Chemical Engineering for Good Challenge
2018 Competition Submission

How Chemical Engineering Can Be Applied to Solve World Problems on a Micro Scale

----

University Name & Location: _Universiti Teknologi PETRONAS_______________
Team Leads: AIChE- Universiti Teknologi PETRONAS
AIChE Universiti Teknologi PETRONAS president: [redacted]
Team Lead email: [redacted]
Team Lead phone:[redacted]
Title of Submission: Gravity Driven membrane Ultrafiltration of Surface water
Submission Type: __X_ underutilized technology ___technology toolkit

----

Contest entries must address **'How chemical engineering can be applied to solve world problems on a micro scale**". Three prizes of $3000, $2000, and $1000 will be awarded as unrestricted grants to the winning chapters. If judges determine that there are less than three submissions worthy of award than fewer prizes will be awarded. Submissions are directed toward problems that could be implemented by engineering service organizations in partnership with communities (often small and rural) in the developing world. Typically these partners have limited technical sophistication, capital, and funds to cover operating expenses. Utilizing appropriate, sustainable (in the broadest sense) technology is critical.
The competition is open to all AIChE student chapters, and entrants are encouraged to partner with other organizations experienced in doing this kind of work. Teams may be of any size, and may include students, faculty and professional engineers.
Submissions should utilize chemical engineering technology and skills (beyond the hydraulics calculations commonly used in designing water systems). Entries will either focus on one chemical engineering-based technology that is currently underutilized by teams working on international service projects (**ISP**) **or** provide a useful toolkit for ISP teams to identify, select, and utilize existing chemical engineering-based technologies to solve specific problems.
Attach to this cover page the information requested below for your type of submission. All submissions to be in electronic format. Only materials in English language will be considered.
1. Recommendation of the application of a specific technology, available today, that is not currently utilized in ISP projects.
A. Define the specific community problem being addressed
B. Describe the specific technology and how it is based on chemical engineering principles; provide electronic copies of or public links to references (papers, descriptions of commercial applications & offerings, patents, other supporting material)
C. Describe what kind of data would be required to design / customize this technology for ISP projects
D. Describe why this technology would be appropriate for implementation in partner communities. . Include consideration of technical, maintenance, financial, and cultural sustainability. Provide estimated typical costs for initial installation, maintenance, and operation.

A. Define the specific community problem being addressed

The 6th Sustainable Development goal set by the United Nations is “Ensure availability and sustainable management of water and sanitation for all”, this goal was developed as still there are places and people without access to clean water and Sanitation. According to the WHO/UNICEF Joint Monitoring Programme Report (2017), as of 2015 these are the key messages:

1. 29% of the world lacked safely managed drinking water supplies.
2. 844 million people still lacked even a basic drinking water service.
3. 263 million people spent over 30 minutes per round trip to collect water from an improved source (constituting a limited drinking water service).
4. 159 million people still collected drinking water directly from surface water sources, 58% lived in sub-Saharan Africa.
5. Contaminated water can transmit diseases such as diarrhoea, cholera, dysentery, typhoid, and polio. Contaminated drinking water is estimated to cause 502 000 diarrhoeal deaths each year.

A basic service is an improved drinking-water source within a round trip of 30 minutes to collect water. According to UNICEF, Advancing WASH in Schools Monitoring, 2015, 31% of schools lack clean water. The United Nations estimates that Sub-Saharan Africa alone loses 40 billion hours per year collecting water; the same as an entire year's labor in all of France!

UNICEF stated that millions of girls are deterred from getting an education because of a dearth of sanitation facilities in schools. The children are plagued by parasites, parasites consume nutrients, trigger malnutrition and reduce the overall performance of children.

The Lack of clean water has caused interruptions of children’s education and to obtain water from and improved water source takes considerable time. However, 159 million people collect water directly from surface water. Surface water contains micro-organisms which can cause water borne diseases such as cholera and dysentery.

A major symptom of these diseases is diarrhea, diarrhea is the passage of loose or liquid stools more frequently than is normal for the individual. It is primarily a symptom of gastrointestinal infection. Depending on the type of infection, the diarrhea may be watery (for example in cholera) or passed with blood (in dysentery for example).

Diarrhea is an indication of disease caused by a large group of bacterial, viral and parasitic living beings the vast majority of which can be spread by Contaminated water. It is more typical when there is a lack of clean water for drinking, cooking and cleaning and fundamental cleanliness is essential in prevention.

Diarrhea can likewise spread from individual to individual, enhanced by poor personal hygiene. Food is another significant reason for diarrhea when it is arranged or stored in unhygienic conditions. Water can taint food during irrigation and fish and other aquatic life may also contribute to it.

Amongst the poor and especially in developing countries, diarrhoea is a major killer. In 1998, diarrhoea was estimated to have killed 2.2 million people, most of whom were under 5 years of age (WHO, 2000). Each year there are approximately 4 billion cases of diarrhoea worldwide.

Surface water can be a viable water source if treated. The focus of this study is to develop a viable method to treat surface water to aid in solving the clean water crisis. Given that 159 million people drink from surface water if it is treated we can provide clean water for 159 million people.

In developing countries, there are problems that arise with centralized water treatment systems, these are due to malfunctions of treatment systems leading to contamination. The Implementation of large scale centralized treatment systems require substantial investments, infrastructure and technical expertise which may be unavailable at the respective countries (Shannon, Bohn, Elimelech, Georgiadis, Marinas & Mayes (2008).

Conventional water treatment methods, usually require multi-stage treatment which are chemically and energetically intensive which can be too costly to build and maintain. (Shannon et al., 2008; Montgomery and Elimelech, 2007). Thus, decentralized or point of use water treatment systems are proposed in this study.

B. Describe the specific technology and how it is based on chemical engineering principles; provide electronic copies of or links to references (papers, descriptions of commercial applications & offerings, patents, other supporting material)

Membrane

Membranes act as a filter that allow certain substances to pass through. The ratio of permeance of a membrane is called selectivity. Membranes can be polymeric, composite or pure. They are used in separation process for increasing the concentration of the permeate and for reducing the impurities in the retentate.

There are 5 main membrane models used in gas separation:

1. Perfect mixing model
2. Cross flow model
3. Counter-current model
4. Co-current model
5. One sided mixing

In this research, only cross flow models are analyzed. This is because it does not require a sweep gas, as this would complicate the design.

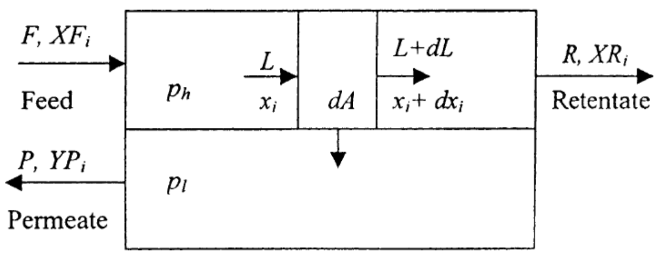

Figure 1: Process flow diagram for a cross flow model Adapted from "Upgrading low-quality natural gas with H2S-and CO2-selective polymer membranes: Part I. Process design and economics of membrane stages without recycle streams." By Hao, J., Rice, P.A. and Stern

x_i	Feed side mole fraction
y_i	Permeate mole fraction
p_h	Feed pressure
p_l	Permeate pressure
A	Area of membrane
L	Flow rate on feed side
F	Feed flow rate
XF_i	Feed mole fraction
R	Retentate flow
XR_i	mole fraction in retentate
P	Permeate flow rate
Ypi	mole fraction in permeate

According to Hao, Rice and Stern (2002) the cross-flow model assumptions and mass balance are as follows.

Assumptions:

1. The gas streams on the feed and permeate sides of the membranes are represented by the *cross-flow* model.
2. The pressure drop on the feed and permeate sides of the membranes was not considered.
3. The permeate flux is governed by Fick's law of diffusion.

The governing equations are as follows:

$$y_i = \frac{J_i}{\sum_{j=1}^{n} J_j}$$

$$\frac{dx_i}{d\theta} = -\frac{y_i - x_i}{(1-\theta)}$$

$$\frac{dA}{d\theta} = \frac{F}{\sum_{i=1}^{n} \left(\frac{P_i}{\delta}\right)(p_h x_i - p_l y_i)}$$

The solution for the cross-flow model requires the solution of differential equations. This will be elaborated further when the design of membrane is involved the in the second phase of the plant design project.

Where:

Ɵ is stage cut

P_i is permeability of substance i through the membrane

δ is the membrane thickness.

In this report, membranes are used in water filtration to ensure that he water is free of contaminants and is safe for consumption. The membrane parameters are based on the material of the membrane and it's fabrication eg: pore size, membrane thickness etc.

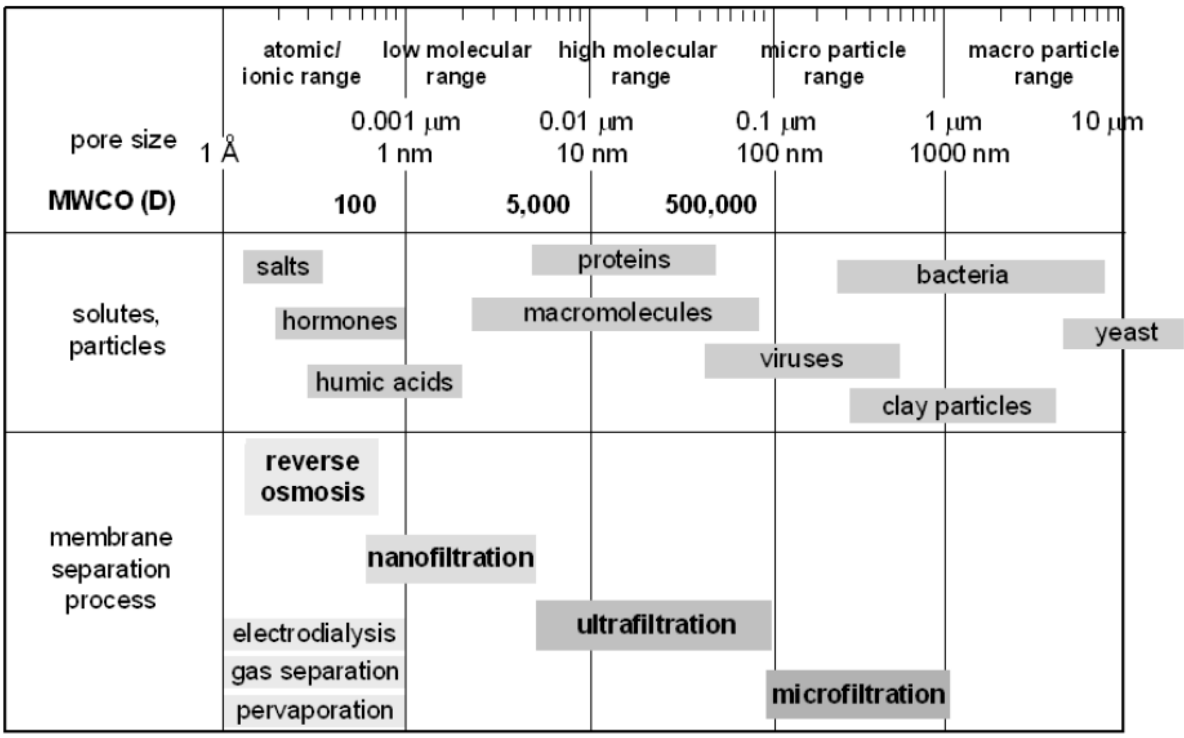

Figure 2 - Membrane separation processes, pore sizes, molecular weight cut-off (MWCO) and examples of sizes of solutes and particles.

In the production of potable water, the degree of separation is important, the greater the separation of water, the greater energy required and solute removal. It is important to assess the degree of filtration with respect to water-borne contaminants. The pore size of Microfiltration was considered to be small enough to remove microbiological hazards, however there have been doubts with its ability to remove bacteria (Wang *et al*., 2007). To avoid this complication, ultrafiltration is considered to be safer and able to remove all kinds of microbiological hazards such as *Cryptosporidia*, *Giardia* and total bacterial counts (Hagen, 1998). With the use of Ultrafiltration, viruses with the range of 30-300 mm can also be removed. While Reverse osmosis and nano-filtration can also be used they require a higher differential pressure and would need to use of a pumping device.

The separation system that will be used to achieve Ultrafiltration (UF) shall be membrane separation. The membrane separation technology will be assessed based on membrane performance during fouling, comparison with conventional water filtration system and implications of membrane technology. There are some ultrafiltration designs which incorporate an activated carbon filter which requires replace every 6 – 18 months.

In comparison to conventional water treatment, the main advantage of membrane filtration is that it occurs in a single stage, without the need for extensive chemical and energy consumption. Membrane technology has undergone developments in the last decades with significant reduction in membrane costs and energy (Churchhouse, 2000). Membranes are usually designed in modules that can be easily implemented to existing water systems.

The main limitation of membrane systems is membrane fouling. Membrane fouling occurs when the solutes that are unable to pass through the membrane begin to cause resistance to fluid flow through the membrane. Due to thus, membranes generally have to back flushed every 30 minutes. (Peter-Varbanets ,Zurbrügg, Swartz &Pronk,2009).To perform this cleaning, automated process control is required, and this complicates the design.

To tackle this issue, a study done by Peter-Varbanets , Margot, Traber & Pronk (2011), was done to understand the behavior of membranes during fouling. To perform this experiment, surface water was taken from 4 sources (natural river water, natural lake water, diluted wastewater of two different dilution rates and disinfected river water). The membranes were studied to observe the effect of different sources of surface water and pressure on flux stabilization. The membrane specifications are as follows:

Table 1.0: Membrane specifications by Peter-Varbanets et al., (2011)

Membrane material	Polyethersulfone
Molecular Weight cutoff/ Pore Size	100 kDA / 9 nm
Membrane configuration	Flatsheet

Molecular Weight Cutoff (MWCO) is used to estimate the pore size, to do the figure 3 is used. From the figure, we can observe that the pore size is 9 nm.

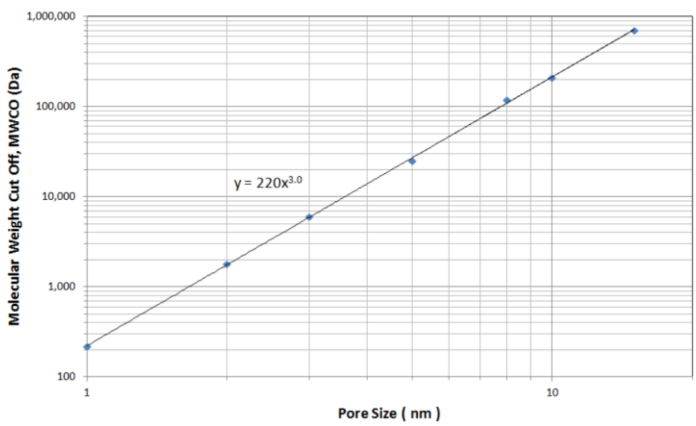

Figure 3: Relation between pore size and molecular weight cut off von Recum, 1999

The experimental setup for the membrane module is shown below.

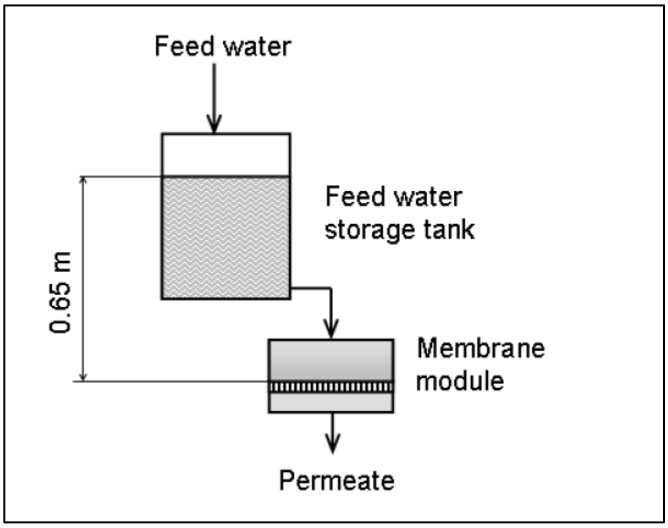

Figure 4: Gravity-driven membrane Ultrafiltration

In the experiment done by Peter-Varbanets et al., (2011). The tank was connected by Teflon tubing to the membrane module. At least three modules were operated in parallel under similar conditions. The permeate flux was measured and logged with an Ohaus Adventure Pro scale and the hydraulic resistance of the fouling layer calculated according to the Darcy law. All the experiments were conducted at 20 ± 2ºC.

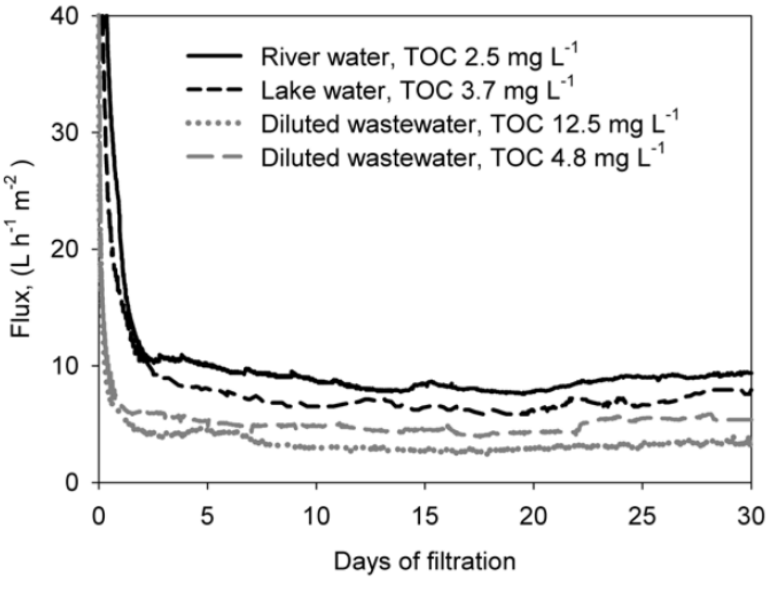

Figure 5 - Membrane flux during 30 days of dead-end operation for different water types

From the figure above, we can observe a sharp decline of flux through the membrane and stabilization of flux. The decline of flux is attributed to membrane fouling; however, it must be noted that the effect of fouling stopped, and the flux stabilized at 4-10 ($L.h^{-1}m^{-2}$), generally river water had the highest flux followed by Lake water and wastewater. This is because the TOC (Total organic carbon) present is in decreasing order.

In another study performed by Peter-Varbanets et al., (2011), these Ultrafiltration systems can be operated for 6 months at a time before requiring clean up. This significantly reduces downtime and maintenance cost.

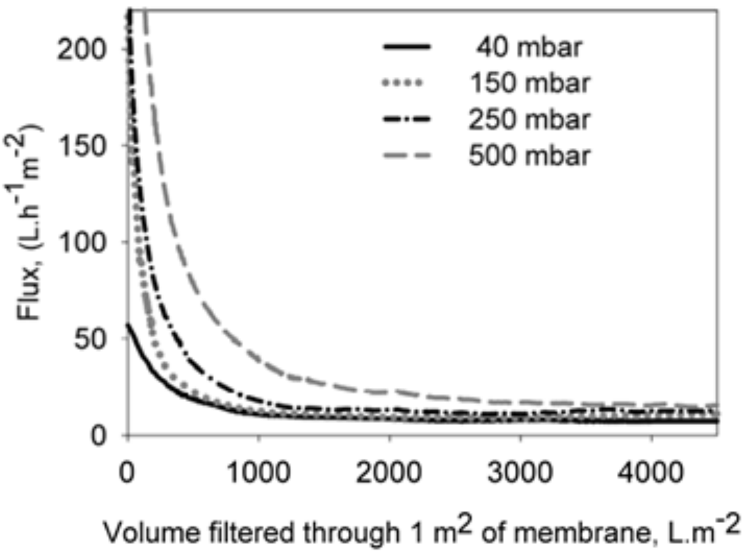

Figure 6- Membrane flux during dead-end ultrafiltration of river water at 40, 150, 250 and 500 mbar.

In the study to analyze the effect of varying pressure, the differential pressure across the membrane was varied and set to 40,150,250 and 500 mbar. The trend is similar to that of varying TOC, where the highest pressure generally has the highest flux and decreases respectively. Similarly, it is crucial to note that the flux stabilizes at a range of 4-10 ($L.h^{-1}m^{-2}$).

Implications

UF systems based on the phenomenon of flux stabilization would require considerably less maintenance and downtime. This discovery by (Peter-Varbanets,Hammes,Vital &Pronk,2010) allows for ultrafiltration systems to be a more attractive method for water filtration method. Given that the differential pressure required is 40mbar, no pumping work is required, and this system can be decentralized for household use. This 40mbar can be achieved through gravity flow via filling water a certain height above the membrane. According to Sobsey (2002), the average household consumes 10 - 40 L·day-1 per family of potable drinking water. For conventional decentralized systems the costs of pumps and auxiliary equipment far supersede the membrane costs (Peter-Varbanets et al., 2009). This system of gravity-driven membranes can operate at a considerable lower price than conventional decentralized systems. While these systems operate at a lower flux of 4-10 ($L.h^{-1}m^{-2}$), as opposed to conventional UF systems 50-100 ($L.h^{-1}m^{-2}$), they are sufficient for point of use systems for a household (Peter-Varbanets et al., 2010).

Membrane Flux stabilization

As stated earlier, the flux of permeate passing through the membrane depends on the membrane material and properties. In the experiment done by Peter-Varbanet (2011), polyethersulfone was used as a membrane with pore size of 9 nm. In a study done by Wu ,Christen, Tan, Hochstrasser ,Suwarno , Xin Liu, Chong, Burkhardt, Pronk and Fane (2017) a different gravity driven membrane was analyzed for the flux stabilization. The membrane specifications are in the table below:

Table 2: Membrane specifications by Wu et al., (2017)

Membrane material	Polyvinylidene difluoride
Pore size	0.08μm
Membrane configuration	Flat sheet

The experiment was performed using the PVDF membrane, to perform ultrafiltration of surface water. Here the water source was from the sea. The hydrostatic pressure of the water was 40 mbar, the membrane was operated for 250 days without interruption. Through this setup the membrane flux was recorded and an extract from the results is shown below:

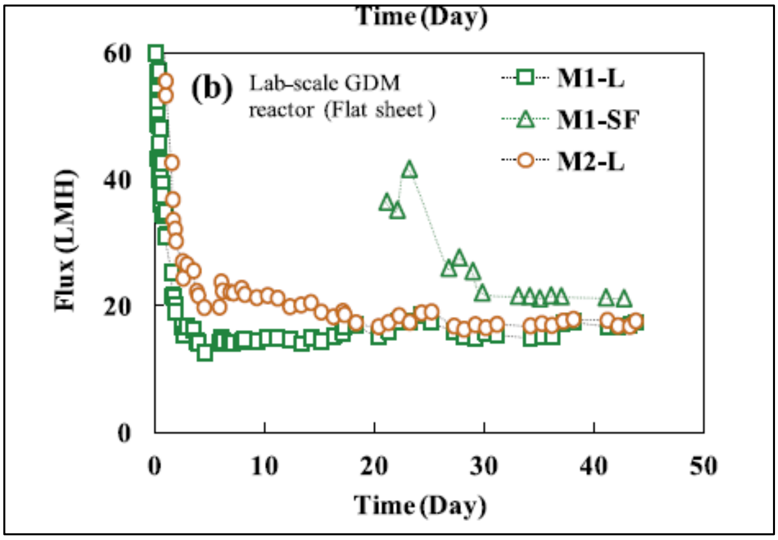

Figure 7: Membrane flux stabilization of the PVDF flat sheet membrane

The extract shows data from 50 days of operation were shown, the membrane flux stabilized approximately at 18 ($Lm^{-2}h^{-1}$). This flux is much higher than the flux of the polyethersulfone membrane. While the operating pressures of both membranes were the same, the pore size and material of the membrane were different. This shows that the flux depends on the organic components in the surface water as shown by Peter-Varbenet et al. (2011) and also on the membrane material and pore size.

This information is important in evaluating the type of membrane to be used when designing the ultrafiltration membrane filter. The membrane flux determines the membrane area required to deliver the specified volumetric flowrate.

C.Describe what kind of data would be required to design / customize this technology for ISP*.

Water Treatment Design

To design the water treatment system, we must obtain the following:

1. Capacity of water treatment.
2. Membrane to be used.
3. Membrane area required.
4. Dimensions of treatment system.
5. Material to be used for treatment system.

To determine the capacity of the Water Treatment System (WTS), the work done by Peter and Maryna (2010) is used as reference. The Table below shows estimates of membrane costs for point-of-use and small-scale community decentralized water.

Table 1 - Estimation of membrane costs for point-of-use and small scale decentralized water treatment

Water Treatment System	Point-of-use (family)	Small Scale (community)
Purpose of water treatment	drinking/cooking 2-8 $L{\cdot}person^{-1}{\cdot}day^{-1}$	basic domestic needs 20 $L{\cdot}person^{-1}{\cdot}day^{-1}$
Capacity	Family of 5 people $\leq 0.04\ m^3{\cdot}day^{-1}$	Community of 250 people $5\ m^3{\cdot}day^{-1}$
Membrane area required assuming flux of 4-10 $L{\cdot}h^{-1}{\cdot}m^{-2}$	0.17-0.42 m^2	21-52 m^2
Membrane lifetime expectancy	2 years	4 years
Membrane costs	3.4-8.4 $\${\cdot}$ $family^{-1}{\cdot}year^{-1}$ 0.68-1.68 $\${\cdot}person^{-1}{\cdot}year^{-1}$	208-521 $\${\cdot}community^{-1}{\cdot}year^{-1}$ 0.83-2.08 $\${\cdot}person^{-1}{\cdot}year^{-1}$

In our WTS design, we will consider Point-of-use system, the maximum capacity required is 40 L/day. The membrane lifetime is expected to be 2 years. However, in our design we will be using an activated carbon which needs to be replaced every 6 months.

Membrane Selection

A suitable membrane must be selected for the water filter. The two membranes that were discussed in the literature were polyethersulfone and polyvinylidene difluoride with membrane stabilization fluxes of 4 to 10 ($Lm^{-2}h^{-1}$) and 18 ($Lm^{-2}h^{-1}$). For this report an experiment was conducted to evaluate the performance of polysulfone membrane for ultrafiltration of surface water at low pressures. The surface water used here was lake water.The experiment was conducted at a hydrostatic pressure of 100mbar.

Membrane material	Polysulfone
Pore size	0.1μm
Membrane configuration	Flat sheet

The membrane was run for 100 minutes to evaluate the membrane flux stabilization and the figure below shows the results.

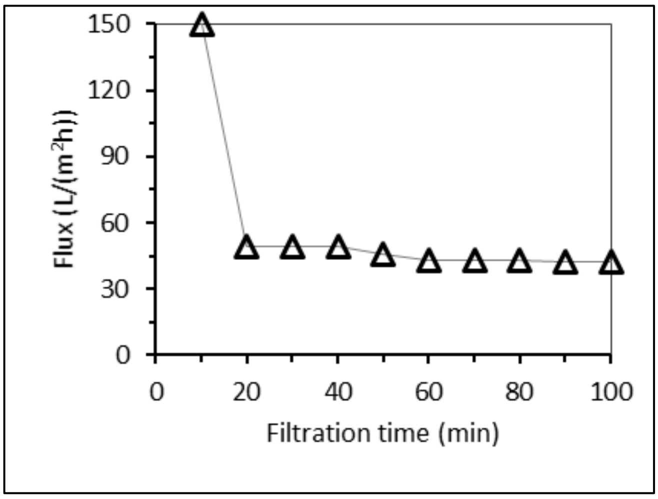

Figure 8: Polysulfone membrane flux stabilization

The polysulfone membrane achieves a flux stabilization of 42 ($Lm^{-2}h^{-1}$), this experimental flux is significantly higher than the flux obtained from literature as the hydrostatic pressure of the surface water was higher. The experiment was done at a hydrostatic pressure of 40 mbar and the flux stabilized at 16 ($Lm^{-2}h^{-1}$). The comparison of the three membranes is shown below:

Membrane	Polyethersulfone(PES)	Polysulfone (PsF)	Polyvinylidene difluoride (PVDF)
Pore size	9 nm	0.1 μm	0.8 μm
Membrane configuration	Flat sheet	Flat sheet	Flat sheet
Pressure	40 mbar	40 mbar	40 mbar
Stabilized Flux	4 – 10 ($Lm^{-2}h^{-1}$).	16 ($Lm^{-2}h^{-1}$)	18 ($Lm^{-2}h^{-1}$).

The PVDF membrane has the highest stabilized flux at 40mbar and will be used as the membrane.

Design Methodology

For a design of a maximum capacity of 40 litres per household per day.

1. Membrane dimensions: Width = 21 cm, Length = Varied (X)
2. Each membrane is two sided.

   $$\text{Membrane area, } A_m = 2 \text{ x } [0.21\text{m} \times (0.05\text{X m} + 0.3\text{m})] \qquad \text{in m}^2$$

3. Total membrane area:

   $$\text{Total membrane area required} = \sum_{X=0}^{a} 2\,[0.21\text{m} \times (0.05\text{X m} + 0.3\text{m})] \qquad \text{in m}^2$$

   where, X = increment in membrane length by a factor of 1

   a = frequency of increment in membrane length

4. Number of frames per unit:

   $$\text{Number of frames per unit, F} = \text{a} + 1$$

5. Number of membranes per unit:

   $$\text{Number of membranes per unit, N} = 2\text{F}$$

6. Length of unit:

   Thickness of frame = 2 cm, Frame Spacing = 5 cm

   $$\text{Length of unit, L} = [0.05\text{m} \times (\text{F} + 2)] + (0.02\text{m} \times \text{F})$$

7. Width of unit, W = 0.21 m
8. Height of unit:

   $$\text{Height above the filter, } H_t = 0.5\text{m} - \frac{1}{2}[(\text{a} \times 0.05\text{m}) + 0.3\text{m}]$$

   If the value is negative, no extra top is required.

   $$\text{Height below the filter, } H_b = \frac{0.04 \text{ m}^3}{0.21\text{m} \times \text{L}}$$

   $$\text{Height of unit, H} = [(\text{a} \times 0.05\text{m}) + 0.3\text{m}] + H_t + H_b$$

9. Volume of unit:

   $$\text{Volume of Unit} = \text{LWH} \qquad \text{in m}^3$$

10. Volume of Activated Carbon required per unit:

   $$V_{AC} = \frac{1}{2}[0.21m \times L \times (a \times 0.05)] \qquad \text{in m}^3$$

Material to be used for treatment system

The WTS will use the PVDF membrane for the filter, the casing will be made from Low density polyethylene (LDPE) with activated carbon as the adsorbent. The WTS will look like this:

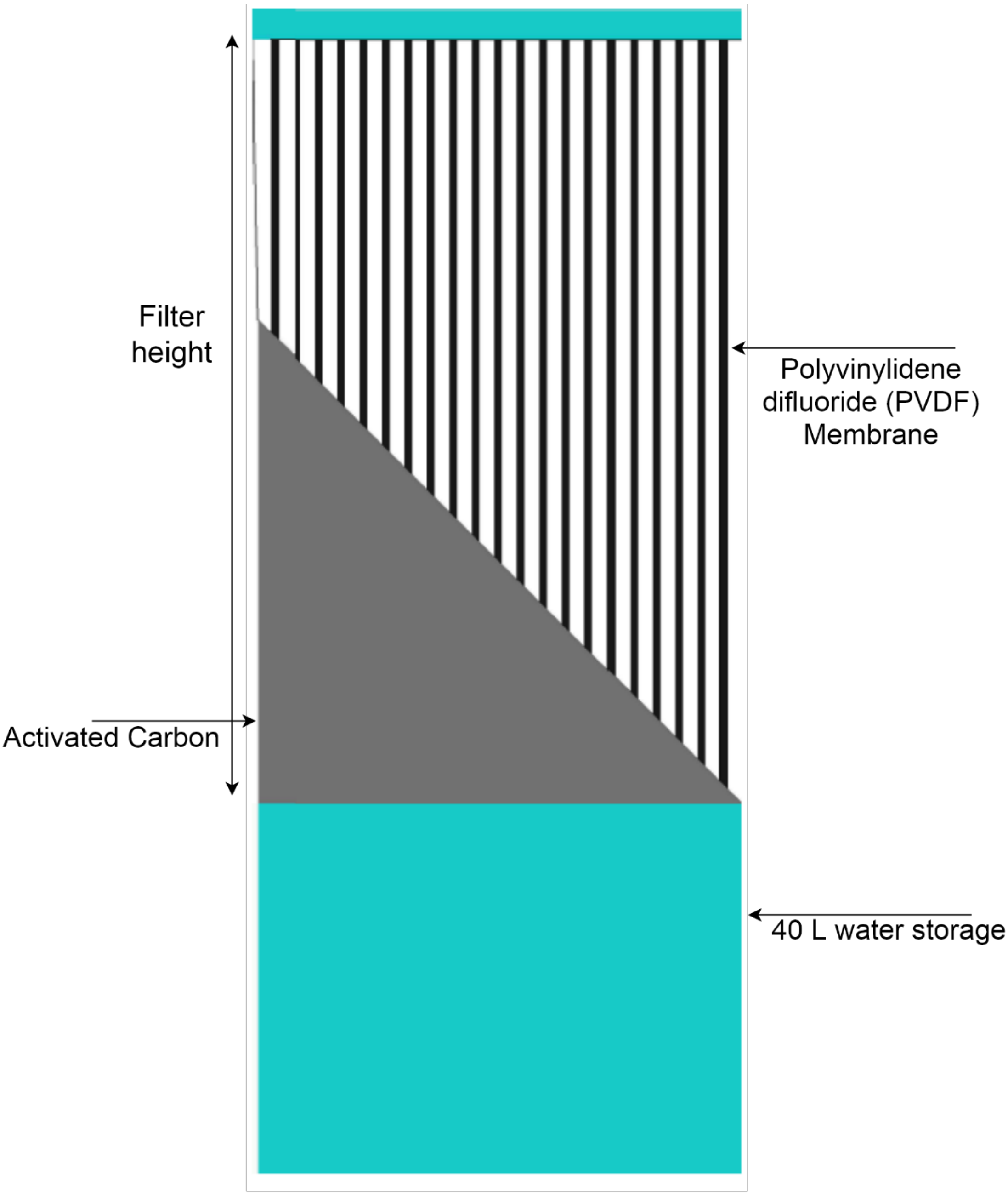

Figure 9: 3D CAD drawing of proposed Water treatment system

D.Describe why this technology would be appropriate for implementation in the developing world partner communities. Include consideration of technical, maintenance, financial, and cultural sustainability. Provide estimated typical costs for initial installation, maintenance, and operation.

The idea of a gravity-driven water membrane ultrafiltration system is one which aims to aid in solving the water crisis. As stated earlier, 159 million people have access to surface water but do not have a means to purify the water. Through membrane design, there is no power consumption for the treatment of water. The Point-of-use system enables every household to be able to have and store water.

The design of the WTS is a simple straightforward method for purifying water, the only requirement for water filtration is that the hydrostatic pressure be above 40 mbar which is equivalent to 40cm of liquid water in height. This membrane which is the key part of the design is able to process different kinds of surface water as shown in literature, the membrane can even be used to filter sea water. Given that the membrane needs to be washed every 6 months and the activated carbon filter needs to be replaced every 6 to 18 months as per shown in the reviewed literature, maintenance and down-time can be shortened. The cost estimation and detailed design for the system is shown below.

By taking the maximum daily requirement of 40 L/day, we can design the membrane based on the flux. Taking an estimate of 2 hours to fill up the 40 L tank.

$$\text{Membrane area required } = \frac{\frac{40\text{L}}{2\text{h}}}{18} = 1.111\ \text{m}^2$$

$$\text{Total area } = \sum_{\text{X}=0}^{\text{a}} 2\,[0.21\text{m} \times (0.05\text{X m} + 0.3\text{m})]$$

$$\text{Solving for a; Total area } = \text{ required area}$$

$$\text{at a} = 6\text{ , Total area } = 1.323\ \text{m}^2$$

$$\text{Number of frames } = 6 + 1 = 7$$

$$\text{Number of membranes } = 2 \times 7 = 14$$

$$\text{Length of unit } = [0.05 \times (7 + 1)] + (0.02 \times 7) + 2\,(0.05) = 0.59\ \text{m}$$

$$\text{Height above the filter, } \text{H}_\text{t} = 0.5\text{m} - \frac{1}{2}[(6 \times 0.05\text{m}) + 0.3\text{m}] = 0.2\ \text{m}$$

$$\text{Height below the filter, } H_b = \frac{0.04\ \text{m}^3}{0.21\text{m} \times 0.54\text{m}} = 0.35\ m$$

$$\text{Height of unit, } H = [(6 \times 0.05\text{m}) + 0.3\text{m} + 0.05\ \text{m}] + 0.2\text{m} + 0.35\text{m} = 1.15\ \text{m}$$

Taking a thickness of 3cm per side:

$$\text{Volume of Casing} = (0.57\text{m} \times 0.24\text{m} \times 1.18\text{m}) - (0.54 \times 0.21 \times 1.15) = 0.031\ m^3$$

$$V_{AC} = \frac{1}{2}[0.21\text{m} \times L \times (6 \times 0.05)] = 0.01701\ \text{m}^3$$

Flowrate Specification

$$\text{Water velocity, } v = C_v\sqrt{2gH}$$

where, v = outlet velocity (m/s)

g = gravitational acceleration (9.81 m/s^2)

H = height of liquid (m)

$$\text{Volumetric flow, } V = C_d A\sqrt{2gH}$$

where, V = volumetric flow (m^3/s)

A = area of aperture – flow outlet (m^2)

$C_d = C_c C_v$, discharge coefficient

C_v = velocity coefficient (water 0.97)

C_c = contraction coefficient (sharp edge aperture 0.62, well-rounded aperture 0.97)

A = area aperture (m^2)

Taking an outlet diameter of 1 cm,

$$A = \frac{\pi}{4}(0.01m)^2 = 7.95 \times 10^{-5}\ m^2$$

$$C_d = 0.97 \times 0.97 = 0.9409$$

Taking the liquid height in the storage tank to be at 50% capacity:

$$H_b = \frac{1}{2} \times 0.33m = 0.165\ m$$

Taking the centre of the nozzle to be 3cm from the bottom of the storage tank:

$H = 0.165m - 0.03m = 0.135m$

$$V = 0.9409 \times 7.95 \times 10^{-5}\ m^2 \times \sqrt{2 \times 9.81\ \frac{m}{s^2} \times 0.135m} = 1.17 \times 10^{-4}\ m^3/s$$

This corresponds to a flowrate of 421.2 L/h.

A desired flowrate of 90 L/h at 50% capacity is targeted which corresponds to a liquid height, H_b of 0.04167m, therefore the required pressure loss across the tap to attain this flowrate is:

$$\Delta \mathrm{P} = \left(1000\ \frac{\mathrm{kg}}{\mathrm{m}^3} \times 9.81 \frac{\mathrm{m}}{\mathrm{s}^2} \times 0.135\mathrm{m}\right) - \left(1000\ \frac{\mathrm{kg}}{\mathrm{m}^3} \times 9.81 \frac{\mathrm{m}}{\mathrm{s}^2} \times (0.04167\mathrm{m} - 0.03\mathrm{m})\right)$$

$$\Delta \mathrm{P} = 1209\ \mathrm{Pa}$$

The Diagram below shows the full WTS system

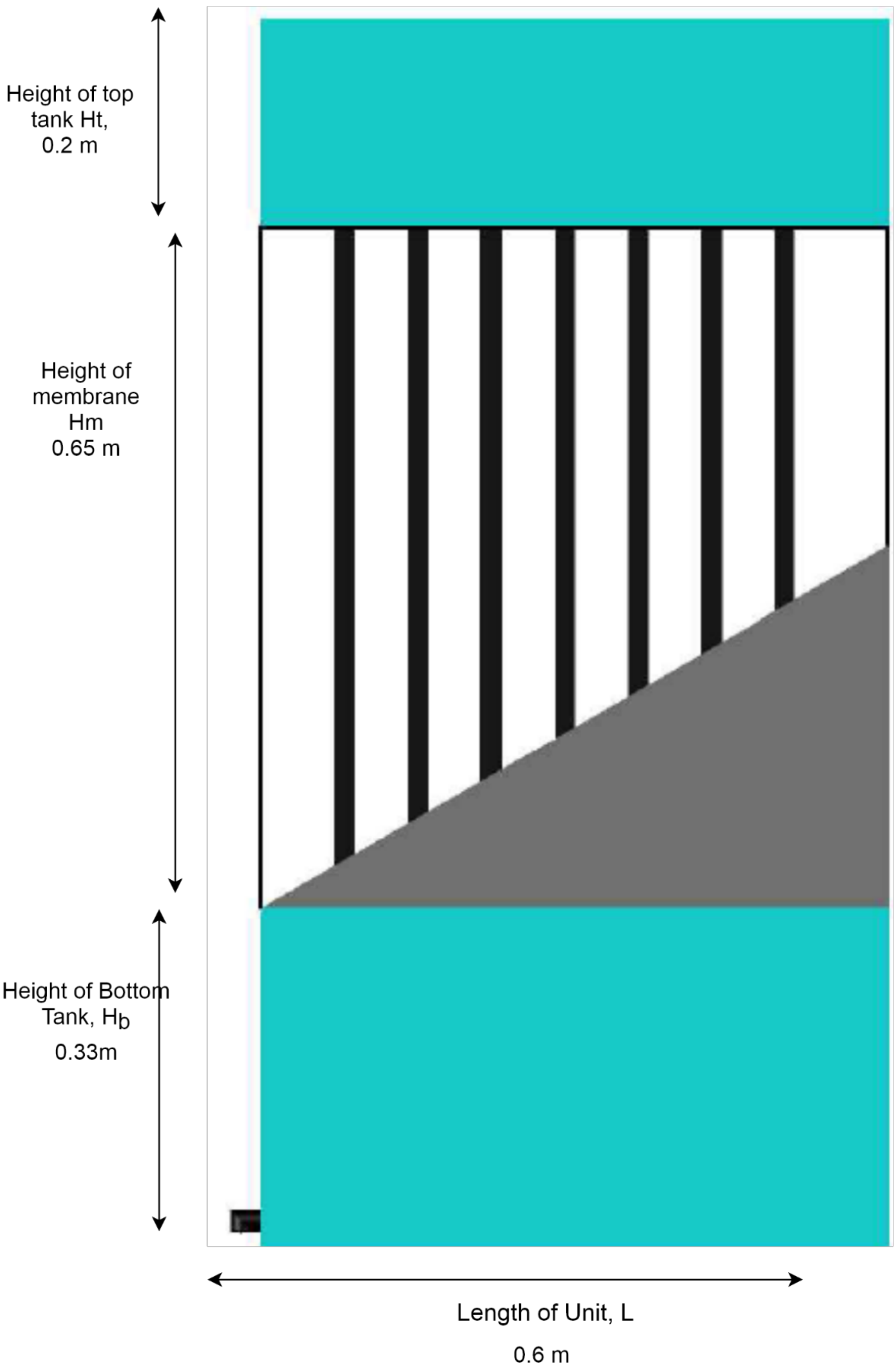

Figure 9: 3D CAD drawing of proposed WTS

Costing

Through using the estimates below the costing for the WTS can be estimated. The price of membrane was in accordance with Churchhouse (2002). The Plastic and activated carbon were estimated from commercial suppliers.

Material	Price per unit
Polyvinylidene difluoride (PVDF)	$40/m^2$
Plastic (LDPE)	$1406/m^3$
Activated Carbon	$2800/m^3$

$$\text{Membrane cost} = \frac{\$40}{\text{m}^2 \text{ membrane}} \times 1.323 \text{ m}^2 = \$52.92$$

$$\text{Casing cost} = \frac{\$1406}{\text{m}^3 \text{ LDPE}} \times 0.031 \text{ m}^3 = \$43.59$$

$$\text{Activated Carbon cost} = \frac{\$2800}{\text{m}^3 \text{ AC}} \times 0.01701 \text{ m}^3 = \$47.63$$

$$\text{Total cost} = \$52.92 + \$43.59 + \$47.63 = \$144.14 \cong \$145$$

The maintenance cost is replacing the membrane every 2 years and the activated carbon filter yearly. The cost for 2 years of operation including capital investment is $ 192.63. The cost per person per year is $19.263.

Conclusion

An advantage of this design is that every household can be equipped with the WTS, this reduces the complexity of design as well as cost of operation and the risks of contamination. To purify the water, surface water can be collected using buckets and is added to the top of the system for water filtration. All in all this system is easy to use, is energy efficient and can aid to end the water crisis by providing a means to purifying surface water. The system flowrate was designed at 90 LPH so that the water flow is not slow, when providing an alternative we must take into consideration the people using the design. 90 LPH is equivalent to filling up a 250 ml cup in 10 seconds. The Full design is roughly 1.2 m which is no bigger than an average water dispenser. With this design surface water can be used as a potable drinking surface and will contribute to reducing the water crisis that is being faced today.

References

1. Peter-Varbanets, M., Hammes, F., Vital, M., & Pronk, W. (2010). Stabilization of flux during dead-end ultra-low-pressure ultrafiltration. *Water research*, *44*(12), 3607-3616.
2. Peter-Varbanets, M., Margot, J., Traber, J., & Pronk, W. (2011). Mechanisms of membrane fouling during ultra-low-pressure ultrafiltration. *Journal of Membrane Science*, *377*(1-2), 42-53.
3. Peter-Varbanets, M., Zurbrügg, C., Swartz, C., & Pronk, W. (2009). Decentralized systems for potable water and the potential of membrane technology. *Water research*, *43*(2), 245-265.
4. Churchhouse, S., 2000, Membrane Bioreactors hit the big time - from lab to full scale application In Membrantechnik, 3. Aachener Tagung (Rautenbach, R., Melin, T., Dohmann, M. ed.), pp. B12, 11-17. Klenkes Druck und Verlag GmbH, Aachen.
5. Shannon M.A.; Bohn, P.W., Elimelech, M., Georgiadis, J.G., Marinas, B.J., Mayes, A.M. (2008) Science and technology for water purification in the coming decades. Nature 452 (7185), 301-310.
6. Montgomery, M.A.; Elimelech, M. (2007) Water and sanitation in developing countries: Including health in the equation. Environ. Sci. Technol. 41 (1) 17-24.
7. F., V. R. (1999). Handbook of biomaterials evaluation: Scientific technical, and clinical testing of implant materials. Estados Unidos: Taylor & Francis