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Design and Fabrication of Human Powered Water Filtration System

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ABSTRACT

Water is the most basic necessity for life yet nearly one billion people in the world lack access to it. In many developing countries, people walk many miles to reach a source of water that is not necessarily portable. This paper proposes to take on challenges associated with the accessibility and cleanliness of water in developing countries by designing and building a filtration system which is portable, durable, and cost-effective.

A pump will be used to pull unsafe water out of one holding tank, pass through a filtration system, and onward into a clean tank while the rider pedals the bicycle. Both the holding tanks and the filtration system will be incorporated into the bicycle carrier as to provide an entire system that is portable and can be easily retrofitted to most standard bicycles.

Given that our design must target a demographic that includes some of the poorest regions in the world, reliability is one of the primary factors incorporated into the design.

Our aim is to remove all the impurities which make the water unsafe for drinking in most economical and efficient way. This paper also helps to create awareness among the people regarding the need and importance of pure and safe drinking water.

Key words: Demographic, filtration system, pump, bicycle, reliability

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INTRODUCTION

When you conserve water, you conserve life! Most of the countries in the world are facing the scarcity of pure drinking water. Water scarcity is the lack of sufficient available water resources to meet water needs within a region. When pure water is not available for drinking people are forced to drink contaminated water which results in adverse effect on their health. People collect water from well, pond, bore wells and other contaminated water bodies. Due to this water, people face various health related problems. The health effects of drinking contaminated water can range from no physical impact to severe illness or even death. Developing countries around the world face debilitating challenges accessing safe and clean drinking water. Alarming statistics led us to the idea that that we could use a simple mechanism of transportation that is common in these areas, such as the bicycle, to help aid their water and sanitation struggles. Our goal is to design a bicycle attachment to purify and transport water from contaminated sources that is active while the rider is pedalling. This attachment, though not a permanent solution, would be a contribution to the improvement of their quality of life. With our model we will be able to provide a working solution that mends the problem and provide safe and clean drinking water.

TYPES OF IMPURITIES PRESENT IN WATER

Physical Impurities

These are the solids which are insoluble like dust, fine sand, clay, rust, etc. They remain suspended in the water and cause muddy water or cloudiness in water. 'Total Suspended Solids' or 'TSS' is the technical term used to measure how much of dirt there is in the muddy water. 'Turbidity' is the term to describe the muddy water and a unit of measurement of cloudy water is based on the transmission of light through the muddy or cloudy water.

Chemical Impurities

The problem with chemicals in water is that they dissolve in water and cannot be removed by simple filtration. 'Total Dissolved Solids' or 'TDS' is the technical term used to give a measure of the amount of dissolved matter in the water and is usually expressed as 'ppm' which stands for 'parts per million' or as 'milligrams per liter' (mg/L). To remove dissolved chemicals in water, it has to be either distilled or purified by using an RO water purifier.

Biological Impurities

Biological contamination of water is caused by the presence of living organisms like algae, bacteria, protozoa, pathogens, microbes, Viruses, Parasites and their eggs (cysts), etc. known collectively known as microorganisms and commonly called 'germs'. The health effects of drinking water contaminated with germs may be severe, but easily curable with modern day medicine. These minute living organisms in water are the causes of diseases from dirty water like typhoid fever, dysentery, cholera, gastroenteritis, etc. Water tanks can sometimes be a breeding ground for microbes in water. In the usual test for microorganisms, only one group of bacteria known as Coliform or e-coli is tested for, this is because it is the most common species, and the first microorganism to infect water. Membrane purification of water actually filters out all bacteria from water unlike UV water purifier which kill bacteria in water but leaves their bodies in the drinking water.

HUMAN POWER AVAILABLE AT PEDAL OF BICYCLE

A person can generate four times more power (1/4 horsepower) by pedalling than by
Hand- cranking. At the rate of 1/4hp, continuous pedalling can be done for only short periods, about10 minutes. However, pedalling at half this power (1/8 HP) can be sustained for around 60 minutes. Pedal power enables a person to drive devices at the same rate as that achieved by hand-cranking, but with far less effort and fatigue.

Pedal power also lets one drive devices at a faster rate than against a slowly yielding resistance. This is neither comfortable nor efficient. Neither is the opposite extreme of flailing at full speed against a very small resistance. A simple rule is that most people engaged in delivering power continuously for an hour or more will be most efficient when pedalling in the range of 50 to 70 revolutions per minute (rpm).

The maximum power which can be delivered using human pedalling is 75 w and normal human being can easily generate 30 W to 40 W power at normal rpm[1].And this power is utilised to drive the pump.

PROPOSED SETUP

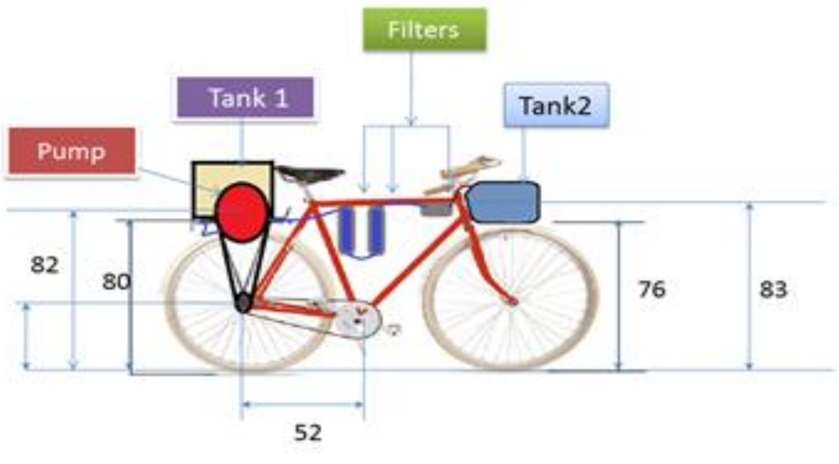

Fig. 1

Water from the source of water is stored in tank 1. As the rider starts pedalling water gets pumped through various filters by the pump as the front wheel sprocket rotary motion will drive rear wheel sprocket through chain and thereby driving sprocket mounted on pump shaft through chain. After passing through various filters water gets stored in tank 2.

Gear Reduction (rpm available at pump sprocket)

Let, N_1 and T_1 be rpm and teeth on front wheel sprocket
N_2 and T_2 be rpm and teeth on real wheel sprocket

N_3 and T_3 be rpm and teeth on pump sprocket
$T_1 = 44$
$T_2 = 18$
$T_3 = 11$
Now rpm of rear sprocket wheel is,
Considering avg human rpm $N_1=30$

$$\frac{N2}{N1} = \frac{T1}{T2} \text{---------- Equation}$$

Therefore,
$N_2 = 73.33$ rpm

$$\frac{N3}{N2} = \frac{T2}{T3} \text{--------- Equation}$$

$N_3 = 120$ rpm.

PUMP SELECTION AND ANALYSIS

A water pump is an essential device used to move the fluid by a mechanical system. In order to pump the water from storage tank to the filters first Peristaltic pump is used but because of failure of Peristaltic pump Vane pump is used. The detailed design and calculations for both the pumps is discussed below.

Peristaltic Pump

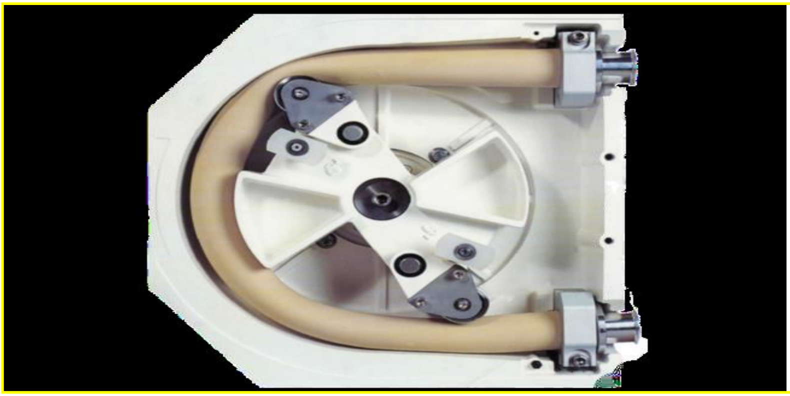

Fig. 2 Peristaltic Pump Motion

The mechanism of Peristaltic pump draws in the fluid content by applying alternating compression and relation motion (rotary).The specialty of this pump is the applied rolling force, or restitution, on the tube creates a compression that seals and acts as suction; therefore, discharge the fluid forward. The advantages of the peristaltic pump are the strong vacuum created to propel the fluid and the no-slip effect. This pump is typically operated in the medical industry to pump intravenous fluids, blood during a by-pass surgery and other viscous fluids. This ideal pump is considered to provide life-long tube efficiency and a free flow fluid rate.

The principles of a peristaltic pump are mostly detected in its distinct tubing designed along with the mechanism produced by the rollers. The tubing is fixed between the tube-bed and the rotor and is continuously squeezed by the rollers pushing the liquid in the direction of the revolving rotor, and producing a “pillow” of liquid between the rollers as shown in Figure. The pillow is the pump chamber and it is used to determine the volume per roller step and consequently the flow rate. The roller-step volume depends on the pump system, tubing liquid properties and application conditions. [2]

The flow rate is then calculated by using the following formulas:

Theoretical flow rate (ml/min) = V * L * N *RPM ----------- Equation

Where,
V = volume of occluded tubing
N = number of rollers
N= rpm
L= length occluded
Q = flow rate per minute

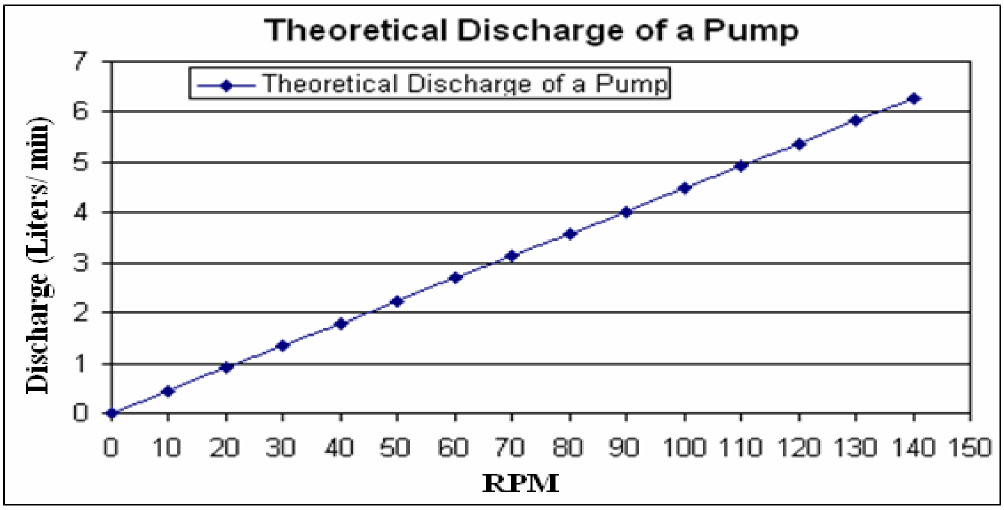

Fig. 3 Theoretical Discharge vs RPM [2]

Reasons for Peristaltic Pump Failure

Could not produce sufficient pressure required to pass water through the UF Filter and Cracks are found on the wooden casing due to increased pressure. Vane Pump which is also suitable for this application is then used.

Fig. 4 Crack on the pump casing

Vane Pump

A Vane Pump is a positive-displacement pump that consists of vanes mounted to a rotor that rotates inside of a cavity. In some cases these vanes can have variable length and/or be tensioned to maintain contact with the walls as the pump rotates. It was invented by Charles C. Barnes of Sackville, New Brunswick, who patented it on June 16, 1874.

A simplified form of unbalanced vane pump with fixed delivery and its operation are shown in Figs. The main components of the pump are the cam surface and the rotor. The rotor contains radial slots splined to drive shaft. The rotor rotates inside the cam ring. Each radial slot contains a vane, which is free to slide in or out of the slots due to centrifugal force. The vane is designed to mate with surface of the cam ring as the rotor turns. The cam ring axis is offset to the drive shaft axis. When the rotor rotates, the centrifugal force pushes the vanes out against the surface of the cam ring. The vanes divide the space between the rotor and the cam ring into a series of small chambers.

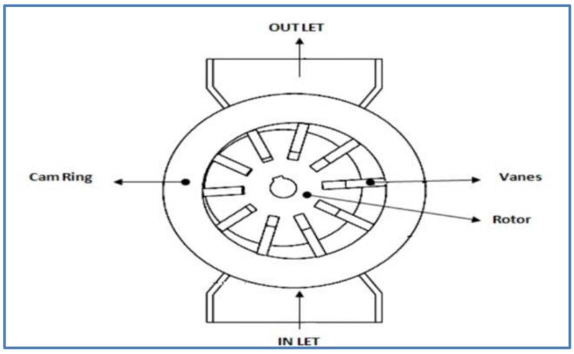

Figure 5: Vane Pump

During the first half of the rotor rotation, the volume of these chambers increases, thereby causing a reduction of pressure. This is the suction process, which causes the fluid to flow through the inlet port. During the second half of rotor rotation, the cam ring pushes the vanes back into the slots and the trapped volume is reduced. This positively ejects the trapped fluid through the outlet port.

In this pump, all pump action takes place in the chambers located on one side of the rotor and shaft, and so the pump is of an unbalanced design. The delivery rate of the pump depends on the eccentricity of the rotor with respect to the cam ring [3].

Calculations for theoretical power and discharge of vane pump

For calculation of flow rate of pump first find out Pump Volume Displacement,

Let,

V_d (pump volume displacement in m^3 /rev)

Dc (diameter of a cam ring) = 0.1 m

Dr (diameter of rotor) = 0.08 m

L (width of rotor) = 0.06 m

N = rpm.

Sg = Specific gravity of fluid

H = head in m

Now, Pump volume displacement,

$V = \frac{\Pi}{4} \times (Dc^2 - Dr^2) \times L$---------- Eq^n

$V = \frac{\Pi}{4} \times (0.1^2 - 0.08^2) \times 0.06$

$= 1.6964 \times 10^{-4} m^3/rev$

Theoretical discharge is calculated as,

$Q = V_{D} \times N$

$= 1.6964 \times 10^{-4} \times 120$ for e.g. 120 rpm

$= 0.2035\ m^3/min$

= 20.35 lit/min

Now power required to drive the pump,

For 1 m head and Sg = 1

$P = Sg \times H \times Q / 6128$---------- Eq^n

$= 1 \times 1 \times 20.35 / 6128$

$= 3.5 \times 10^{-3}$ Kw

=3.5 Watt.

FILTERS USED FOR REMOVAL OF IMPURITIES

Pre-sediment Filters

Fig. 6 Pre-sediment Filter

This cartridge features a unique multi-depth poly sediment filter. This filter uses the entire depth of its media by trapping the largest sediment particles on the outside of the filter, then gradually stepping down the size of particles it will reject as the water moves closer to the core of the filter. The outer layer is rated at 70 microns.

The subsequent layers are rated at 50 microns, 20 microns, and finally 10 microns. The result is a longer filter life and higher flow rates (less pressure drop).

In a radial flow design, water flows through the wall of the filter into the inner core. This arrangement provides filtering surface that consists of the entire length and circumference of the cartridge. The filter above is a "depth" filter. Pleated filters offer even more filtering surface.

Table -1 Specifications of Pre-sediment Filter

Pore size	5 Microns
Length	10 Inches
Capacity	10800 lit (18 Months)

Activated Carbon Filter

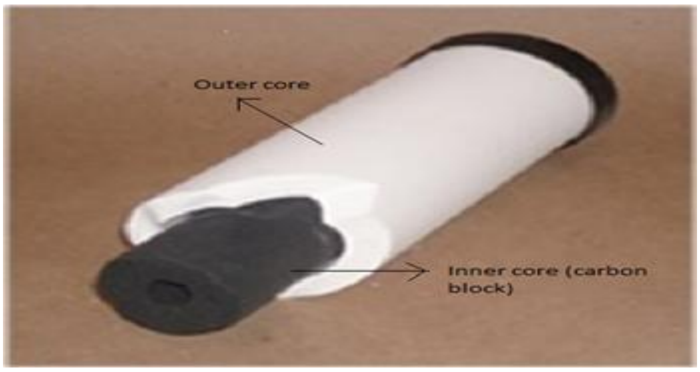

Fig. 7 Activated Carbon Filter

Carbon filtering is a method of filtering that uses a bed of activated carbon to remove contaminants and impurities, using chemical adsorption.

Each particle/granule of carbon provides a large surface area/pore structure, allowing contaminants the maximum possible exposure to the active sites within the filter media. One pound (450 g) of activated carbon contains a surface area of approximately 100 acres (40 Hectares).

Activated carbon works via a process called adsorption, whereby pollutant molecules in the fluid to be treated are trapped inside the pore structure of the carbon substrate. Carbon filtering is commonly used for water purification, in air purifiers and industrial gas processing, for example the removal of siloxanes and hydrogen sulfide from biogas. It is also used in a number of other applications, including respirator masks, the purification of sugarcane and in the recovery of precious metals, especially gold. It is also used in cigarette filters.

Active charcoal carbon filters are most effective at removing chlorine, sediment, volatile organic compounds (VOCs), taste and odor from water. They are not effective at removing minerals, salts, and dissolved inorganic compounds.

Typical particle sizes that can be removed by carbon filters range from 0.5 to 50 micrometers. The particle size will be used as part of the filter description. The efficacy of a carbon filter is also based upon the flow rate regulation. When the water is allowed to flow through the filter at a slower rate, the contaminants are exposed to the filter media for a longer amount of time.

Table -2 Specifications of Activated carbon filter

Outer Diameter	**65 mm**
Length	**210 mm**
Capacity	**6000 lit.**

Ultra Filtration Membrane

Ultrafiltration (UF) is a variety of membrane filtration in which force like pressure or concentration gradients lead to a separation through a membrane. Suspended and solutes of high molecular weight are retained in the so-called retentate, while water and low molecular weight solutes pass through the membrane in the permeate. This separation process is used in industry and research for purifying and concentrating macromolecular (10^3 - 10^6 Da) solutions, especially protein solutions. Ultrafiltration is not fundamentally different from microfiltration. Both of these separate based on size exclusion or particle capture. It is fundamentally different from membrane gas separation, which separate based on different amounts of absorption and different rates of diffusion. Ultrafiltration membranes are defined by the molecular weight cut-off (MWCO) of the membrane used. Ultrafiltration is applied in cross-flow or dead-end mode. It removes Collids, bacteria, virus, parasides, protozoas, cyrogens, herbicides, aglaee, fungi, cyst.

ACTUAL SETUP

Fig. 8 Actual Setup

PROJECT COST

Table -3 Project Cost

Sr. No.	Component	Quantity	Price(Rs.)
1.	Water filter cartridge(sleek)	1	400
2.	Biostatic activated carbon block	1	500
3.	UF Membrane	1	300
4.	Vane Pump	1	800
5.	Tank	2	600
6.	Cycle	1	3000
7.	Miscellaneous		1500
	TOTAL		7100

TESTING AND RESULTS

Actual Discharge

The discharge obtained from the filter outlet for various rpm ranges is measured with the help of calibrated beaker as follows:-

Table -4 Actual Discharge

Sr. No.	RPM	Discharge (ml)
1.	20	266
2.	30	400
3.	40	530
4.	50	650

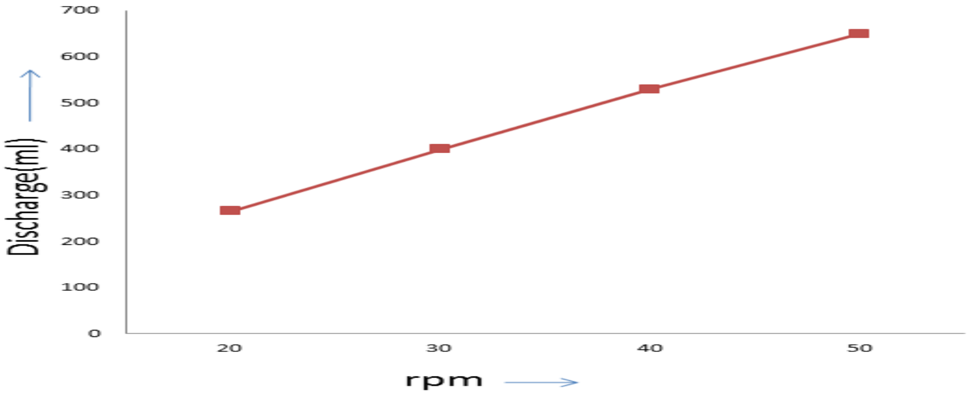

Fig. 9 RPM vs. Discharge

Actual Pressure

Table -5 Actual Pressure

Sr No.	Component outlet	Pressure in Kg/cm^2
1.	Pump	8
2.	Filter 1	6.8
3.	Filter 2	5.5
4.	UF membrane	1.8

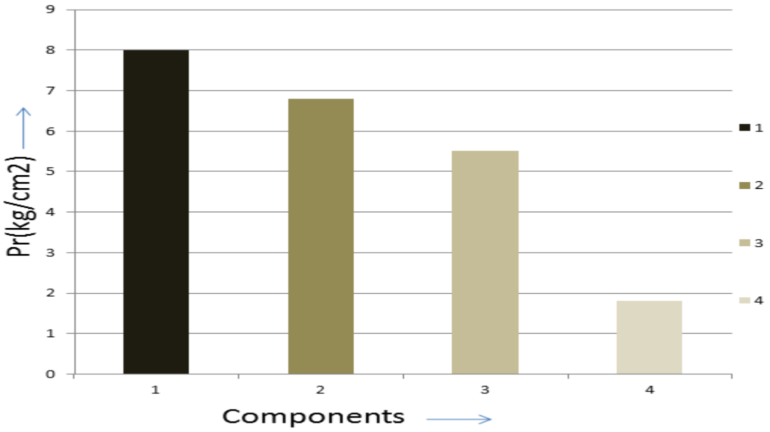

Fig. 10 Pressure drop at various levels

CONCLUSION

Human Powered Water Filtration System provides pure drinking water free from contaminants and micro-organisms in an efficient and economical way. The power which is required to drive the vane pump is 3.5 watts and humans can easily develop 40 watts. System is used for a suction and delivery head of 1m and 1.8m respectively as obtained from the test results. A discharge of 400ml/min is obtained at a minimum speed of 30 RPM.

The pressure obtained at the outlet of pump is 8 Kg/cm^{2}whereas the pressure required to pass the water is 1.2, 1.3 and 3.7 Kg/cm^2 for filter 1,2,3 respectively, thereby obtaining a pressure of 1.8 Kg/cm^2 at the outlet of our arrangement. This system is detachable and is also used to deliver water upto a height of 1.2 meter in varying conditions.

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