DRINKING WATER TREATMENT BY ULTRAFILTRATION MEMBRANE: A REVIEW

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***Abstract*: With the improvement of living standards, people on drinking water quality is also put forward higher requirements, so the standard of drinking water is becoming more and more strict. Compared with conventional water treatment technology, membrane separation technology has good water quality, stable operation, small occupation area, easy to realize the automatic control, has an extremely wide application prospect in municipal water treatment industry. This method briefly introduces the domestic types and development situation of materials of preparing ultra-filtration membrane. Membrane filtration in drinking water treatment has become a more attractive technology in recent years as a possible alternative treatment.**

***Keywords*: Ultrafiltration, Disinfection, TDS, Ultraviolet, Sources, Membrane arrangement.**

INTRODUCTION

Membrane ultrafiltration (UF) in drinking water treatment has become a more attractive technology in recent years as a possible alternative treatment to conventional clarification. Comparing to the conventional treatment, membrane filtration offers several advantages such as (1) superior quality of treated water, (2) a much more compact system, (3) easier control of operation and maintenance, (4) fewer chemicals, and (5) less production of sludge [1,2]. The major factor of this limitation is the long-term flux decline due to so-called membrane fouling, which results in a lowered production of treated water or higher energy consumption for production and the necessity for frequent membrane cleaning with chemicals. Membrane fouling in this case is a phenomenon whereby substances in raw water, such as suspended inorganic particles, bacteria, viruses, and organic molecules (e.g., humic substances) may either adsorb into the membrane pores or plug the pores, and in many cases are deposited onto the membrane surface [l-6]. The deposition eventually forms a gel or cake layer on the membrane and is a dominant resistance to filtration.The membrane fouling process is considerably dependent on membrane materials, the nature ofthe foulants, circumstances of the feed solution and upstream hydrodynamic conditions [1,3].

Millions of life in developing countries depends upon drinking water which can get polluted due to microorganisms, particulate matter and organic substances, which come from the polluted water. Ultrafiltration (UF) can be such a way to remove the contaminants from the drinking water, with a relatively low cost compared with nano filtration and reverse osmosis. With the intense regulatory activity and scarce high quality source water, UF is considered as a very promising process for drinking water production because of its compactness, easy automation, and high removal rate of turbidity, organic matters (such as humic substances), Giardia and also virus.[4] UF is recognized as a low-pressure membrane filtration process. When the source water is passing through the filter under a trans-membrane pressure provided by the gravity or a pump, the bacteria and most viruses can be removed, the water-related disease and death from microorganisms can be prevented, the drinking water quality can be satisfied for consumers, and the use of chemicals, capital, and operating cost can be reduced. With the decreasing cost of the ultrafiltration membrane, UF technology is gradually accepted by the developing countries compared to other low-pressure membrane technologies. Today, UF, as a fast-growing industry, has a significant growth for drinking water production.[17]

A moderate pretreatment method to integrate higher removal of contaminants, lower rate of losing permeability, and lower cost of the whole process for overcoming problem of membrane fouling. This work views the applications and small level process of UF as a membrane process for drinking water production as well as its affecting factors and advantages & comparative studies between various types of drinking water processes.

LITERATURE REVIEW

2.1 Multiple drinking water treatment processes: Formation of disinfection by product

Yimeng zhang and wenhai (2016) studied that the formation of disinfection by-products (DBPs) in chlorinated drinking water results in the adverse health effects on human beings. In the past four decades since the identification of chloroform (CF) as a DBP, hundreds of DBPs have been identified in drinking water.[4] Whereas Krasner et al., (2006) studied that generally, the currently regulated carbonaceous DBPs (C-DBPs) such as Control of aliphatic halogenated DBP precursors with multiple drinking water treatment processes: Formation potential and integrated, brominated trihalomethanes (THMs) and halo acetic acids (HAAs) have been well studied. However, nitrogenous DBPs (N-DBPs) and iodinated DBPs (I-DBPs) represent an emerging concern. Therefore, the objective of the study is to evaluate the changes of FPs(formation potential) of a range of DBPs (C-DBPs, N-DBPs, and I-DBPs) in the upgraded multiple drinking water treatment process flows, including pre-ozonation, conventional treatment (coagulation–sedimentation, pre-sand filtration , advanced treatment, and post-sand filtration. Then, to assess the potential toxic risks of DBPs by combing their FPs and toxicity values, which is expected to better understand the DBP control in drinking treatment processes. This is also a preliminary attempt to look for preferred controlled DBPs, which will be helpful for DBPs health risk assessment, regulation and water treatment process optimization.[5]

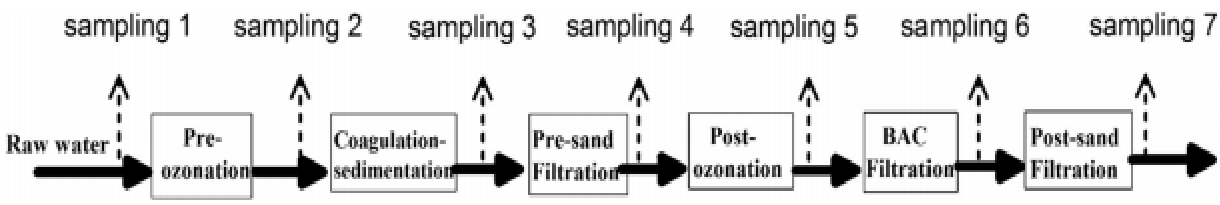


Figure 1: multiple drinking water treatment processes[7]

Shah S., (2011) studied that the treatment processes adopted in the DWTP included pre-treatment (pre-ozonation, O_3 dosages: 0.5–0.8 mg/L), conventional treatment (coagulation–sedimentation (the used coagulant polymeric aluminum chloride dosage: 15 mg/L) and pre-sand filtration), advanced treatment (post-ozonation [O_3 dosages: 0.8–1.0 mg/L] and biological activated carbon (BAC) filtration (granular activated carbon was used)), post-sand filtration (intercepting microorganism leakage from BAC filtration), and chlorination disinfection, which are prevalent in Chinese DWTPs using the polluted source water (esp. eutrophic water)as shown in figure 1.The sample pH was adjusted to 7.5 by addition of H_2SO_4 or NaOH; it was noted that pH did not change more than 0.3 pH unit. The removal of DBPs by each process was calculated by Equation given below. All samples were prepared in triplicate and the error bars in the figures represent the standard deviation of replicate measurements (n = 3).[7]

$$\text{Removal} = \frac{C_A - C_B}{C_A}$$

Where C_B: DBP FP after each treatment process &C_A: DBP FP after each treatment process

2.2 Cross flow Ultrafiltration membrane

Shuji Nakatsuka, (1995) studied that the system consisting of two parts: a cross flow UF unit with a recirculation loops and permeate backwashing unit. The recirculation loop is comprised of a membrane module, a circulation pump, a prefilter with a 200 pm mesh screen, a flow meter, and inlet and outlet pressure gauges between the module as shown in figure 2. The raw water used was from the River downstream.[6]

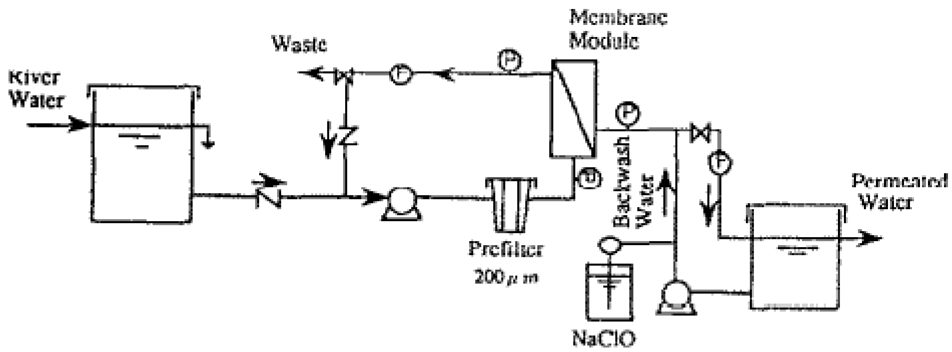


Figure 2: Schematic diagram of UF test and apparatus. [6]

The raw water in a tank was pumped and prefiltered and then delivered to the membrane module in the loop. A part of the water was ultrafiltered through the membrane as permeate, and the remaining water was recirculated as concentrate that was mixed with the feed water. The crossflow UF tests were conducted at constant transmembrane pressure of 50 kPa in most test runs. Where as J.P. Hagstrom (1989) studied that the crossflow velocity of feed water which passed through the lumen side of hollow fibers in the modules was maintained at a constant value of 0.16 m/s. In order to compare the UF performances under various operating conditions using the same raw water quality, a test apparatus with four independent recirculation loops for each module was used.UF fluxes (J) were determined by measuring the permeate volumes (per unit filtration area) collected over the measured time intervals. The flux measurements were performed within a few minutes after periodical backwashing was finished. The flux was corrected to a temperature of 20°C. [3]

2.3 Photo catalysis + UF System:

Below figure 3 shows a schematic diagram of the experimental setup, which consists of a cross-flow ultrafiltration module and a photocatalytic reactor has been studied by Kwang-Ho Choo(2001), that the configuration of the UF unit was plate and frame. The membranes used were of the type cellulose acetate (CA) UF has an effective surface area of 26.85 cm^2. The flux was continuously measured using a balance and recorded on an on-line personal computer. After measurement,the permeate was returned to the photocatalytic reactorin order to keep the reactor volume constant. Cross-flowvelocities were controlled by adjusting the pumping rate(i.e., circulation flow rate), and transmembrane pressures were regulated with a back-pressure valve. [9]

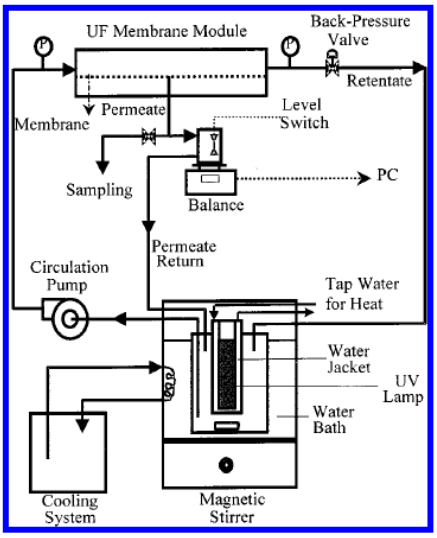


Figure 3.Schematic of lab scale of UF.[9]

Allard, S., (2013) studied that the photocatalytic reactor was composed of three compartments, namely, an inner chamber, an outer chamber, and a void space between them. A UV light source was placed in the inner chamber of the reactor. The outer chamber can hold 2 L of liquid for the photocatalytic reaction. During the experimental runs, tap water was continuously passed through the void space to prevent the reactor from being overheated by UV illumination. The temperature of the liquid was kept at 20 ±2 °C by another heat exchanger along the circulation line. P-25 TiO_2 particles (Degussa, Frankfurt, Germany) were used as photocatalysts for the experiments. The suspension was irradiated using a 450-W.[8]

VARIOUS PROCESSES FOR DRINKING WATER TREATMENT:

Water purification is the process of removing undesirable chemicals, biological contaminants, suspended solids and gases from water. The goal is to produce water fit for a specific purpose. Most water is disinfected for human consumption (drinking water), but water purification may also be designed for a variety of other purposes, including fulfilling the requirements of medical, pharmacological, chemical and industrial applications. The methods used include physical processes such as filtration, sedimentation, and distillation; biological processes such as slow sand filters or biologically active carbon; chemical processes such as flocculation and chlorination and the use of electromagnetic radiation such as ultraviolet light.[12]

Purifying water may reduce the concentration of particulate matter including suspended particles, parasites, bacteria, algae, viruses, fungi, as well as reducing the concentration of a range of dissolved and particulate matter.

The standards for drinking water quality are typically set by governments or by international standards. These standards usually include minimum and maximum concentrations of contaminants, depending on the intended purpose of water use.

Other popular methods for purifying water, especially for local private supplies are listed below. In some countries some of these methods are also used for large scale municipal supplies. Particularly important are distillation (de-salination of seawater) and reverse osmosis.[16]

1. Boiling: Bringing water to its boiling point (about 100 °C or 212 F at sea level), is the oldest and most effective way since it eliminates most microbes causing intestine related diseases, but it cannot remove chemical toxins or impurities. For human health, complete sterilization of water is not required, since the heat resistant microbes are not intestine affecting. The traditional advice of boiling water for ten minutes is mainly for additional safety, since microbes start getting eliminated at temperatures greater than 60 °C (140 °F). Though the boiling point decreases with increasing altitude, it is not enough to affect the disinfecting process In areas where the water is "hard" (that is, containing significant dissolved calcium salts), boiling decomposes the bicarbonate ions, resulting in partial precipitation as calcium carbonate. Boiling does not leave a residual disinfectant in the water. Therefore, water that is boiled and then stored for any length of time may acquire new pathogens.
2. Granular Activated Carbon adsorption: a form of activated carbon with a high surface area, adsorbs many compounds including many toxic compounds. Water passing through activated carbon is commonly used in municipal regions with

organic contamination, taste or odors. Many household water filters and fish tanks use activated carbon filters to further purify the water. Household filters for drinking water sometimes contain silver as metallic silver nanoparticle. If water is held in the carbon block for longer periods, microorganisms can grow inside which results in fouling and contamination. Silver nanoparticles are excellent anti-bacterial material and they can decompose Toxic halo-organic compounds such as pesticides into non-toxic organic products.

3. Distillation involves boiling the water to produce water vapour. The vapour contacts a cool surface where it condenses as a liquid. Because the solutes are not normally vaporised, they remain in the boiling solution. Even distillation does not completely purify water, because of contaminants with similar boiling points and droplets of unvapourised liquid carried with the steam. However, 99.9% pure water can be obtained by distillation.
4. Reverse osmosis: Mechanical pressure is applied to an impure solution to force pure water through a semi-permeable membrane. Reverse osmosis is theoretically the most thorough method of large scale water purification available, although perfect semi-permeable membranes are difficult to create. Unless membranes are well-maintained, algaeand other life forms can colonize the membranes.
5. The use of iron in removing arsenic from water.
6. Direct contact membrane distillation (DCMD). Applicable to desalination. Heated seawater is passed along the surface of a hydrophobic polymer membrane. Evaporated water passes from the hot side through pores in the membrane into a stream of cold pure water on the other side. The difference in vapour pressure between the hot and cold side helps to push water molecules through.
7. Desalination – is a process by which saline water (generally sea water) is converted to fresh water. The most common desalination processes are distillation and reverse osmosis. Desalination is currently expensive compared to most alternative sources of water, and only a very small fraction of total human use is satisfied by desalination. It is only economically practical for high-valued uses (such as household and industrial uses) in arid areas.
8. Gas hydrate crystals centrifuge method. If carbon dioxide or other low molecular weight gas is mixed with contaminated water at high pressure and low temperature, gas hydrate crystals will form exothermically. Separation of the crystalline hydrate may be performed by centrifuge or sedimentation and decanting. Water can be released from the hydrate crystals by heating.
9. In Situ Chemical Oxidation, a form of advanced oxidation processes and advanced oxidation technology, is an environmental remediation technique used for soil and/or groundwater remediation to reduce the concentrations of targeted environmental contaminants to acceptable levels. ISCO is accomplished by injecting or otherwise introducing strong chemical oxidizers directly into the contaminated medium (soil or groundwater) to destroy chemical contaminants in place. It can be used to remediate a variety of organic compounds, including some that are resistant to natural degradation
10. Bioremediation is a technique that uses microorganisms in order to remove or extract certain waste products from a contaminated area. Since 1991 bioremediation has been a suggested tactic to remove impurities from water such as alkanes, perchlorates, and metals. The treatment of ground and surface water, through bioremediation, with respect to perchlorate and chloride compounds, has seen success as perchlorate compounds are highly soluble making it difficult to remove. Although a bioremediation technique may be successful, implementation is not feasible as there is still much to be studied regarding rates and after effects of microbial activity as well as producing a large scale implementation method.[11]

MEMBRANE ARRANGEMENT:

Depending on the shape and material of the membrane, different modules can be used for ultrafiltration process. Commercially available designs in ultrafiltration modules vary according to the required hydrodynamic and economic constraints as well as the mechanical stability of the system under particular operating pressures[9] .The main modules used in industry include:

Tubular modules

The tubular module design uses polymeric membranes cast on the inside of plastic or porous paper components with diameters typically in the range of 5 – 25 mm with lengths from 0.6 - 6.4 m. Multiple tubes are housed in a PVC or steel shell. The feed of the module is passed through the tubes, accommodating radial transfer of permeate to the shell side. [12]

Figure 4 : Tubular module[12]

Spiral-wound modules

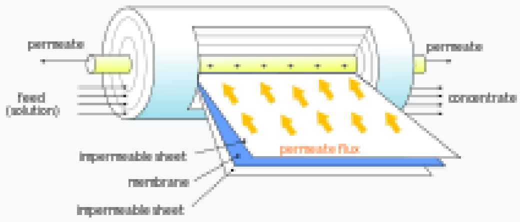


Fig 5 : Spiral wound module[14]

They are composed of a combination of flat membrane sheets separated by a thin meshed spacer material which serves as a porous plastic screen support. These sheets are rolled around a central perforated tube and fitted into a tubular steel pressure vessel casing. The feed solution passes over the membrane surface and the permeate spirals into the central collection tube. Spiral-wound modules are a compact and cheap alternative in ultrafiltration design, offer a high volumetric throughput and can also be easily cleaned. However it is limited by the thin channels where feed solutions with suspended solids can result in partial blockage of the membrane pores.[14]

3.3 SOURCES OF WATER:

1. Groundwater: The water emerging from some deep ground water may have fallen as rain many tens, hundreds, or thousands of years ago. Soil and rock layers naturally filter the ground water to a high degree of clarity and often, it does not require additional treatment besides adding chlorine or chloramines as secondary disinfectants. Such water may emerge as springs, artesian springs, or may be extracted from boreholes or wells. Deep ground water is generally of very high bacteriological quality (i.e., pathogenic bacteria or the pathogenic protozoa are typically absent), but the water may be rich in dissolved solids, especially carbonates and sulfates of calcium and magnesium. Depending on the strata through which the water has flowed, other ions may also be present including chloride, and bicarbonate. There may be a requirement to reduce the iron or manganese content of this water to make it acceptable for drinking, cooking, and laundry use. Primary disinfection may also be required. Where groundwater rechargeis practiced (a process in which river water is injected into an aquifer to store the water in times of plenty so that it is available in times of drought), the groundwater may require additional treatment depending on applicable state and federal regulations.
2. Upland lakes and reservoirs: Typically located in the headwaters of river systems, upland reservoirs are usually sited above any human habitation and may be surrounded by a protective zone to restrict the opportunities for contamination. Bacteria and pathogen levels are usually low, but some bacteria, protozoa or algae will be present. Where uplands are forested or peaty, humic acids can colour the water. Many upland sources have low pH which require adjustment.
3. Rivers, canals and low land reservoirs: Low land surface waters will have a significant bacterial load and may also contain algae, suspended solids and a variety of dissolved constituents.
4. Atmospheric water generation is a new technology that can provide high quality drinking water by extracting water from the air by cooling the air and thus condensing water vapor.
5. Rainwater harvesting or fog collection which collect water from the atmosphere can be used especially in areas with significant dry seasons and in areas which experience fog even when there is little rain.
6. Desalination of seawater by distillation or reverse osmosis.
7. Surface Water: Freshwater bodies that are open to the atmosphere and are not designated as groundwater are termed surface waters.

METHODOLOGY:

SAND FILTER WITH ACTIVATED CARBON:

Taking 1 litre bottle & cutting ¾ th of it from the bottom. Making hole in the cap of known diameter of pipe & fitting it with the help of connector. Arranging different types of layers of sand i.e. fine sand layer (1st), activated carbon (2nd) layer, pebbles & coarse (3rd) layer, gravels (4th) layer. Separating the layers with the help of mesh. Between two sponges a second layer is there. (PARA)

Figure 6: Sand filter with activated carbon

ELECTRICAL CONNECTION:

First, inserting UV lamp of 11 Watt inside the UV barrel of 8 inch. Connecting UV chock adapter to the both ends of UV barrel and the third wire of the adapter get connected to main switch board by using electrical wire. By switching ON button, the light glow is seen in the elbow connector, which tells us whether the UV barrel is working or not.

Figure 7: UV barrel

Figure 8: UF filter

WORKING AND ASSEMBLING:

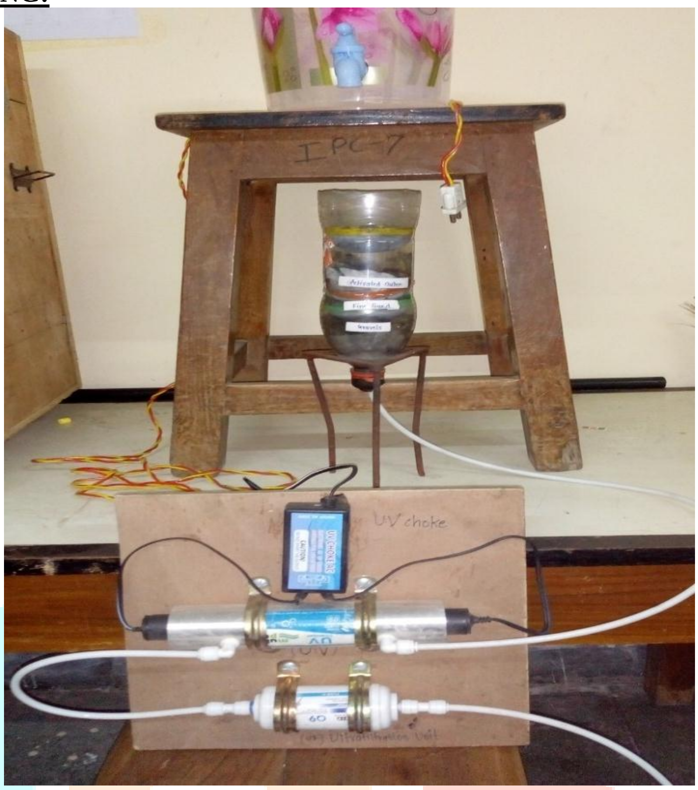


Figure 9 : Set up

BLOCK DIAGRAM OF THE PROCESS

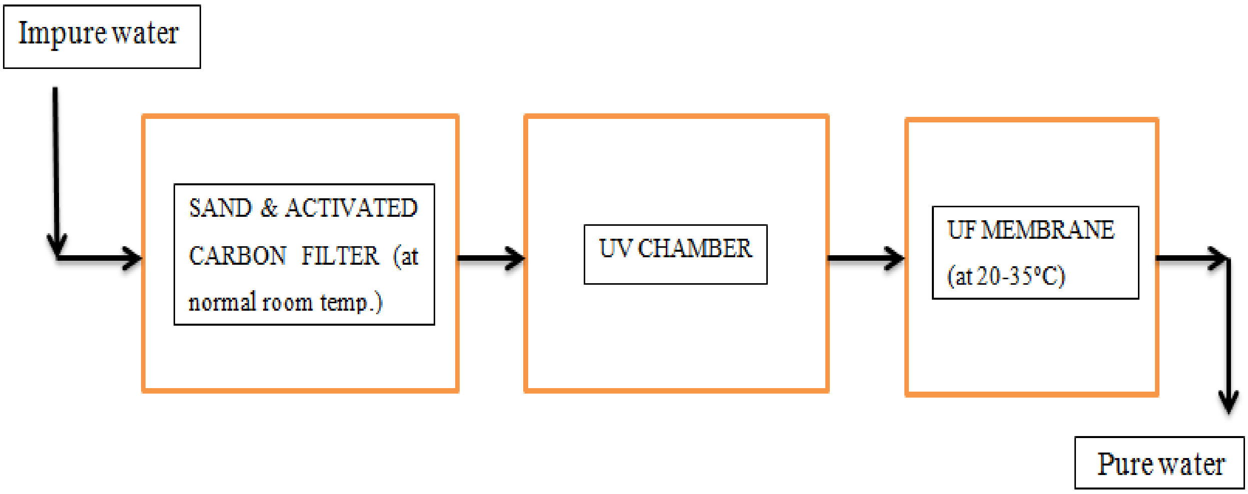


Figure 10 : Process block diagram

The impure water is first poured in the rapid sand filter, where the suspended solids are get removed. Then filtered water coming from the rapid sand filter is admitted as a feed into UV Membrane for further purification. Here Bacteria & Viruses are killed with the help of UV lamp. Then the product is further passed into UF Filter for purification, to remove all dissolved solids present in the water. After that we get filtered water.

LIMITATIONS:

1. Changing the filter paper & sponge after its two time use.
2. Leakage of water from UV and UF filters can take place if fitting rings are not joined.
3. Taken runs on lab scale of UF(0.1 microns).
4. Volume taken of impure water cannot be exceeding than 5 liters, if it exceeds we have to again fill up the container.
5. Membrane fouling.
6. Replacement of membrane.

TEST:

After the pure water is collected in a separate beaker the following test are conducted to check whether it is safe to drink or not:

A) Test for TDS[11]
B) Test for pH[11]
C) Test for chemical oxygen demand {COD}[11]
D) Test for CO_2 Determination[11]
E) Test for Chloride Determination [11]

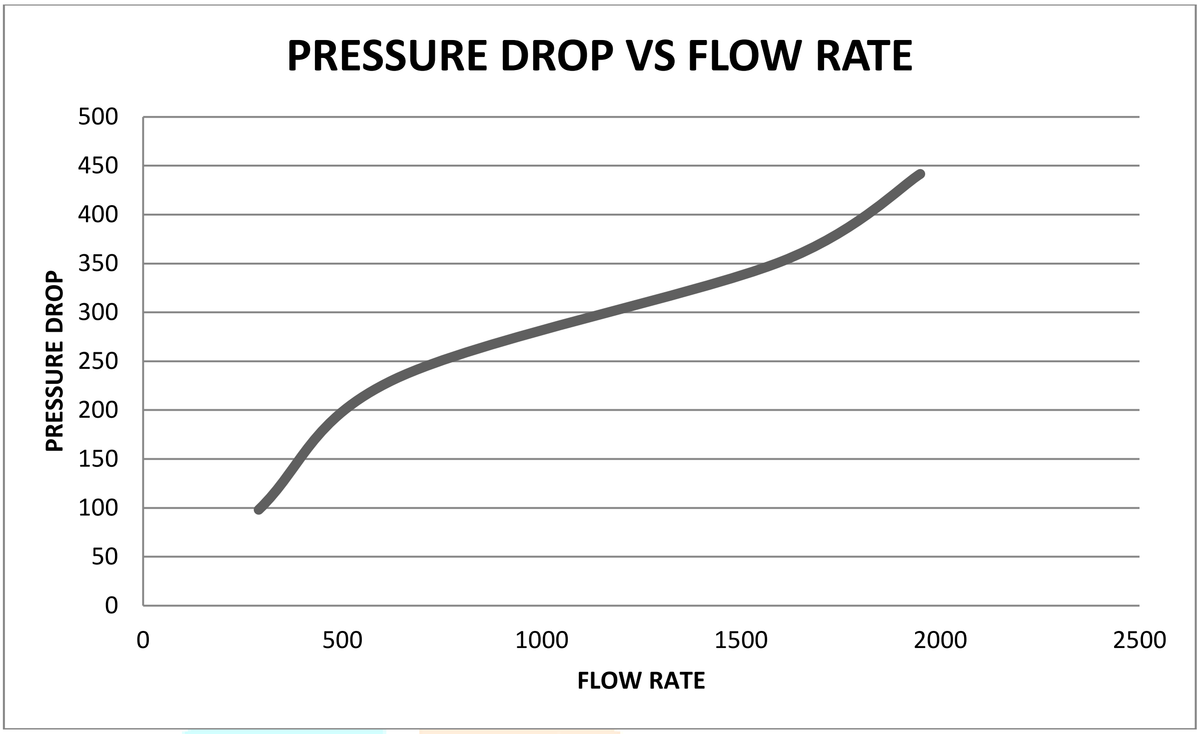
RESULT AND DISCUSSION :

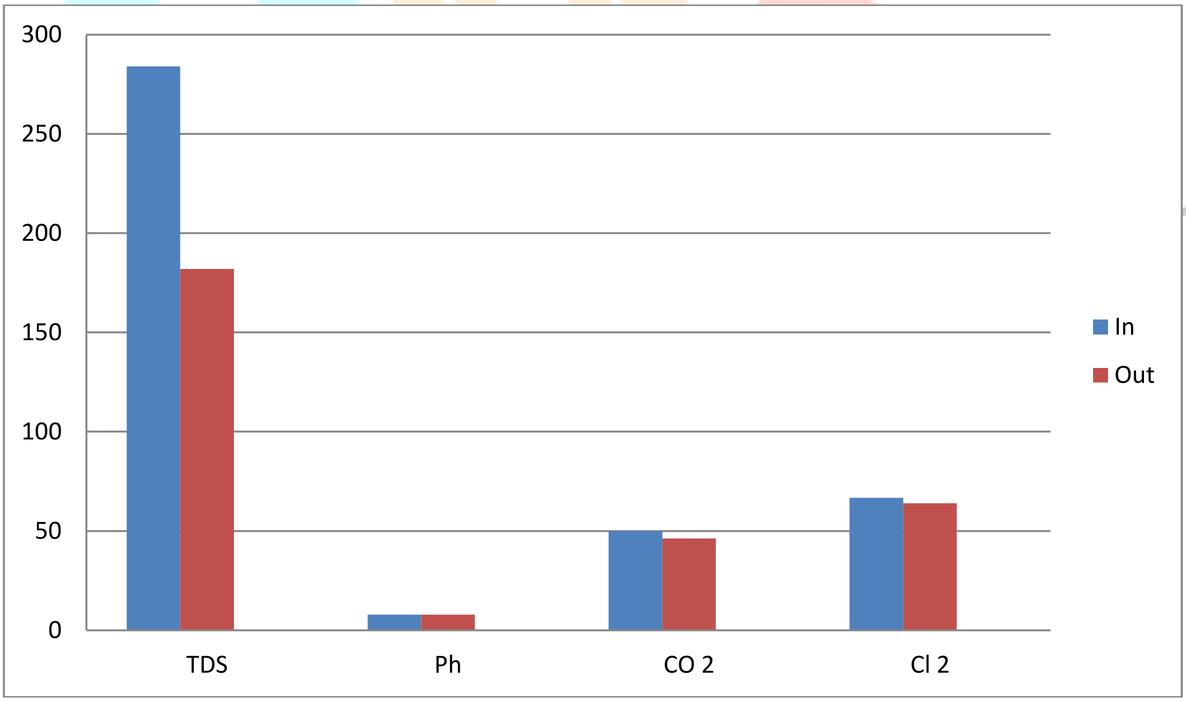
SOURCE: MUDDY WATER

Inlet flow rate (ml/min)	$\Delta H = h_2 - h_1$ (cm)	$\Delta P = \Delta H \times \varrho \times g$ (Pa)	TDS In	TDS Out	% reduction in TDS	pH In	pH Out	% reduction in pH
290	1	98.12	284	182	35.99	7.8	7.9	1.2
630	2.3	231.4	287	181	36.9	7.8	8.1	3.8
1600	3.5	351.8	280	185	33.9	7.8	8.1	3.8
1950	4.4	441.5	280	183	34.6	7.7	8.2	6.5

CBR reading of CO_2 (ml) In	CBR reading of CO_2 (ml) Out	CO_2 (mg/lit) In	CO_2 (mg/lit) Out	% reduction in CO_2
2.3	2.1	50	46.2	7.6
2.5	2.0	50	45	10
2.31	1.8	51	41.3	19
2.3	2.2	50	48.4	3.2

CBR reading of Cl_2 (ml) In	CBR reading of Cl_2 (ml) Out	Cl_2 (mg/lit) In	Cl_2 (mg/lit) Out	% reduction in Cl_2
5	4.5	71	63.9	10
4.8	4.5	68.3	63.9	6.4
4.8	4.6	68.3	65.3	4.4
4.7	4.5	66.7	63.9	4.2





From above graph it is concluded that, as pressure drop increases flow rate increases. From observations, it is seen that Cl_2 value does not exceeds than permissible limit value i.e 250 mg/l. And TDS value for drinking water should be less than 500 mg/l & pH should be between 6.5 to 8.5. Thus, comparing above result with IS STANDARD unit, outlet water is advisable for usage of domestic purpose such as washing, drinking, cleaning, etc. For Presence CO_2 the sample solution should not turn pink & permissible limit is 45 mg/l .[11] This experiment has been concluded using different sample at various flowrates. The salted water used has pH level around 6.9 which was checked using litmus paper and color chart, TDS level of 230 mg/l checked with the help TDS meter & COD value of 12 mg/l. After getting purified water it was seen that TDS level was reduced to 48 mg/l & COD to 4 mg/l.

The muddy water sample had pH around 8.1 and TDS value was around 180 ppm which was checked using pH meter & TDS meter at varying flowrates like 290ml/min, 630, 1600,1950 ml/min respectively. % reduction in TDS value for this sample was nearly 35% & reduction in pH was 3.8% while for bore well water sample % reduction in TDS & pH approximately were near 30 % & 2.5% respectively. Whereas for salted water % reduction in TDS & pH approximately were near 42 % & 32 % respectively as well as for lake water sample % reduction in TDS & pH approximately were near 45 % & 4 % respectively.The experimental setup which consists of a cross-flow ultrafiltration module and a photocatalytic reactor whereas our experimental setup consists of

UV + UF system. The configuration of the UF unit was plate and frame in above photocatalytic reactor research paper and we are using hollow type of membrane.[8] The photocatalytic reactor was composed of three compartments, namely, an inner chamber, an outer chamber, and a void space between them. A UV light source was placed in the inner chamber of the reactor. The outer chamber can hold 2 L of liquid for the photocatalytic reaction. During the experimental runs, tap water was continuously passed through the void space to prevent the reactor from being overheated by UV illumination.[9] During our experimental run, the capacity of water passing through the sand filter is 750 ml approximately and the water passing through UF filter 3 lpm.

Above survey reported that the system consists of two parts: a cross flow UF unit with a recirculation loops and permeate backwashing unit. The recirculation loop is comprised of a membrane module, a circulation pump, a prefilter with a 200 µm mesh screen, a flow meter, and inlet and outlet pressure gauges between the module which can be used for waste water treatment as well as drinking water treatment. [3,6] But our unit is useful only for domestic purposes as it consist of one unit of UF + UV. Here raw water passed through CA hollow fiber membrane has pH level of 6.6 – 8, turbidity of 5 – 67, total bacteria around 500 l/ml while pure water has pH around 8, turbidity less than 5 where as our test conducted like TDS, Cl_2 determination ,presence of $CO_{2,}$ pH from various sample water like salt water, muddy water, lake water as well as bore well water TDS value was approximately between 250 – 460 ppm, pH was around 4 to 7, CO_2 of sample water was between 50 to 60 mg/l & chloride was around 70 mg/l of sample water.

Cost estimation of the project is instead of using sediment and activated carbon filter of Rs. 1000/- each, we had prepared homemade rapid sand filter having small cost. UF Filter of Rs. 480/- and UV barrel of Rs. 380/- having UV lamp of 12 W of Rs. 190/- using all these we made water purification system. Another example is a municipal seawater desalination system for drinking water where UF is being used ahead of RO, at say 3,000 meters cube per hour (which is a really large flow). A system at this rate could be Rs.600 ($10 million) for the complete UF system and Rs.900 ($15 million) for post-seawater RO, making the entire system about Rs. 1500($25 million), give or take 25%.

The feasibility of the UF membrane is it can be used in small scale as well as in some large scale industries and for domestic purpose. UF membrane can be combined with UV technology or with RO in filtration unit for water purification, desalination and waste water treatment. Reverse Osmosis Purifier (RO), Ultraviolet Rays Purifier (UV), Ultra Filtration (UF) are the three most important methods of purification technologies that are widely used in India. The UF Water purifier doesn't require electricity since it doesn't require Tap water pressure and works well with the regular pipe water pressure.

APPLICATION:

Other applications of UV+UF system apart from drinking water treatment can be as follows:

- Dairy industry;
- Food industry;
- Metal industry (oil/water emulsion separation);
- Textile industry;
- Pharmaceutical industry;
- Chemicals industry;

CONCLUSION:

We have concluded that filters used in the project are useful for small as well as large industries and for domestic uses. The set up runs properly according to our expectation i.e we get clean and purified water. Test conducted for checking the quality of water satisfied our result as mentioned above. The comparative study between the survey and our methodology has been done with respect to the parameter like TDS, COD, Ph,$CO_{2,}Cl_2$. Suspended solid and bad odor gets removed as well as the dissolved solid. It has selective function filtering DS, unwanted chemicals, microorganisms for eg., algae, bacteria, fungi, etc & maintaining its purity. Sand filter has advantage that they can be cleaned (back flushed) and reused.[15] In UF, no chemicals and no electricity are required where as in UV kills bacteria.[13]

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