking as well as other domestic purposes.

Materials and Methods

Experimental Procedures

Experiments have been carried out on the pilot Scale Reverse Osmosis membrane filtration system. The membrane used is spiral wound polyamide composite model BW30-4040 purchased from DOW Film Tec™. The specifications (provided by the manufacturer) of ROBW30-4040 membrane is shown in Table I.

Table 1. Characteristics of RO membrane used in the plant (provided by manufacturer)

Product name	BW30 -4040
Membrane Type	Polyamide Thin-Film Composite
Dimensions	3.9" W X 40" L
Nominal active surface area	78 ft^2
Maximum Operating Temperature	45°C
Maximum operating pressure	41 bar
pH Range, Continuous Operation	2-11

The RO unit consists of high pressure positive displacement pump (CAT) whose discharge pressure is controlled by gate valve in the bypass line from pump discharge to the pump suction. This valve ensures that the maximum pressure (25-30 bars) will not be exceeded. Fixed speed motor of 2.3kW is used in the pump.This pump is connected with the pressure relief gate valve, membrane with the help of membrane cell holder, high pressure concentrate solenoid gate valves, rotameters and pressure indicators in the feed, permeate and retentate streams.Rotameters are fixed on permeate and retentate streams to measure permeate and retentate volumetric flow rates.

A feed tank with a capacity of 40 L made of stainless steel, equipped with a jacket which keeps the feed water temperature constant. Two tanks are installed for the collecting permeate and retentate water after treatment. The schematic of the RO unit is shown in Fig 1. The RO polyamide membrane was first soaked by passing distilled/purified water through membrane at 20 bars of feed pressure for an hour to remove the left-over chemicals deposited on the membrane surface so that the membrane compaction can be stopped during the RO experimental work. Distilled water is then permeated out from the feed water tank by varying pressure from 5 bars to 30 bars to measure the water permeation fluxes at different pressures. After wetting the membrane, feed water was stored in feed water tank by measuring its temperature, TDS and pH before starting the pump. NaCl was added to the feed water to adjust the TDS. Feed and permeate water sample was taken for analysis of physical, chemical and biological parameters.

Performance of membrane was measured in terms of permeate water flow ratentate rejection (R). Rejection is the salt recovery from the feed stream by the membrane and is defined as

$$R = (1 - C_p / C_f) * 100\% \qquad (1)$$

Where C_p and C_f are the concentrations of salt in permeate and feed streams [10].

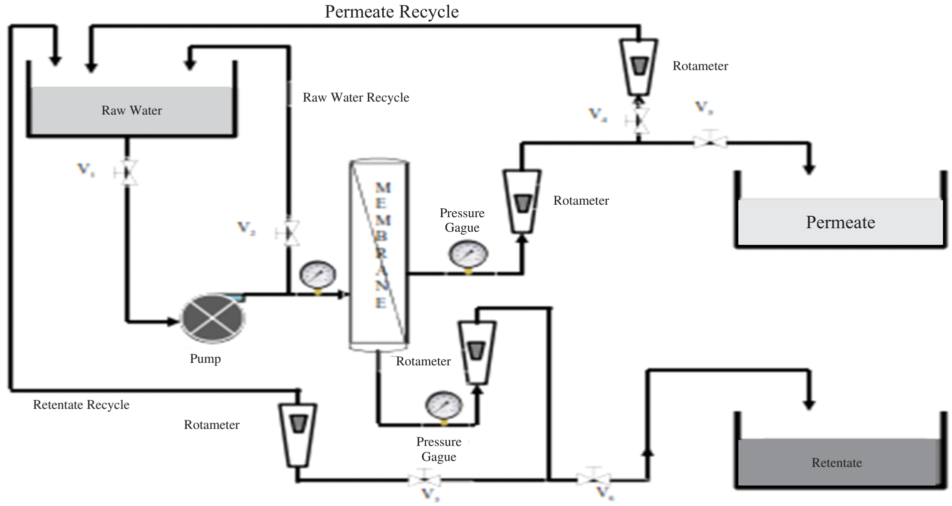

Figure 1: Reverse Osmosis (RO) based pilot scale unit for wastewater treatment

RO Membrane Cleaning

After treatment the equipment was cleaned with RO permeate water and the membrane was then washed by using NaOH solution with pH 12. The cleaning solution was circulated in the module with low pressure (4 bar) and high flowrate (12 L/min) for 25 minutes so that it can remove all the organic foulants. Then for the removal of inorganic scalantse specially calcium carbonate and Iron oxide/hydroxide the membrane was washed with HCL solution at pH=2 for a period of 25 minutes at 4bar and high flow rates. Washing the membrane with NaOH and acid solution will restore the permeate flux upto 90 % of its original permeate flux tested for distilled water under the same operating conditions.

Methods of Analysis

Samples were taken in sterilized Whirl Pak sample bags at regular interval to determine permeate and feed water quality. pH was measured using Hanna-HI-98127 pHmeter. Temperature and electrical conductivity was measured using Hanna-HI-98312 Electrical Conductivity/Temperature/TDS tester. Total Coliform unitand fecal coliform unit were analyzed by using Multiple Fermentation Tube method and membrane filtration method using membrane laurel sulfate broth as feed solution for bacteria.

The permeate and retentate streams mass flow rates were measured by rota meters. Pressure of feed, permeate and retentate streams were monitoredby pressure gauges installed on each stream.

Results and Discussions

The effect of different operating parameters on the performance and efficiency of RO membrane has been studied by changing one parameter at a time while the other parameter is kept constant.

Effect of Feed Pressure

Experiments were carried out to investigate the effect of operating pressure on the performance of RO process. The water was taken as feed with TDS equals 2000. The temperature of the feed water was 30±3 ^{0}C. As shown in Fig 2 that an increase in operating pressure increases the permeate flow rate. The permeate water flow rate indicates the linear increase with the increase in feed pressure within the studied operating range. Permeate flow rate raised from 1.2 L/min to 4.2 L/min at the operating pressure of 5 and 25 bar, respectively. However it has been noted from literature that a limiting value of feed pressure is reached beyond which permeate flux cannot be increased. This is attributed to the addition of salts on the surface of membrane which employs a high osmotic pressure[11, 12].

Similarly permeate recovery is plotted against operating feed pressure in Fig 3 for feed TDS of 2000 mg/L at 30±3 ^{0}C. It can be observed from Fig 3 that permeate recovery increases from 13.8 % to 56.8 % when feed pressure is increased from 5 bars to 25 bar, respectively. On the other hand as the feed water pressure increases from 5 bar to 25 bar, salt rejection increases from 90.6% to 94.7% (calculated from equation 1). In fact salt rejection decreases at high pressure because of the increase in osmotic pressure due to deposition of salts on the membrane surface.

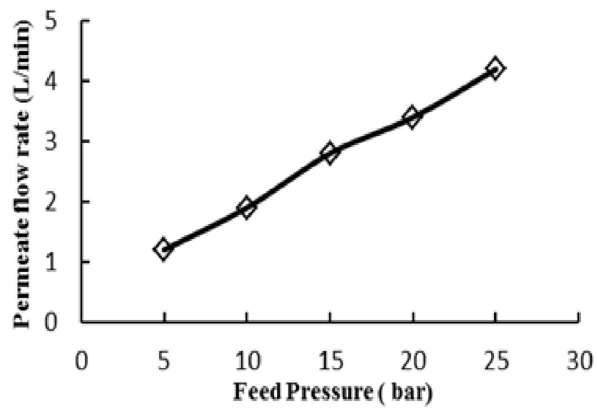

Fig 2: Effect of feed water pressure on permeate flow rate, T = 30±3 ^{0}C, Feed TDS = 2000 mg/L, pH = 6.8±2

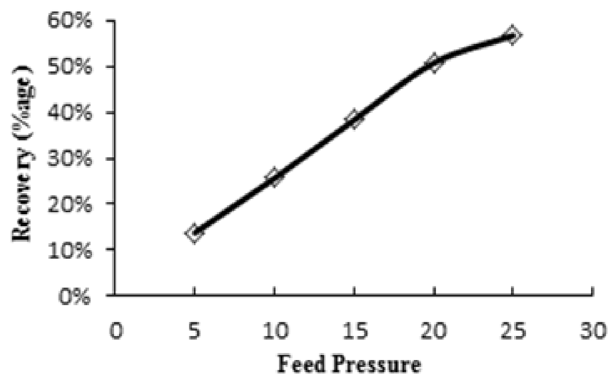

Fig 3: Effect of feed pressure on membrane recovery, T = 30±3 ^{0}C, Feed TDS = 2000 mg/L, pH = 6.8±2

Power consumption was also measured and it can be found from Fig 4 that specific power consumption increases with increase in applied feed pressure. The power consumed at 25 bars was measured to be 1.71KW-hr/m^3. Further increase in pressure increased power consumption while its effect on permeate flux and its quality is least. So for better product water result and less power consumption the plant was operated mostly at optimum pressure of 25 bar under the studied operating conditions and pollution load.

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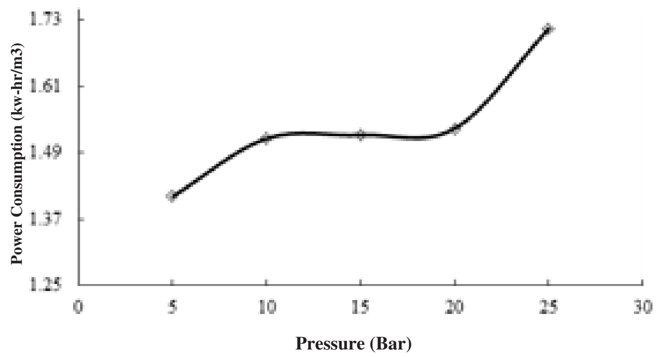

Fig 4: Effect of feed water pressure on Power Consumption, T = 30±3 ^{0}C, Feed TDS = 2000 mg/L, pH = 6.8±2

The permeate water samples were analyzed for Total Coliform unit, Fecal Coliform, Cry-ptosporidium, Giardia Lambia and hardness at each operating condition. It has been found from water quality tests that the water produced in the permeate qualifies all the WHO guidelines for clean and safe drinking water.

Effect of Feed Water Salinity (TDS)

Feed water salinity has an inverse impact on the recovery ratio. Four feed water samples have been set with TDS concentration of 1000, 2000, 3000 and 4000 mg/L. All feeds were operated as various constant pressure of 5 - 25barwith 5 bars increment at temperature of 30±3°C. The results were plotted for permeate salinity (TDS) vs feed pressure for different feed concentration as shown in Fig 5.

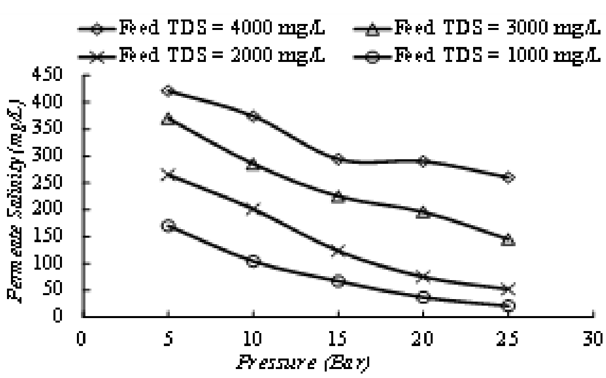

Fig 5: Effect of feed pressure on permeate salinity (TDS), pH = 6.4 – 7.8, T = 30±3 ^{0}C

It is observed from ***Figure 5*** that feed water with low salt concentration in feed achieveshigh salt rejection in comparison tothat high salt concentration.For example for feed TDS of 4000 mg/L at 25 bar, the permeate water salinity was 260 mg/L but the permeate water salinity drops to 21 mg/L if feed TDS was kept 1000 mg/L at the same feed pressure and temperature. It is also observed that operating pressure has also influences the salt rejection. Slat rejection increases of permeate salinity decreases with the increase of feed pressure. For example permeate water salinity is noted as 421 mg/L at 5 bars for feed TDS of 4000 mg/L. Nonetheless for the same TDS permeate water salinity drops to 260 mg/L if the operating feed pressure is raised to 25 bars. It is due to higher driving force to the feed because at constant pressure, osmotic pressure is directly proportional to the salt concentration in the feed. Increasing salt concentration increases osmotic pressure which decreases net driving pressure (NDP), as a result the permeate flow decreases which decreases recovery ratio [12].

Conclusions

The performance of RO system was studied and analyzed experimentally on the pilot scale Unit. Pressure effect on the performance of membrane was the most vital one. It was observed that higher feed water pressure results in a better operation of RO unit with good quality permeate as well as maximum recovery ratio of 56.8%at feed pressure of 25 bar for feed water salinity of 2000 mg/L. Salt rejection of 94 to 98 % was noted for operating pressure ranging between 5 to 25 bar and for feed salinity between 1000 to 4000 mg/L. Permeate water was analyzed during all experiments and was found to be free from bacteria, viruses and pathogens. In areas where salinity is high (more than 5000 ppm) thena micro-filtration membrane unit is recommended for the pretreatment of feed water so that efficiency of RO membrane will not affect due to fouling/scaling.

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