Human Powered Reverse Osmosis for Producing Potable Water for Developing Countries

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ABSTRACT

The aim of this paper is to discover whether human powered reverse osmosis is a viable option for producing potable water for developing countries. The matters at hand are to determine whether human power is enough to operate such a system, how much clean drinking water it will produce, and if it produces a reasonable amount for the work put in.

A device was designed to test the practicality of this idea through a numerical analysis. The device uses a bicycle to harness human motion to convert it into usable power to run a reverse osmosis filtration system. The flow rate was determined according to given information from the reverse osmosis manufacturer. This was used to calculate the power needed to power such a design and was then compared with researched data of available power from humans. It indicated that a human could easily provide enough power to run a reverse osmosis system such as this. The flow rate was then used to determine how useful this power was by considering how fast it could produce clean drinking water and how much water a person needs to drink daily. Ultimately from all of the research and results, it was determined that human powered reverse osmosis is not only a viable option, but an incredibly economical and effective means for providing potable water for developing countries.

Keywords: potable water, filtration, reverse osmosis, human powered, developing countries

1. INTRODUCTION

1.1 GLOBAL WATER CRISIS

The Earth is covered in over 75% water, yet one of the world's greatest issues is a lack drinking water. "Nearly one billion people do not have access to clean drinking water" (Water.org Inc., 2009). That is about one eighth of all the people living on earth right now. Every year, almost four million people die from water-related diseases and 98% of those occur in the developing world (Water.org Inc., 2009). Humans can live for weeks without food, but only a few days without water (Water.org Inc., 2009). Many people in developing countries barely have access to any water source at all and for those that do, the water is completely filthy and disease-ridden.

Clearly, access to potable water around the world is an exceedingly urgent issue in which action should be taken immediately. In response to such a need, this idea is proposed to produce clean drinking water by reverse osmosis filtration by means of human power. There are several means to purify water; however, because of its incredible thoroughness, a reverse osmosis system has been preferentially selected for this design.

1.2 REVERSE OSMOSIS

Osmosis is a natural process in which a liquid from a less concentrated solution flows through a semi-permeable membrane to a more concentrated solution. Reverse osmosis (RO) is just as it sounds, the reverse of osmosis. Pressure is applied on the more highly concentrated solution so that liquid flows from the higher concentrated solution to the lower concentrated solution. Figure 1 shows an illustration of this process. In this case the highly concentrated solution is dirty, undrinkable water. For this system, pressure is applied so that "water molecules are forced through a 0.0001 micron semi-permeable membrane… separating it from unwanted substances" (FreeDrinkingWater.com, 2010). These substances are then drained from the system by being carried away by the unprocessed rinse water so that they do not build up and clog like ordinary filters. This allows a reverse osmosis filter to last for several years rather than just months (FreeDrinkingWater.com, 2010)

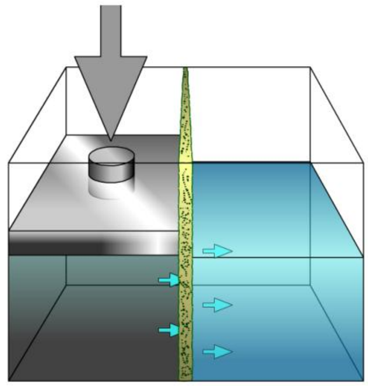

Figure 1: Reverse Osmosis

2. DESIGN

2.1 POWER SOURCE

To use an RO system, there needs to be a form of energy applied to force pressure through it. There are many forms of power that can be used, but most are highly expensive or inefficient, such as fuel or photovoltaic cells. Human power has not been extensively researched as a means for powering an RO system, but it has innumerable advantages to any other power source. The issue is whether human power is actually enough to run an RO system and whether the potable water that is produced from it is effective enough for the work put in. A bicycle was chosen to harness human power effectively because of its simplicity, widespread use, and relatively great power potential from human leg strength.

2.2 COMPONENTS

A design was created for the purpose of calculating the feasibility of human powered reverse osmosis. The components of the system design were picked carefully with quality and price in mind. The main component list for the system set-up is relatively small. This is done intentionally so that it is cheaper, light-weight, and more mobile. The components are as follows: bicycle with mechanical drive system, compressor pumps, reverse osmosis system, and water tank with filter bags.

The bicycle can be either single or multi-speed, as both are easily adapted to link up to the drive gear on the pumping arm. A single-speed bicycle simply utilizes an extended length chain connected to the system driving gear and a few pulleys to redirect the chain to keep it riding on the gears. A multi-speed bicycle can be adapted more easily and directly by running a separate chain from the one of the unused rear gears to the system driving gear. The bicycle will also have a reinforced luggage rack, which will hold the tank and RO system. Being a bicycle, this also naturally allows water to be obtained from distant sources with the option of being cleaned during travel.

The pump system starts with a gear driven shaft attached to the bicycle chain. The shaft turns a disk and connection rod. The pump handles are fixed to the other end of the connection rod, and the pump ends are connected directly to fittings tapped into the main tank. The diameter of the drive disk is equal to the throw of the pumps. Each pump has a 120 psi capability. Two pumps are used to build pressure faster, to maintain pressure, and for redundancy in the event of failure. The pumps are fairly inexpensive in the event that they need to be replaced.

The tanks are modified jerry cans. The initial five gallon filter tank will be fitted with several layers of 5-200 micron filter mesh bags to remove as much heavy sediment as possible before the water is further purified. These filter bags are easily removed for cleaning and reuse. The filter tank also has two fittings for the pressurization pumps as well as an exit for the pre-filtered water. To prevent the pressurization system from overpowering the reverse osmosis filters, the filter tank will also have a 100 psi relief valve. Storage tanks for rinse and potable water can be mounted as saddle bags to give better weight distribution if desired.

The main component of the entire design is the APEC RO-CTOP Ultra Reverse Osmosis System. It has four different filtering stages used to purify and improve the quality of the water. The main filter in this system utilizes reverse osmosis to remove any impurities down to 0.0001 microns in size. This removes virtually any traces of metals, dust, bacteria, and viruses as it is the most thorough of filters. The particle size removed by this RO system is shown in Figure 2 (FreeDrinkingWater.com, 2010).

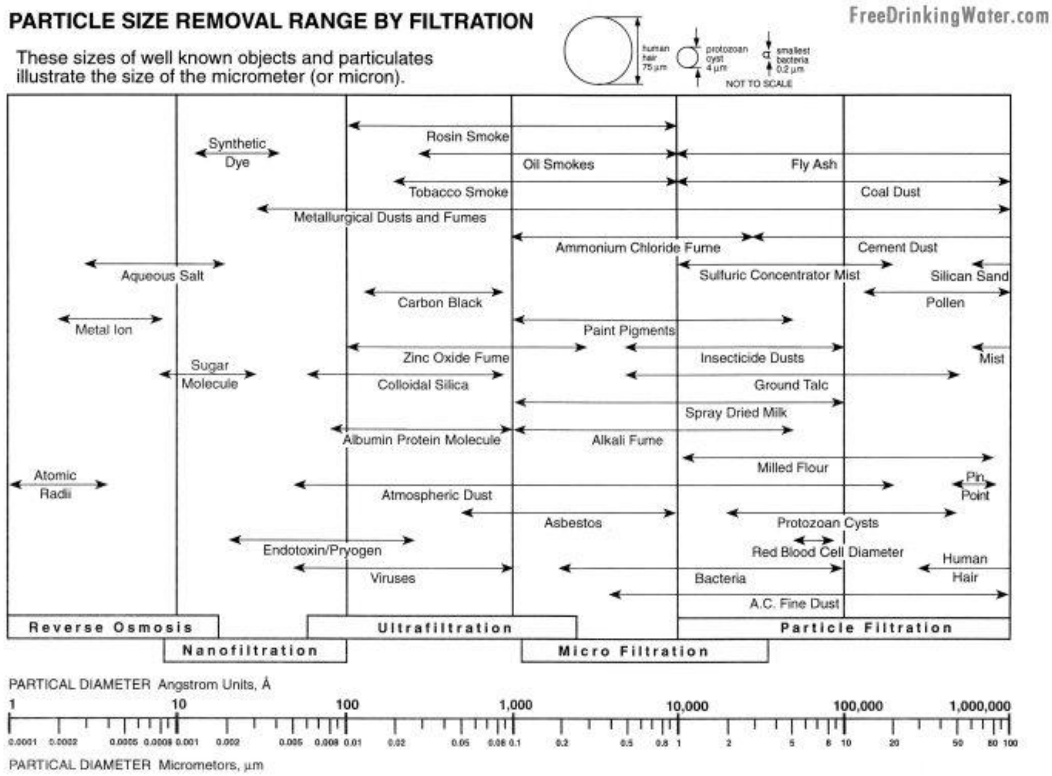

Figure 2: Particle Size Removal Range by Filtration

2.3 PROCESS

The entire process of the design begins by adding dirty water (fresh-water that is, not salt) into the tank. All of the heavy sediment is immediately removed as the water passes through several layered mesh micron filters. The initial filtering step is crucial because the RO filter would quickly clog if it had to filter heavier sediments. The tank lid must then be sealed securely so that pressure can be built in the tank.

To set the purification system in motion the user needs only to begin pedaling the bicycle. Since the pump mechanism is geared to minimize effort needed to operate it, the user feels little to no difference in having to power the pump system compared to riding a regular bicycle. As the pedals turn the chain, the drive gear spins the shaft which is attached to the pressurization drive disk and arm. The arm operates the pumps as the disk rotates, thus converting the rotational power of the bicycle to translational work. The air pumps build pressure in the tank quickly and are capable of reaching 120 psi. If pressure goes above 100 psi in the tank, the RO system will likely be damaged. This potential issue is remedied with a pressure relief valve which allows a maximum of 100 psi to build in the tank. The pressure in the tank then pushes the water out through the tank.

The water then enters the four stages of filters in the RO system. The first stage removes any very heavy sediment down to five microns still left in the water that the first set of filters did not catch. The second stage removes any unwanted color, taste, and odor. These two stages prepare the water for the most crucial step: reverse osmosis. Without these previous two filters, the RO membrane could easily be destroyed by certain chemicals that may be in the dirty water. The more filtered the water is before passing through the RO membrane, the longer the membrane will last. This third stage is the heart of the system as it removes all particles down to 0.0001 micron in size. The fourth and final stage is a repeat of the second stage, purely to optimize water quality. From here, the water exits the system as potable water and rinse water. It is important to note that only the purest water is used for drinking and that alone. The rinse water however can be used in many ways other than drinking, such as cooking, cleaning, or irrigation so that it never gets wasted.

3. RESULTS

3.1 NUMERICAL ANALYSIS

A simple numerical analysis was performed based on this design in order to calculate for the power input required by a person. This is to determine if human powered reverse osmosis is practical enough to be actually implemented.

To calculate the work needed to power such a system, the following equation was used:

$$P = Q*p$$

(where P is Power, Q is volumetric flow rate, and p is pressure).

A higher flow rate is desired for faster potable water production. The higher the applied pressure, the faster the flow rate and more efficient reverse osmosis is as well. To achieve the maximum flow rate, the pressure is set and capped to 100 psi (maximum operating pressure of the RO system) (FreeDrinkingWater.com, 2010). According to Figure 3 (FreeDrinkingWater.com, 2010), with this pressure, about 6.34 gallons per hour of drinking water can be produced.

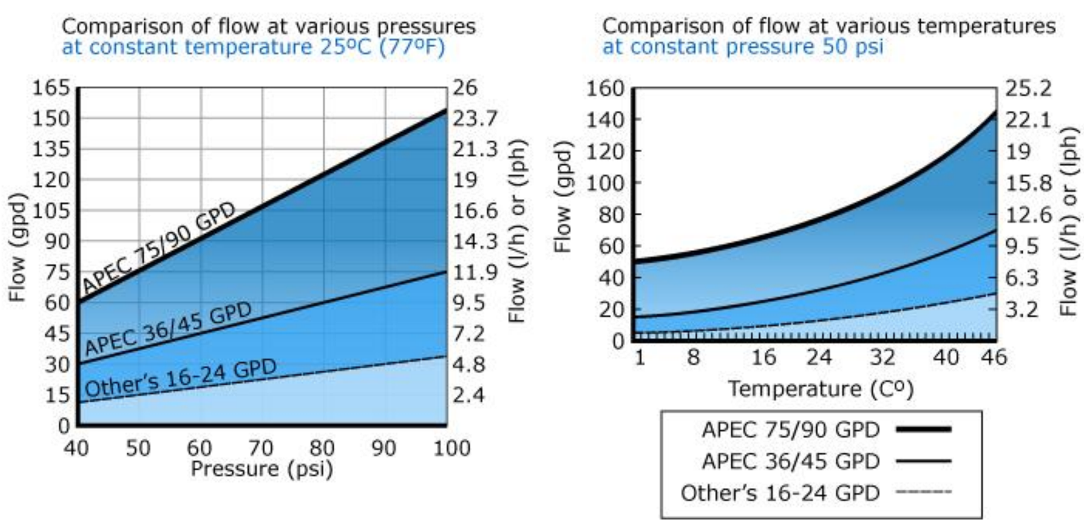

Figure 3: RO flow rates

Because the system has a 2:1 ratio of rinse to potable water production (FreeDrinkingWater.com, 2010), 6.34 gph of cleaned water and 12.68 gph of rinse water is produced. The total flow rate of the entire system is 19.02 gph. *Q* = 19.02 gph. Multiplying the pressure with the total flow rate then solves for the approximate work required.

$$P = \left(\frac{19.02\ \cancel{gal}}{\cancel{hr}}\right)\left(\frac{100\ \cancel{lbs}}{\cancel{in^2}}\right)\left(\frac{1\ HP}{550\ \cancel{lb}*\cancel{ft}/\cancel{s}}\right)\left(\frac{1\ \cancel{hr}}{3600\ \cancel{s}}\right)\left(\frac{1\ \cancel{ft}}{12\ \cancel{in}}\right)\left(\frac{231\ \cancel{in^3}}{1\ \cancel{gal}}\right) = 0.0185\ HP$$

This means that this design requires 0.0185 HP to produce 6.34 gph of potable water. This also means that it takes approximately 10 minutes (after pressure reaches 100 psi) of constant cycling to produce one gallon of drinking water.

A possible consideration for faster production is two of the same RO systems running simultaneously in parallel resulting in double the flow rate and production. Therefore *Q* = 38.04 gph, and:

$$P = \left(\frac{38.04\ \cancel{gal}}{\cancel{hr}}\right)\left(\frac{100\ \cancel{lbs}}{\cancel{in^2}}\right)\left(\frac{1\ HP}{550\ \cancel{lb}*\cancel{ft}/\cancel{s}}\right)\left(\frac{1\ \cancel{hr}}{3600\ \cancel{s}}\right)\left(\frac{1\ \cancel{ft}}{12\ \cancel{in}}\right)\left(\frac{231\ \cancel{in^3}}{1\ \cancel{gal}}\right) = 0.0370\ HP$$

Likewise this means that it takes 0.0370 HP to produce 12.68 gph or about 5 minutes of constant cycling meaning double the work to produce one gallon of drinking water.

3.2 PRACTICAL FEASIBILITY

Research shows that a healthy human can provide a constant 0.10 HP for eight hours before exhaustion (Urieli, 2007). This device more than accounts for any health level by the fact that only about 0.02-0.04 HP would only need to be performed for 5-10 minutes per gallon of potable water. Because of how low the power requirement is, there is plenty of room to increase it (considerably even) to account for all friction inherent in the device.

"A normally active person needs at least one-half gallon of water daily just for drinking" (FEMA, 2010). That means that just two and a half to five minutes of cycling is all that is required per person per day.

4. DISCUSSION

Considering the amount of potable water that this device can produce with even only one RO system, it is more economical to use just one. That makes the total estimated cost of the system to be approximately US $400 initially (based on the current prices of the components). In this case, a single person could spend around five minutes of easy pedaling to achieve a day's worth of drinking water. Since it only takes a few minutes per person, this design could be used to provide daily drinking water for not only a family, but a small village. This reverse osmosis filter is expected to last at least two to three years and the entire system could easily last for decades with minimal maintenance (such as replacing filters and lubricating bicycle and gear system). To make the best use of this device, the rinse water can be used to cook with, clean with, irrigate, and can even be boiled to drink due to being pre-filtered quite well. The bicycle also acts as an easy way to transport water over far distances.

5. CONCLUSION

As long as there is access to some sort of fresh-water, whether filthy or not, this system could easily provide clean drinking water as well as water used for cooking and cleaning. for the daily needs of a small village for a couple decades for approximately US $500. Considering other water purification systems, a human powered reverse osmosis system is not only feasible, but quite an economical and effective means for providing potable water for developing nations.

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