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**ESCUELA DE INGENIERÍAS
INDUSTRIALES**

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Grado en Ingeniería en Tecnologías Industriales

WATER PURIFICATION FOR SMALL MOBILES

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RESUMEN

El objetivo de este Trabajo Fin de Grado es conseguir una producción de 1700 L/d de agua potable mediante un método previamente desarrollado conocido como Ósmosis Inversa, reduciendo tamaño del sistema a utilizar.

Se procede entonces a diseñar un modelo para el sistema lo más compacto, móvil, ligero y económico posible y, para ello, se seleccionan los elementos necesarios más apropiados para la construcción, basada en un sistema de filtros. Una vez desarrollado y construido, se ensaya con ayuda de una bomba de pistón.

Tras obtener los resultados de las pruebas, se comparan con los resultados de cálculos teóricos llegando a la conclusión de que la velocidad mínima que debe llevar la rueda es de 0.842 m/s para lo cual el agua del río debe fluir a una velocidad mayor de 1 m/s.

Por último, se documenta y compara con otros sistemas de obtención de agua potable mencionados.

PALABRAS CLAVE

1. Filtro
2. Agua potable
3. Ósmosis Inversa
4. Velocidad
5. Sistema compacto

ABSTRACT

The aim of this Bachelor Thesis is to achieve a production of 1700 L/d of drinking water through a method previously developed, Reverse Osmosis, reducing the size of the system to be used.

It has been chosen a model for the most compact, mobile, lightweight and economic system possible. For that, the most appropriate elements for the construction have been selected based on a filter system.

Once developed and constructed, it is tested by means of a piston pump.

After obtaining the results of the tests, it is compared with the results of the theoretical calculations, reaching the conclusion that the minimum velocity that the wheel must carry is 0.842 meters per second, and for that, the river water must flow at a velocity greater than 1 meter per second.

Finally, it has been documented and compared with other obtaining drinking water systems.

KEYWORDS

1. Filter
2. Water
3. Reverse Osmosis
4. Velocity
5. Compact system

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List of abbreviations

BET	Brunauer–Emmett–Teller
GmbH	Gesellschaft mit beschränkter Haftung
NF	Nano Filtration
RO	Reverse Osmosis
WHO	World Health Organization

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1. INTRODUCTION

1.1. MOTIVATION

Consuming non-potable water implies serious health risks. Diseases related to the use of water include those caused by microorganisms and chemical substances present in drinking water; diseases such as schistosomiasis, which has part of its life cycle in the water; or Malaria, whose potential is such, that in undeveloped countries can lead to death.

It is estimated that diarrheal diseases cause around 3.6% of the total years of life adjusted for disability due to diseases and cause 1.5 million deaths each year (WHO, 2012). According to estimates, 58% of this burden of disease - that is, 842,000 deaths per year - is due to the lack of clean water and poor sanitation and hygiene. And includes 361,000 deaths of children under 5 years of age, most of them in low-income countries. [1]

So drinking water is essential for life, not only of human beings, but of any living being: animals, plants, etc.

Despite this fact, today there are still places in the world where it is not accessible, or not as easily as in developed countries can be obtained.

Over the years, different devices or water treatment plants have been built to try to solve or, at least, minimize this situation. However, these plants are still too inaccessible for certain places or situations, either because of their cost, their transport or their size. Therefore, it has been tried to develop a system that helps to purify the water in a simple, accessible and smaller way than the aforementioned devices.

In addition, this device can be used as a security device. That is, for example, to meet the needs in certain situations of disaster or accident in the water treatment plants those are normally responsible for supplying the demand for such drinking water. The form of production can be substituted, so that the problem of shortage of a good necessary for the population for a limited time (enough to cover it during the inactivity of the general plant) is solved.

A clear example of a country where the drinking water is very limited is the African country of Kenya, where due to abrupt terrain, lack of water and lack of communication networks as well as economic means, it is very difficult to obtain adequate water for consumption through a conventional water

purification plant. So there is a high rate of diseases that affect the population alarmingly.

As it is shown in the following photos, it has been installed a device to purify water in this country. After installing it and putting it into operation, 210 litres of water per day are obtained and are used for animal consumption as well as for irrigation in the fields because of the lack of water that will be there in the subsequent months. [2]



Figure 1: Front view of the installed purify water device in Kenya [2]



Figure 2: Top view of the installed purify water device in Kenya [2]

2. STATE OF THE ART

During the years, there have been many inventions, advances and new devices in order to provide drinking water.

It can be found a variety of patents, literature and sources of information about this field of the engineering.

Today, Reverse Osmosis, also known as Hyper-filtration by the industry, represents state-of-the-art in water treatment technology. Reverse Osmosis (RO) was developed in the late 1950's under U.S. Government funding, as a method of desalinating sea water. Today, reverse osmosis has earned its name as the most convenient and thorough method to filter water. It is used by most water bottling plants and by many industries that require ultra-refined water in manufacturing. Nowadays this advanced technology is available to homes and offices for drinking water filtration. [3]

There are many systems for drinking water production that are using this method of water purification. In this thesis is explained some of them, as well as other devices, methods and technics that are used for this aim.

RECIRCULATING, PURIFYING, DISINFECTING, COOLING, DECONTAMINATING, FEEDBACK CONTROLLED WATER SYSTEM FOR DRINKING WATER AND OTHER USES TO IMPROVE HEALTH AND WELL BEING OF ANIMALS AND HUMANS.

This system has been developed in order to provide clean water for livestock consumption. It consists of a continuous recirculating water circuit that achieves this aim. A circulation pump brings the water within the water circuit in a flow direction optionally.

On the other hand, a particle filter system (or systems) is connected in series and removes solids or dissolved particles in water. After that, an ozone purification system (and/or other antimicrobial or purification agents) is connected in parallel to a part of the monitored continuous recirculation feedback and controls the water circuit. The aforementioned ozone purification system is given downstream of the particulate filter system and the RO system (or comparable) in relation to the flow direction.

Finally, after this ozone purification system, a feed station is connected in series with the continuous recirculating water circuit disposed downstream in relation to the direction that the water is following. [4]

PURIFICATION DEVICE AND PURIFICATION METHOD FOR WATER UTILIZING FILTER CARTRIDGES

This purification device for water consists of a housing with a longitudinal axis, an upper and a lower end and a substantially round cross section.

The system is composed by a first holder, arranged parallel to the longitudinal axis of the housing, which is used for a first purification. After that, it has a second holder, which is also arranged parallel to the longitudinal axis of the housing, for a second purification process.

The holder for the second purification is arranged eccentrically with respect to the longitudinal axis of the housing. [5]

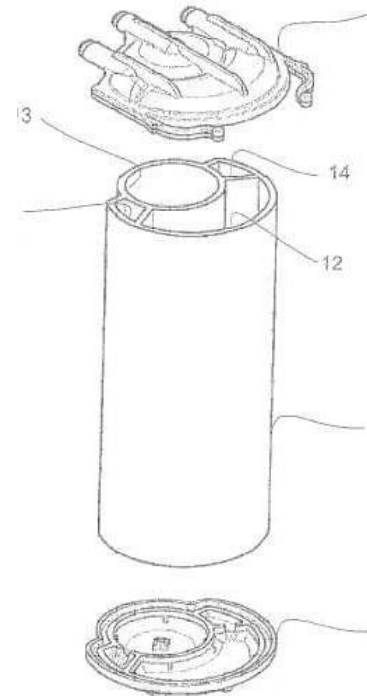


Figure 3: The purification device [5]

PURIFICATION UNIT FOR WATER TREATMENT

The main use given to this system is the treatment of water used in the industrial sector, sea water, drinking water and pool water. It is composed of, at least, two purification elements (35, 50) which are connected to each other in fluid communication through a connection line (40). One of the purification elements (35) encloses a particulate absorbent purifying substance of a

minimum BET¹ surface area of 100 m²/g (300 m²/g for the removal of amines, organic substances and halogenated hydrocarbons).

The second purification device (50) includes a chemically inert particulate purification material for the elimination of substances in suspension, especially against disinfectants. This material is characterized in that its particles are spherical and have a plane surface with a roughness (Ra) below 10 of 1 µm. [6]

In the following picture it can be appreciated the unit explained.

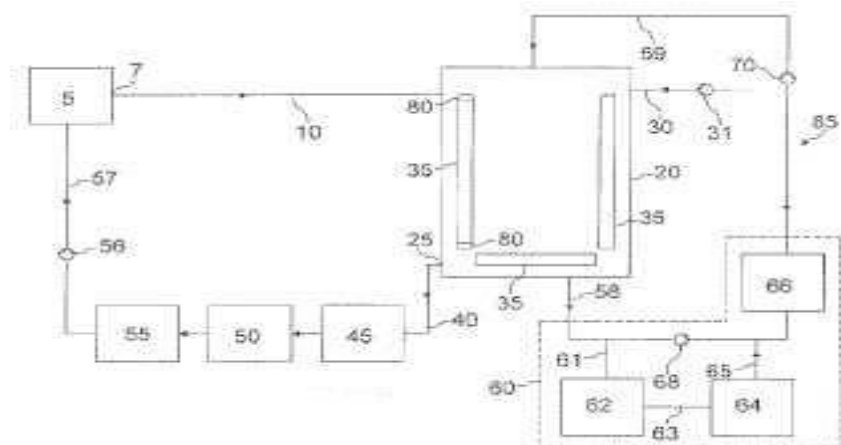


Figure 4: Purification unit for water treatment [6]

COMPACT WATER TREATMENT PLANT FOR THE PRODUCTION OF DRINKING WATER

According to the different models and sizes, this system has a wide range of capacity of production and it is safe in each one of its different models.

It is composed by novel elements and dispositions of them that allow performing the coagulation-flocculation² and sedimentation stage, greatly increasing the overall efficiency of the plant.

The plant incorporates a mechanical flocculator with spherical cover, a combination of mechanical and hydraulic flocculator and a high-rate dual-stage settler. [7]

¹ Brunauer-Emmett-Teller: Method of measurement to calculate the specific surface area of a sample including the pore size distribution from gas adsorption.

² Coagulation-Flocculation: Chemical process of contact and adhesion whereby the particles of a dispersion (colloids) form larger-size cluster (flocs or flakes) allowing them to be more easily removed from water.

DEVICE AND METHOD FOR THE PREPARATION OF DRINKING WATER

The device is composed of a water tank (4) removable to fill with water and for the collection of drinking water to be purified (6), a pump (8) for the water transport and a membrane filter unit (10).

This membrane filter unit has a water inlet (12), a membrane filter (14), a purified water outlet (16), a cleaning water outlet (18) and a water return pipe (26), which connects the cleaning water outlet (18) with the water tank (4).

The water inlet (12) is supplied with water from the water tank (4) through a supply duct (24) directly or indirectly and arranged in the flow direction (19) behind the membrane filter (14). One part of the water conducted through the water inlet (12) of the membrane filter unit (10) leaves the membrane filter unit (10) through the cleaning water outlet (18). The membrane filter (14) is connected with the carbon filter (20).

The activated carbon filter is characterized by making a part of the water supplied through the water inlet (12) of the membrane filter unit (10) is conducted for waste removal through the membrane filter surface. The liquid sucked by the pump (8) of the water tank (4) can be conducted backwards through an additional conduit (32) to the water tank (4).

The bifurcation of the additional conduit (32) is arranged in front of the filters (20, 14) and the additional conduit (32) can be closed with a valve (34). [8]

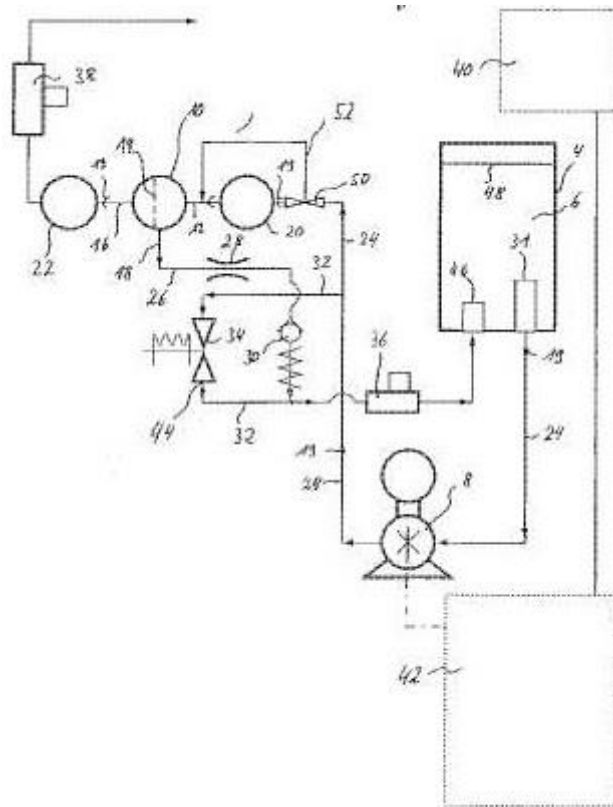
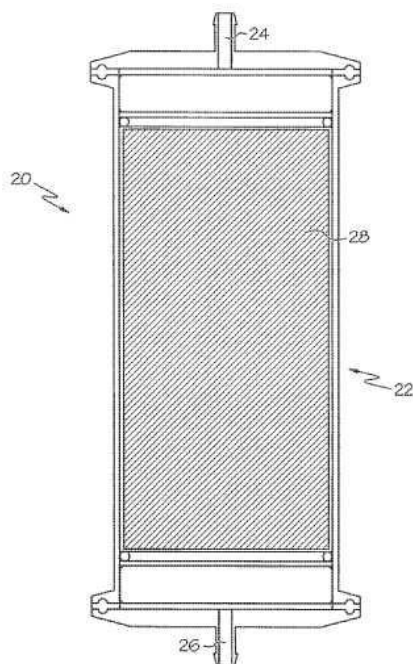


Figure 5: Process for preparation of drinking water [8]

WATER FILTERS AND METHODS THAT INCORPORATE ACTIVATED CARBON PARTICLES AND SURFACE CARBON NANOFILAMENTS



It is a device to provide drinking water consisting of a cover (including an inlet and a water outlet) and a filter disposed inside the casing.

The filter is composed of a material that is characterized by particles of activated carbon and a diversity of carbon nanofilaments.

The nanofilaments are arranged on the surface of the particles of activated carbon in which the filter can be operated to produce drinking water by removing the contaminants from a current of liquid water. This current

Figure 6: Section drawing of the device [9]

flows from the water inlet to the water outlet of the housing. [9]

APPARATUS, METHOD AND SYSTEM FOR DESALINATING WATER

In addition to purify water, the apparatus, system and method can effectively release the brine effluent.

The apparatus can be built with an offshore structure. This structure contains a water intake device connected to a pre-desalination filters and a diversity of reverse osmosis filters which are communicated with a purified water line and an element whose aim is discharge the stream.

There are a variety of filters in order to eliminate solid contaminated before running the filtered water through the reverse osmosis system to the discharge element and purified water lines.

During this project is also developed a wastewater discharge system. This system consists in a control panel that manage the offshore structure diversity of filters, plurality of reverse osmosis filters, purified water line and discharge element, to ensure successful water purification.

Here it has also been explained a method that uses the apparatus and/or system that are described above. The method consists of obtaining an offshore structure comprising a water purification system, flowing water into an inlet device, pumping the water through a filtration system, flowing the filtered water through a diversity of reverse osmosis filters; flowing purified water through a purified water line; and finally flowing discharge effluent through a discharge element. [10]

FILTER AND PURIFIER OF DOMESTIC WATER

This system is a set of filters and purifiers totally known, whose elements that make it result as novel invention.

The water purification filter is presented in a compact manner and inside a housing of rectangular geometric shape where the constituent elements of this novel invention will be integrated.

This comprises synthetically the combination of an activated carbon filter and an ozone generating unit. The activated carbon filter assists to eliminate both

those foreign particles that accompany the water and a series of bacteria and, at the same time, eliminate unpleasant odours and flavours such as residual chlorine. This will be done through the combination of a lamp that contains a stainless steel mesh, an intermediate glass tube and a second stainless steel mesh.

These meshes are interconnected to a source of high frequency electric current and protected that set inside a tube with an output, whose purpose will be to produce ozone through the electric discharge while eliminating all kinds of pathogenic germs that could pass through the activated carbon filter.

There is also an electro-valve in this combination, which allows water to pass after it has been mixed with ozone, operated by means of a power switch.

Another device to consider in this combination is the check type retention valve, which has the purpose of protecting the ozone producing unit, preventing the passage of water to said ozone generating unit.

The combination also contains a Venturi-type tube, whose purpose will be to cause a vacuum at the point of union with the filtered water stream and feed the flow of ozone generated in the generating unit and thus, to enter the ozone in contact within from the breast of water. This Venturi tube is placed after the electro-valve, of cards or slats containing a series of electronic elements connected in such a way that it is suitable to generate a high frequency rectified electric current and that it will be connected to the meshes of the unit generator of ozone.

The electronic tablet contains a series of electronic elements with which the purification of domestic water is achieved. [11]

DRINKING WATER MACHINE

The drinking water machine is characterized because it is constituted by a prismatic general housing that presents a power source and a connected water tank.

The water tank provides water to the machine by a means of pipe. This pipe is equipped with a water volume indicator. The aforementioned pipe gives water to some filters from which water comes to a water cooling serpentine and to a water dispenser (once water output is regulated by means of a volume actuator operated by the machine).

The machine has a base where the water filling container is positioned, and the base of this water filling container is connected to a residual water tank. [12]

MOBILE, NO ENERGY, NON CHEMICAL ULTRAFILTRATION WATER PURIFICATION



This device is used above all in disaster or emergency areas or in rural applications. It is developed to provide drinking water out of any sweet raw water since it filters out dangerous, harmful contaminants such as worm eggs, bacteria or even viruses.

It is characterized by high mobility and light weight and a small footprint as well.

There is no electricity or chemicals required and it provides a high flow rate (0.5 m³/h) with a 100% recovery.

This system eliminates colloidal, bacteria, high molecular weight material and suspended particulates,

It has been built in such a way that it offers a Capillary Type configuration (Out-to-In) with a surface area of 50 ft². [13]

Figure 7: Ultrafiltration Water Purification device [13]

WATER PURIFICATION TRAILER

This device has been specially designed for disaster relief, military camps and temporary application.

Is equipped with a solar powered water treatment system for sweet water or a RO-system for desalination and provides 7.000 to 15.000 litres of clean drinking water per day from any water source.

Powered by renewable solar and/or wind energy it can run 24 hours a day without on-going fuel and fuel transport costs. The system produces extra energy for running different electric installations.

This trailer is composed by borehole type delivery pump, an exclusive automatic back-flushing filtration, batteries, solar panels and controls. An ultrafiltration membrane for sweet water sources or a reverse osmosis system (for sea or brackish water) removes all virus, bacteria and salt without requiring chemical treatment.

The water purification trailer has many advantages such as being independent and mobile, extremely fast installation, it works quiet, minimal maintenance requirements, very low energy consumption, without on-going fuel costs, certified filtration system and that its product water meets WHO standards. [14]

ULTRAVIOLET WATER FILTERS

The energy used in this system is a sort of energy found in the electromagnetic spectrum, lying between x-rays and visible light.

The Ultraviolet water filters work with unusual lamps that emit UV light of an especially wavelength that have the ability, because of their length, to agitate the DNA of micro-organisms. These UV light waves are also referred to as the Germicidal Spectrum or Frequency. It is used a frequency of 254 nanometres (nm) in order to eliminate microorganisms.

As water flows through a UV water treatment system, living organisms in water are exposed to UV light which attacks the genetic code of the microorganism and reorganizes the DNA /RNA, removing the microorganism's capacity for reproducing. If a microorganism can no longer reproduce, it cannot replicate,

consequently it cannot contaminate other organisms with which it has contact.

This process eliminates 99.99 % of harmful, dangerous microorganisms without adding any chemical to water that is the reason because of is considered a simple but very effective method. [15]

This system is composed by the elements that are showed in the following figure:

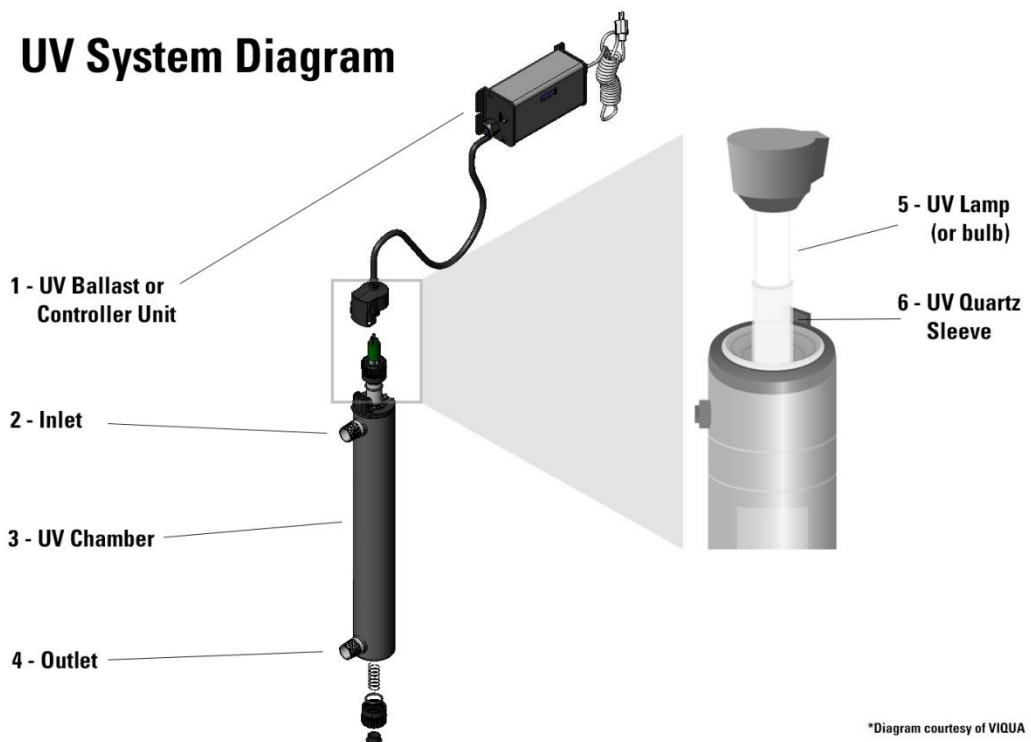


Figure 8: Components of UV system [15]

SOLAR STILLS

The aim of this system is to provide fresh water from brackish water by directly using sunshine. It represents the best technical solution to provide remote villages or settlements with fresh water without depending on high-tech and skills.

The method that is used to achieve the aforementioned aim is the following:

The sun's energy heats water to the point of evaporation by means of a glass cover. As the water evaporates, water vapour rises, condensing on the glass surface for collection. This process removes impurities like salts and heavy metals as well as eliminates microbiological organisms.

Solar stills can produce far more than 15 l/m² fresh water per day. For that reason this device is known as one of the best regarding to drinking water production.

It has advantages such as being small, modular high-performance stills with the possibility of decentralised use, less maintenance and robust construction that can help to moderate or decrease fresh water lack.

Nowadays, the technical optimization is still in process in order to increase the efficiency of these systems. [16, 17]

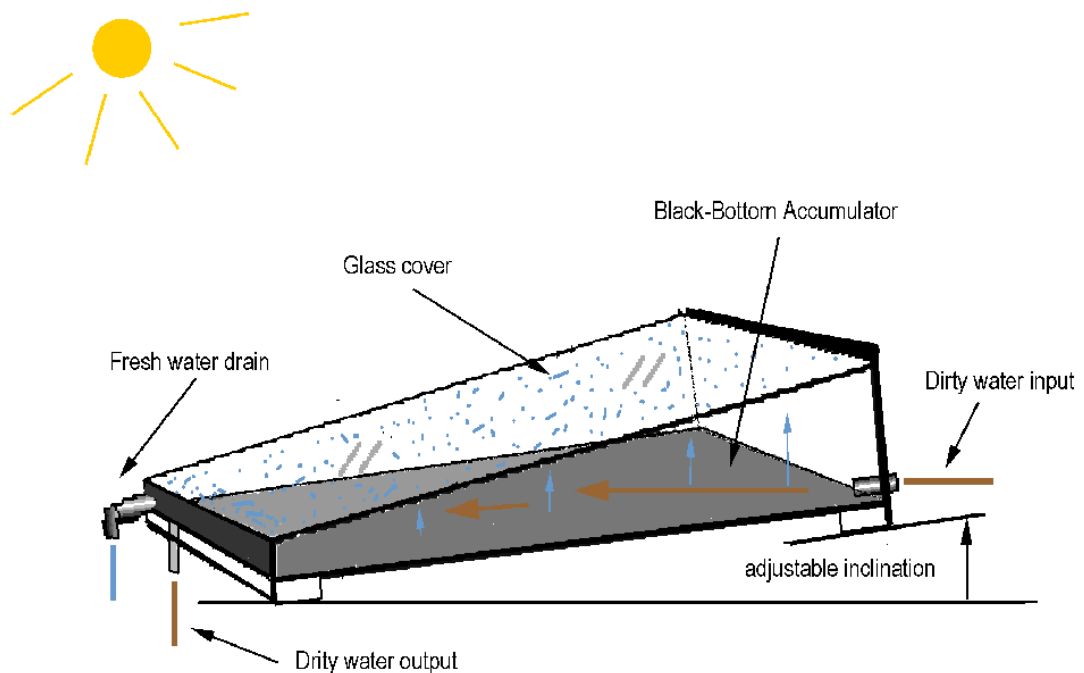


Figure 9: How works a Solar still system [16, 17]

ION EXCHANGE (WATER SOFTENER)

Ion exchange column is also known as a water softener and it is one of the most usual water treatment devices.

It consists of a cation exchange system that eliminates elements like:

- calcium and magnesium compounds
- barium
- radium
- low concentrations of dissolved iron and manganese

In order to eliminate nitrate and fluoride an anion exchange unit can also be installed in.

This water treatment system works by flowing water through resin beads.

In anion exchange columns, the resin beads are coated with negatively charged chloride or hydroxide ions, which exchange with nitrate or fluoride in your water. In cation exchange units, the beads are coated with positively charged sodium ions. These sodium ions commute places with magnesium, calcium and other “hard” ions in the water.

The explained water treatment system should be periodically charged so that coating ions are available. This problem has been solved and many water softener devices are automatically recharged from a sodium storage tank. [18]

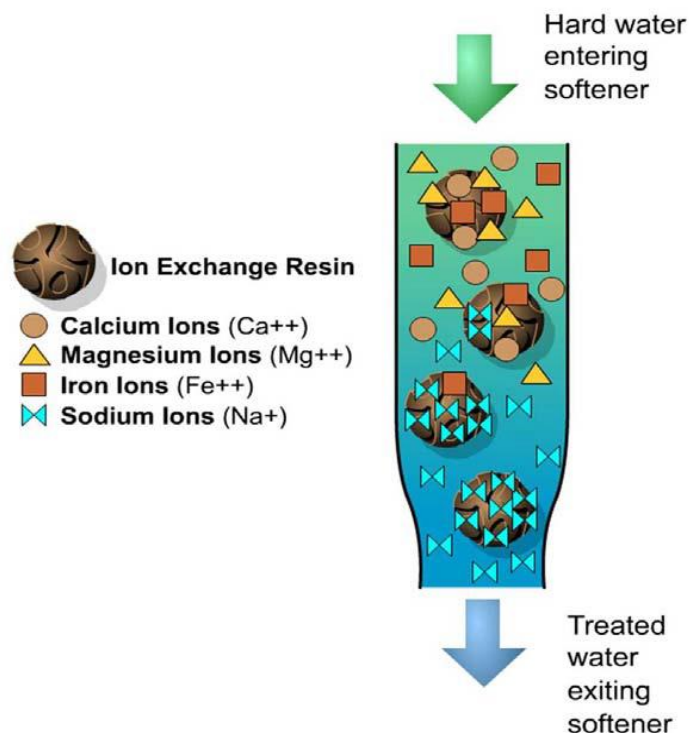


Figure 10: Ion exchange column process [18]

SUNSPRING SYSTEM

It consists of a system that can purify water by using a wind turbine with an attached solar panel. Using batteries charged by entirely renewable energy, it can disinfect up to 5,000 gallons of water per day.

It obtains fresh water from a near located source, like a swimming pool, stream or lake by pumping. The water then flows through a seven-mile membrane that's 0.02 microns thick, particularly designed to block microbiological contaminants.

The water comes out from a pair of water spigots. The decontaminated water can also be accumulated in cisterns with chlorine treatment.

This system is being used in orphanages in villages where the access is complicated and in places where earthquakes or hurricanes takes place. [19]



Figure 11: Sunspring system [19]

FILTERING WATER BY USE OF ULTRASONICALLY VIBRATED NANOTUBES

This water filtration innovation's highlight is the method used to purify the fresh water. While the rest of devices and systems try to eliminate

contaminants from water, this system's method is move water away from the contaminants.

In the beginning, it was created in order to decontaminate wastewater for reuse aboard the International Space Station, but nowadays the innovation is applicable to several situations on Earth.

This water filtration innovation is an acoustically driven molecular sieve embedded with small-diameter carbon nanotubes.

Water flows into the device and first contacts the filter matrix, which can be made of ceramic, metallic compounds or polymer depending on end-use needed. Carbon nanotubes within the matrix permit only water molecules to pass through, leaving behind any contaminants and larger molecules.

In order to help drive water through the filter, acoustics is used as technology. An oscillator circuit connected to the filter matrix is responsible for propagating the acoustic vibration as well as for the water molecules to be deactivated and moved through the filter. This use of acoustics also eliminates dependence on gravity (and thus filter orientation) to move water through the device.

When water leaving the system reduces to a pre-determined set point, a cleaning cycle is started to eliminate the sediment from the inlet of the filter, re-establishing the standard system flow rate. Unlike other filtration systems, flushing of the filter system is not required. [20]

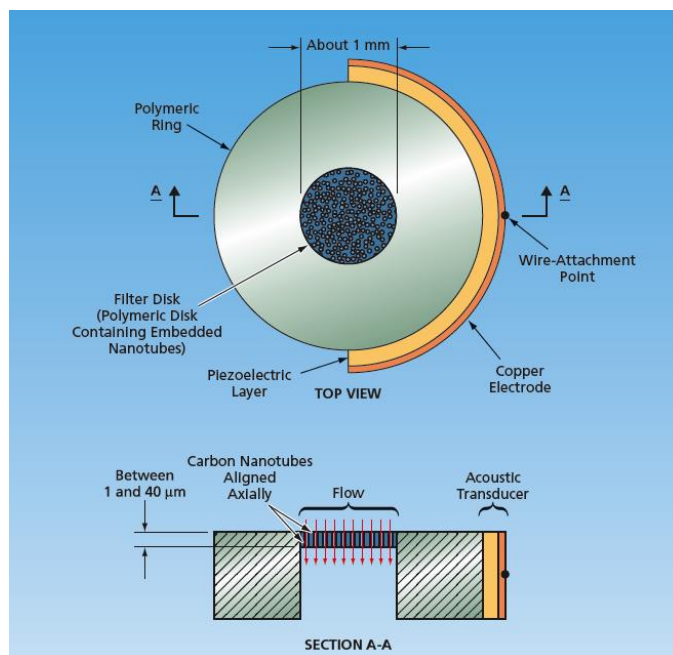


Figure 12: Section A-A drawing of the device [20]

PHOTOCATALYTIC WATER PURIFICATION TECHNOLOGY

This system disinfects dirty water at high speeds, creating healthy, safe and drinking water by means of photocatalysts and the UV rays from sunlight.

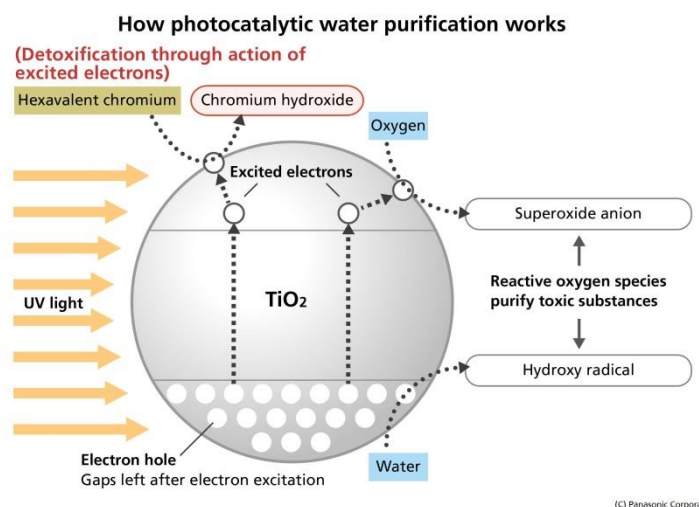


It has been invented a procedure of binding TiO_2 to a particle, zeolite, which allows photocatalysts to maintain their essential surface active site. Furthermore, since the two particles are bound together by electrostatic force, binder chemicals are not required.

TiO_2 is released from the zeolite and dispersed throughout the water once these novel photocatalytic particles are agitated. The result is a reaction speed is markedly elevated compared to conventional methods of fixing TiO_2 on a surface of substrates, allowing a large volume of water to be transformed in a short period of time.

Figure 13: Photocatalytic water purification system [21]

The photocatalysts will be reused in a later time. This is possible because it is easy to separate and recover them from the water once they have left the water, causing TiO_2 to bind zeolite again. [21]



(C) Panasonic Corporation

Figure 14: Method of photocatalytic water purification [21]

LIFESTRAW



It consists on a water filtration system that the straws are designed to hang around the neck for individual use, filtering water as people drink through it. The two components are a membrane and charcoal filter, which are separated into different compartments. The end containing the membrane filter is placed into the water and the water must be sucked upwards through the straw to be purified.

The membrane filters are made up of hollow fibers with small pores that effectively filter out any large contaminants, such as bacteria, sand, moulds, and large viruses.

Figure 15: LifesStraw device [22]

Then, the water moves through a filter of activated charcoal, which traps carbon-based contaminants and other chemicals such as chlorine. Non-profit organizations distribute the straws, enabling people to drink from any water source without worrying about consuming contaminants. [22]

CERAMIC BUCKET FILTER

This device represents the simplest way of water filtration. It can filter 5000 GPD and it can be cleaned with a elementary abrasive pad.

It consists of two-bucket system, one mounted on top of the other one. The material it is built of must be plastic. On the other hand, there is no restriction for its size (it can be two gallon, five gallon or ten gallon). [23]

The system eliminates waterborne bacteria through the following three-stage method:

- Submicron filtration:

The external ceramic cover eliminates particulate matter, cysts and bacteria in a very effective way at 2 μm .

- Sterilization:

The water flows through the colloidal silver within the ceramic cover. This device stops the growth of bacteria and provides protection to the water.

- Granular activated carbon

This device removes different particles such as:

- Chlorine
- Foul taste and odours
- Organic chemicals

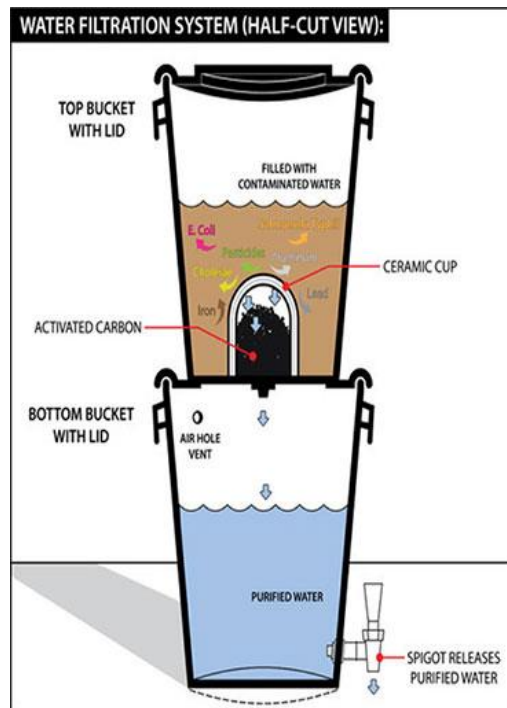


Figure 16: Ceramic Bucket water filtration system [23]

NANO BUCKET FILTER

This device provides an effective way to purify water by using a physical barrier filtration to eliminate pathogens from water.

It can remove harmful bacteria and microorganisms larger than 1 μm of diameter by means of polysulfone micro tubes.

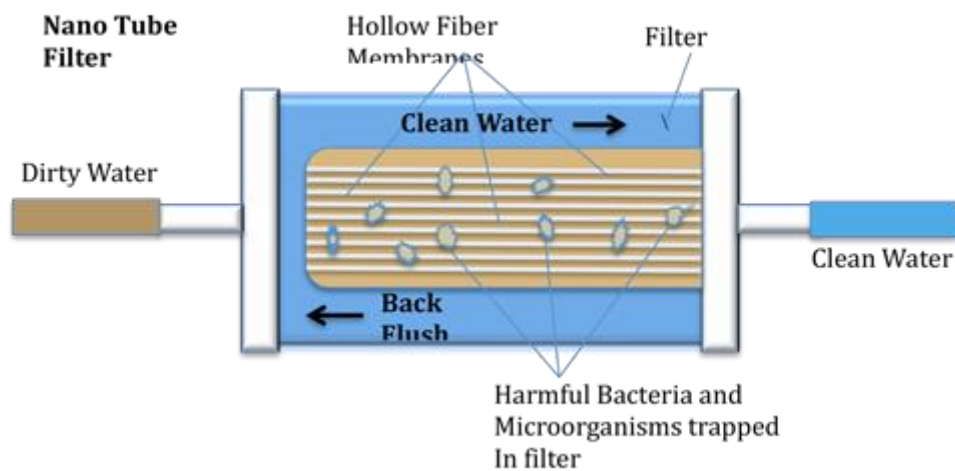


Figure 17: Nano Bucket method for water purification [23]

Some of its characteristics are that it should be built with one specific material (plastic) and that the range for its size is from two to five gallons.

The main advantage of this product is that it does not eliminate valuable, natural minerals (like magnesium or calcium). And some of its highlights are that this purification system does not need chemicals and it is very efficient. [23]

3. GOAL

The aim of the investigation is to provide water - the essential liquid of human life - in remote areas where access to water is not well provided as in developed ones.

The objective of this Bachelor Thesis is to provide, at least, 1700 litres of drinking water per day with a mobile solution.

Solutions as described were carried out by various companies in the past and are still in development, but the main difference to existing solutions is that the system needs to be as small as possible in order to make it portable. In this way, it will be possible to access areas where today there is no chance to do it by limitations of the size of the systems.

To achieve this goal, the system needs to be lighter and more compact than the solutions on the market today to ensure the portability of the overall product.

During the construction process all components were laid out as reasonably as possible to get a very compact design.

Being mobile is the most important characteristic required, but not the only one. For the overall design there is a need for an economical and simple construction. Therefore as less number of elements/parts were used to simplify the mobile solution. Further this approach ensures a comparison between products provided from various companies for such solutions.

A simple way to use solution will be handy when it comes to maintenance and servicing a mobile solution. The phrase "Keep It Simple" (KIS) should be omnipresent during the complete development process. Because of that, no highly trained or specialized personal will be needed to operate or fix the mobile water solution. This system can be operated by every person who is in charge, and in cases like undeveloped countries like Kenya, this will be essential because of the lack of knowledge even about common topics in other countries.

Nevertheless, citizens of developed countries are not used to this sort of gadgets and procedures; therefore simplicity is important not only for people in undeveloped countries but for people all over the world.

4. WORKFLOW

To achieve the goal explained in the previous chapter there have been several steps. The whole process is going to be explained in the following pages.

The objective of this thesis is to produce 1700 litres per day of drinking water using a reverse osmosis system as compact as possible and suitable for easy handling and transport. Once this was demanded, the first step needed was to find information about the process that takes place during reverse osmosis, the elements that are needed for it, the costs, dimensions, etc.

On the other hand, given that this way of obtaining drinking water has been developed previously to this thesis and that the innovation or improvement that is sought in this is the transportation, manageability and compactness of the system, it was necessary to find a way to improve that form to produce drinking water. For this reason, it has been sought information about the devices and systems that exist in the market nowadays as innovations.

All this information has been obtained from scientific articles, patents, books and data that have been found in web sites specialized in this research topic. It can be found conveniently referenced in the final chapter of this thesis.

After having obtained the necessary information, it has proceeded to conclude the design of the system. It has been tried to accomplish a more compact and manageable system than those existing in the market by innovating in its structure as explained later in the "Design" part of the chapter called "Construction" in this project.

Once the design, structure, etc. has been decided it is necessary to start thinking about looking for the elements that carry out the process.

For this, certain characteristics that the aforementioned elements must comply with in order to achieve the expectations of compactness and manageability have been taken into account.

These characteristics have been:

- ✓ First, the main or most important property to take into account has been the dimensions, to keep the device as small as possible.
- ✓ The weight: the lighter the system, the easier it is to transport it.
- ✓ The economic aspect, in order to make it accessible to people from areas where the economy is not good and do not have many resources.
- ✓ And finally, the proximity of the companies that provide these devices, for a faster delivery and security.

Thereafter, it has been created a list to make the delivery of these pieces easier and with greater speed and order.

The pieces were initially distributed by a company, but eventually suppliers were changed as a result of a modification in the needed pieces.

This modification was due to the fact that the main element of the reverse osmosis system (membrane of the water film osmosis reverse) was not sufficient for the objective that was required to reach. That is, it was not able to produce the amount of water that was required.

Once it was realized that it was not possible to reach that amount, it was necessary to start again the search for elements to other distributors, always maintaining the characteristics that these elements had to fulfill.

In such a way that finally the necessary orders were made to different suppliers: "Solar-Heizung Handel" for the dust trap, "Bongartz GmbH" (that is a company that provides devices from Purway Crystal Group) for the "front side" of the system and "EcomStores GmbH" (that is a company that provides devices from Osmofresh) for the "back side". That ensured a good connection between the pieces.

After receiving the pieces, it was proceeded to the construction of the system as detailed below with illustrations and explanations of the procedure that has been followed:

Before starting with the construction, all the pieces were double checked in order to ensure that it would fit each other's and any problem could not appear.

The construction of the system began with the introduction of the first three filters that take part in the process (Sediment Pre-filter, Activated carbon water filter and Activated carbon block water filter) in the TRIO housing.

These elements were provided with a device whose objective is to centre the filters inside the housing and prevent them from moving, but it was unnecessary to use as the filters fitted perfectly to the housing.



Figure 18: TRIO housing assembly

The next step was to connect the dust trap to the left end of the TRIO housing through a connector as well as to find a hose that could adjust to the requirements demanded for this thesis and connect it to the aforementioned dust trap. This hose would be responsible for supplying the system with enough water to treat.

After assembling the front part of the system, it started thinking about assembling the “back side” of the system, concluding that it was more efficient to build the necessary plate to hold both sides before that.

Thus, it was proceeded to take the necessary measures (maximum height and width) that could have the system and, using a radial, to cut the plate with the appropriate dimensions. In this way it was ensured that the measurements were not oversized (avoiding problems of size and ensuring that the system is as compact as possible) but not undersized, that is, that the plate was able to support the weight of both parts of the system and both parts would be placed inside the plate, without protruding.

It should be mentioned that special attention had to be paid to the fact that the system would go through the plate. That is the flow meter would be the device which would connect both parts of the system and would be placed between both, having to make an appropriate hole for it in the plate. This fact would improve the compactness of the whole system making it smaller.

At the same time, the needed measures were taken to make the necessary holes to place both sides of the system on the plate, holding them with screws.

Once the plate was prepared and cleaned, the assembly of the “back side” of the system was started, joining the last three filters (and their previously added connectors) that are involved in the process through adequate size double head clamps.



Figure 19: "Back side" assembly

All this was then mounted on the plate using specific clamps with their respective screws to fasten it on.

With all the devices already assembled, the flow meter was connected (previously joined to the connectors of necessary dimensions to be able to join with both sides), which was considered the most critical part in the assembly due to its location within the system, since it is responsible for connecting both parts and in order to do this, it must go through the plate.

After this, as a last step of the assembly, it was proceed to connect the filters on the back of the system with 1/4" tubes; as well the housing of the membrane filter was connected to the dust trap by means of a 3/8" tube.

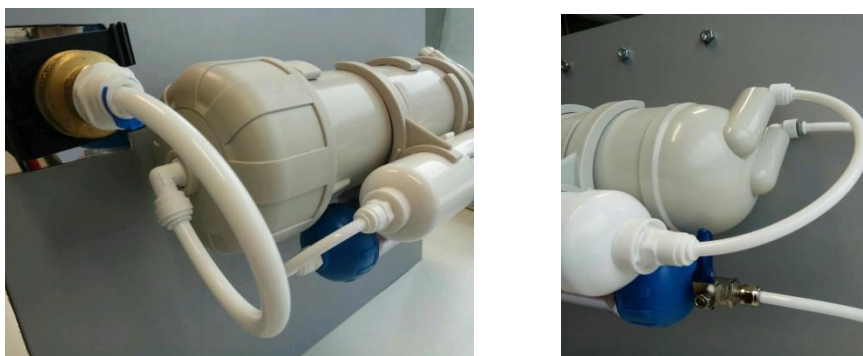


Figure 20: Tubes assembly

Once the entire system was already assembled, the tests could begin.



Figure 21: Entire system assembly

How these tests were carried out and the results they showed are reflected in the "Construction" chapter of this Thesis.

In this way a real vision of what has been theoretically calculated is obtained, that is, these tests were carried out to then compare them with the calculations made during this project, which are explained in detail in the "Calculation" chapter of this thesis.

On the other hand, as in the aforementioned chapter is explained, the calculations have been made theoretically from data and information provided by the manufacturer of the pump used to test the system and by the Master thesis that was previously performed testing various types of pumps, including the pump used in this project. [40]

5. COMPONENTS

In this chapter is explained which elements are needed to compose the system that is developed as it has been described in the previous chapter.

These elements appear in the order in which they act according to the sequence of work in the procedure.

5.1. *DUST TRAP*

The dust trap that has been used for this method is provided by Solar-Heizung-Handel and it is 1/2”.



Figure 22: Dust trap [25]

This device has the function of removing all the heavier particles that are introduced at the beginning of the process while extracting the water. The heavier particles are trapped in its lower part, and can be extracted from the system in a simple way. [25]

The characteristics of this device are the following ones:

- Stainless steel sieve

- Body material: Brass
- Max. working temperature: 180°C
- In/Output diameter: 1/2"
- Length: 56 mm

5.2. CONNECTORS

These components are used in order to join the different devices that the system is composed of.

Its structure is a cylindrical tube whose ends are threaded (external or internal) and can be bent (90°) or straight structure.

These elements are made of plastic or brass depending on the manufacturer and size required. [26]

Here is explained the different connectors that can be found along the method developed in this Thesis:

- ✓ Connector 3/4"- 1/2": To join the hose and the dust trap.
- ✓ Connector 1/2"-1": To join the dust trap and the TRIO housing.
- ✓ Connector 1" (90° angled): To join the TRIO housing and the flow meter.
- ✓ Connector 1"-1/2"+ 1/2"-3/8": To join the flow meter and the tube that connects with the water filter membrane housing.
- ✓ Connector 3/8" (90° angled): To connect the tube with the water filter membrane housing.
- ✓ Connector 1/4" (90° angled): To join the output of the membrane filter and the tubes that connects with the next filter and retire the waste water.
- ✓ Connector 1/4": To join the tubes needed with the input and output of the inline post carbon water filter.



Figure 23: Straight and angled (90°) connectors [26]

5.3. *SEDIMENT PRE-FILTER*



It has been used the model FCPS 5 μm 10", provided by Bongartz GmbH.

The filter cartridge is made of melt-blown polypropylene. Its structure is similar to a sponge, on whose surface is located a large number of open micropores. [27]

This filter is the one whose aim is eliminate solid and coarse contaminants such as: sand, volatile substances, rust and other mechanical impurities. It also prevents the development of microorganisms. The high density of the cartridge allows eliminating impurities of up to 5 microns.

Its dimensions are:

- Length: 10 inch
- Input diameter: $\frac{1}{2}$ inch
- Max. working temperature: 45°C

Figure 24: Sediment Pre-filter [27]

5.4. *ACTIVATED CARBON WATER FILTER*



It has been selected for this function the model PLA 10 SX TS 10", which is filled with activated-carbon granulate, made from coconut shell for the reduction of chlorine, taste, bad smell and taste and volatile organic compounds, designed to provide the highest contact time of the water through the whole activated-carbon bed.

Its main aim is to provide water protection against impurities such as chlorine, organic substances, volatile organic compounds, pesticides, insecticides, solvents, oils and flavours, as well as chlorine and unpleasant tastes and smells. [28]

Figure 25: Activated carbon water filter [28]

Its dimensions are:

- Length: 248 mm
- Width: 70 mm
- Head Opening: 26 mm
- Max. working pressure: 6,0 bar
- Max. working temperature: 45°C

5.5. *ACTIVATED CARBON BLOCK WATER FILTER*



In this case, it has been selected the model PCB 4500L/h 10 µm from Bongartz GmbH.

This element is made from pressed activated carbon providing fine sediment filtration and reduction of chlorine, taste, bad smell and taste, volatile organic compounds and solvents.

It filters substances such as lime scales, flakes, chlorine, organic substances, pesticides, fine particles, insecticides, solvents, oils and flavour. [29]

Its dimensions are:

- Length: 250 mm
- Width: 70 mm
- Head Opening: 26 mm
- Max. working temperature: 45°C

Figure 26: Activated carbon block water filter [29]

5.6. *FILTER HOUSING*



In order to keep the filters as clean and safe as possible, it has been introduced into a triple housing.

This housing is called DP 10 Trio 1 OT TS by its manufacturer.

It ensures a minimal size and provides space-saving head as well. [30]

Figure 27: TRIO Housing [30]

Its main characteristics are the following ones:

- Max. flow rate at 3 bar pressure approx. 5500 l/h.
- Height: 325 mm
- Width: 336 mm
- Depth: 103 mm
- In/Out connection brass thread: 1 inch
- Max. working pressure: 8,0 bar
- Max. working temperature: 45°C

5.7. *WALL BRACKET FOR FILTER HOUSING*

The aim of this gadget is to fix the Triple filter housing on the plate. It is provided with some screws to join these two elements in such a simple and quick way. [31]

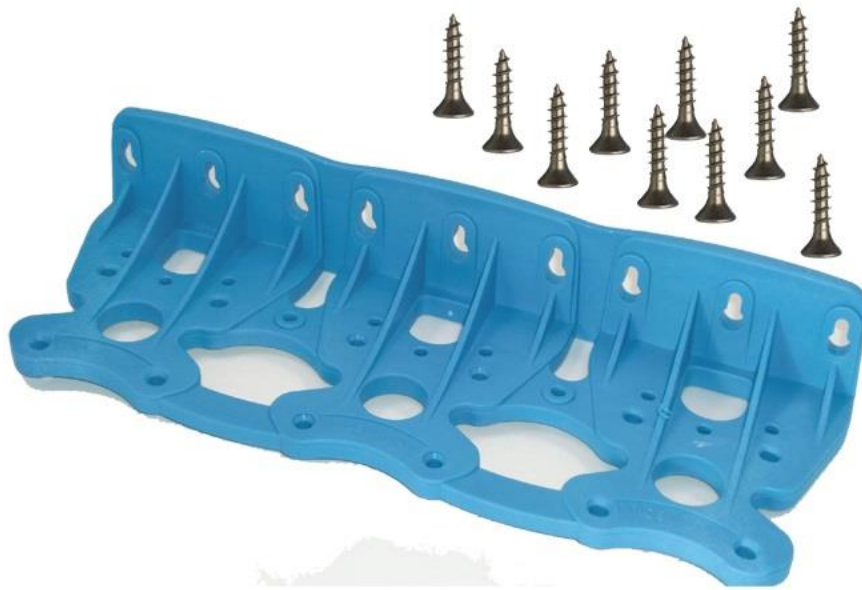


Figure 28: Wall Packet and screws [31]

5.8. *TUBE*

The tube, like the connectors and the plate, is one of the objects that will connect the elements of the system.

The material that is made of is plastic and has been used in two different sizes: $\frac{1}{4}$ " between filters and at the end as a means of transporting the water already treated to the deposit where it is stored; and $\frac{3}{8}$ " between the flow meter and the membrane filter housing.

On the other hand, a hose has been placed at the beginning of the process through which the water to be treated is collected from the water source. Its diameter dimension is 19 mm ($\frac{3}{4}$ "). [32]



Figure 29: $\frac{1}{4}$ " and $\frac{3}{8}$ " Tubes [32]

5.9. PLATE

This element is a support for both “sides” of the system. It is made by “Dibond”, a material compound of aluminium and composite. It has holes that allow the other elements being fixed on it. Additionally, the flow meter goes through it and connects the “front side” of the system with the “back side” by means of a bigger hole made in the extreme of the plate.

Its dimensions are:

- Height: 400 mm
- Width: 4 mm
- Length: 520 mm

5.10. REVERSE OSMOSIS WATER FILTER MEMBRANE

This device is the one that removes all many types of dissolved and suspended species from water, including bacteria, ions, molecules and larger particles from drinking water.

It has been used the model 600 GPD. [33]



Figure 30: Reverse osmosis water filter membrane [33]

Its main characteristics are the following ones:

- Max. flow rate: 2000 l/d.
- Length: 335 mm
- Diameter: 75mm
- Working pressure: 2,8 -6,0 bar
- Material: multi-layer polymer film

5.11. REVERSE OSMOSIS WATER FILTER MEMBRANE HOUSING



This housing is provided by the same manufacturer as the reverse osmosis water filter in order to ensure it fix with the mentioned filter.

It has been made for the 600 GPD model with plastic as material. [34]

Its dimensions are:

- Length: 390 mm
- Diameter: 125 mm
- Connections: 3/8" and 1/4"

Figure 31: Reverse osmosis filter membrane housing [34]

5.12. INLINE POST CARBON WATER FILTER

As inline post carbon water filter has been selected the filter from Osmofresh. Its purpose is to achieve freshly filtered clean water by filtering one more time the water after the Reverse Osmosis process. It removes all the last particles of dirt and completes the taste of the water. [35]

Its dimensions are:

- Length: 390 mm
- Diameter: 54 mm



Figure 32: Inline post carbon water filter [35]

5.13. MINERALIZATION CARTRIDGE



Figure 33: Mineralization cartridge [36]

This is a post filter whose aim is to re-add the minerals that the Reverse Osmosis has removed in the previous step.

Another function that is carried out by this device is to give the osmosis water the taste of mineral water. [36]

Its main characteristics are the following ones:

- Length: 255 mm
- Diameter: 53 mm

The mineral filter enriches the osmosis water with the following minerals:

- ✓ calcium
- ✓ magnesium
- ✓ sodium
- ✓ potassium

5.14. CLAMP

This element allows filters, housings and the plate getting joined. As the plate, it provides order to the system and allows it to be more compact, which is an important characteristic for the objective pursued in this thesis.

There are three different types of this element used during the process of drinking water production:

- Double head clamp: to support inline post carbon water filter and mineralization cartridge. [37]



Figure 34: Double head clamp [37]

- 2" clamp: to join the membrane housing to the plate.



Figure 35: 2" clamp [37]

- Double head clamp 2": to support inline post carbon water filter and membrane housing.



Figure 36: Double head clamp 2" [37]

5.15. SPANNER



This element allows open the housings, so it is used to keep the maintenance of the system with procedures such as changing filters or check the parts that are involved on it.

For each housing there is a spanner whose dimensions are appropriate to. They are provided by the same company that provides the housing in order to avoid any doubts about these elements would fit the housings. [38]

Figure 37: Spanner for front part housings [38]

5.16. FLOW METER



This device allows knowing the amount of water that runs through the pipe, tube or other element where it is located.

In this thesis it will be used in order to test the system. This flow meter will be placed between the TRIO housing and the back side part of the system, in order to show if the aim of 1700 litres per day is achieved or not. [39]

Figure 38: Flow Meter [39]

Its characteristics are the following ones:

- In/Output diameter: 1 inch
- Battery feed (AAA): 1,5 v

5.17. VALVE



Valve is used to control the flow of the drinking water that exits the system, behaving like an orifice of continuously variable area.

Its input/output dimension is 1/4".

It connects the last filter of the process with the tube that drinking water is collected through.

Figure 39: Valve

6. CONSTRUCTION

6.1. METHOD

This method of filtering and reconditioning of drinking water has been developed years ago, starting with big filtering applications. But during the research and in the investigations made for this project, there was a different way of interpreting those well-known techniques. On the one hand, it consists in diverse steps of filtering of brackish water up to obtaining the level of purity required (drinking water). On the other hand, to create a system as small as reasonably possible regarding the flow rate of about 800 GPD (Gallons Per Day) and an efficient package.

In order to explain this complex process in a structured way, the procedure is divided into two main stages which will include different sub-stages itself.

They will be mentioned according to the order of action that each of them provide in the process. In this way it can be explained how to develop the steps through the design from the “front” side of the system to the “back” side of the system.

In the aforementioned front of the system will be the start where the procedure begins to take place:

First of all, the water is gathered by dammed water from a river, reservoir, lake or any suitable source of water that can provide a quantity enough to start this process.

After that, across a few flexible tubes that are connected to a dust trap, the primary water will flow into this device with the aim of being separated from certain particles (since this is the end of the above mentioned device) before entering this liquid in the filters that are attached to following steps.

The remaining separated particles are stored in the lower part of the dust trap and are expelled on the outside by opening the cavity. This realizes every certain time not to accumulate particles and to prevent the device from collapsing, and the general procedure from turning out to be affected.

When the larger sized particles have been eliminated, the water continues its course towards the first of three filters in the process. The dust trap is connected by means of a connector of 1 inch to 1 inch threaded connection.

When the water is entering the first filter (a sediment pre filter) this one realizes its function, which is to eliminate solid and coarse contaminants such as:

- Sand
- volatile substances
- rust and other mechanical impurities

It also prevents the growing of microorganisms. The high density of the cartridge allows eliminating impurities of up to 5 microns.

By means of a connector, the water (without all the aforementioned components) flows into an activated carbon granulate water filter which is also inside the three connected housing as was the first filter.

In this second filter, water protection it is provided against impurities such as:

- chlorine
- organic substances
- volatile organic compounds
- pesticides
- insecticides
- solvents, oils and flavours
- unpleasant tastes and smells

Following this, the water is flowing into the third filter out of three in the same way as in the previous two were described in the triple housing.

In this third step, the carbon block PCB-EC filters substances like:

- lime scales and flakes
- chlorine
- organic substances
- pesticides
- fine particles
- insecticides
- solvents
- oils and flavours

It also helps from preventing bad taste and smell of the water.

Once the water has gone through this front part of the system, it flows to the “back” side by means of a tube that ensures the approach to the next main stage.

This part of the system starts with a membrane filter. The aim of this filter is to retain and eliminate all types of pollutants such as:

- bacteria and viruses
- metals
- excess salt
- chlorine
- etc

Membranes are relatively sensitive to chlorine, for this reason two activated carbon filters are used before the membrane filter.

In this case, there will be two outlets in the membrane housing in order to separate the treated, sound water from the water that should be removed from the process. This will be carried out by connecting two flexible tubes with the before mentioned outputs of the case from the membrane. One of them will carry the treated water to the next filter, while the other one will extract waste water from the process.

The filter where the treated water is carried to is an active carbon post-filter. Its purpose is to improve the water quality, since it is specially designed to improve the taste and, in short, to leave the water in the best possible conditions for the consumer. Another advantage of this filter is that it removes any residue, impurities and odours from the tank and the pipes.

After this step, the water flows into the last filter of the process. This filter is the mineralization post filter. It has the following functions:

- Eliminate the possible residual taste that could result from the passage of water through the osmosis membrane
- Regulate the pH of the outlet water and mineralize the water.

Once the water has gone through this filter, it can be considered drinking water. Therefore, the only step that is missed is picking it up and storing it safely.

6.2. DESIGN

The design of this system has been focused on the greatest possible simplicity and compactness.

For this purpose, it has tried to find the necessary elements to develop the process of obtaining drinking water in the smallest possible size as well as attending to its manageability and difficulty of operation.

That is the reason because of it has been designed this system in a different way that it can be found in the industry nowadays.

This novel design consists of placing the "second" part of the process (the last 3 filters) behind the first 3, instead of putting the set of three last filters of the process on top of the three filters that take part on the process firstly, what is usually done.



Figure 40: Usual structure of a water production RO system

Both parts will be fixed on a plate that is placed between them, thereby providing stability, lightness and order to the whole system.

In the abovementioned plate, necessary holes are made at suitable distances to ensure the correct connection of the front part with the rear one in a simple way by means of light tubes and connectors.

In this way, the system acquires a more balanced and orderly structure, very important qualities to obtain a manageable and suitable system for an uncomplicated transport.

Taking into account that these characteristics are the main initial objectives of this Thesis, with this new provision that the system acquires, an effective solution has been reached for the posed problem.

6.3. TEST

After building the whole system, it has been tested in order to compare the theoretical calculations with the reality.

The test has been started looking for a piston pump, since the one that has been used in the theoretical calculations has been of this type, and placing it in the system that is located in the laboratory. The piston pump is the model APME 28/40/4, made by Pumpenfabrik Salzwedel GmbH.

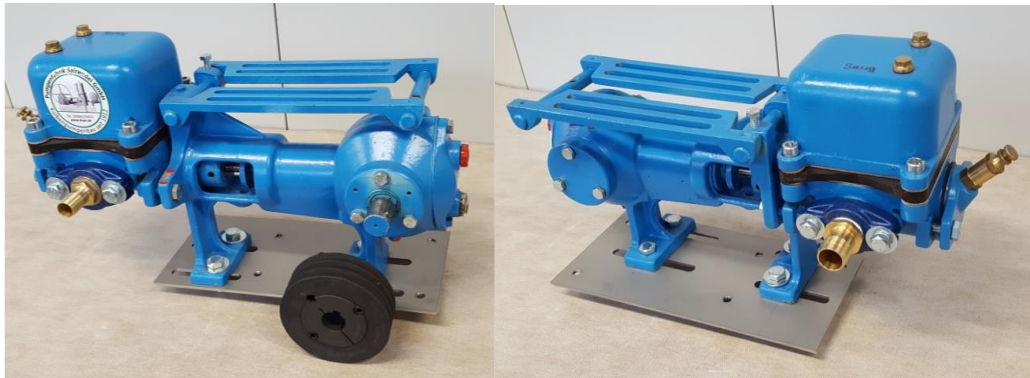


Figure 41: Piston Pump APME 28/40/4 [40]

The system located in the laboratory is provided with a simulated vane wheel, as in the calculations of the point 6.5. of this thesis is simulated.

After having properly assembled the pump on the paddlewheel system in the laboratory using transmission belts and adjusting the necessary measures, the needed connectors and hoses were searched to start the simulation. In such a way that the water production system developed in this thesis was connected through an appropriate connector and also the hose whose purpose when placing it from the beginning was to provide water to be treated by the aforementioned system.

At the other extreme of the system containers were placed to collect waste water on one hand and drinking water on the other.

After verifying that each connector was properly connected and that each element was in the correct position to be able to perform its function, the test was started.

The test was carried out creating a movement similar to the one that would result if the paddle wheel system was in a river (which is its real application). That is, giving the wheel a certain velocity. This velocity will be compared in the calculations as the speed that carries the river, u .

The velocity mentioned in the previous paragraph induces a movement in the wheel, which begins to rotate and, by means of the transmission belt placed between it and the pump, movement is generated in the piston that the pump used in this test contains.

Thus, this device starts pumping water by means of a hose that takes water to be treated from a previously placed tank.

Once it is ensured that there is no air in the hose that carries the water to the pump, (otherwise the system does not work because the water cannot be pumped), the water is pumped correctly. It begins to run through the system developed in this thesis, flowing first through the sediment pre-filter, the activated carbon water filter and the activated carbon block water filter, in a few seconds.

Then it flows to the “back side” of the system by means of a flow meter that gives the necessary results. In this last part of the system, it passes through the last three filters (Reverse Osmosis water filter membrane, inline post carbon water filter and the mineralization cartridge) to finally produce drinking water fulfilling the specifications required from the beginning.

This procedure has been carried out several times by applying different velocities to the wheel and measuring the number of revolutions it gives in one minute and the amount of drinking water that is produced in those conditions during one minute.

Therefore, different results are obtained and can be compared with the theoretical work developed and lead to certain conclusions that are exposed in the following chapters.

6.4. TEST RESULTS

The system has been tested several times in order to obtain results with different velocities of the wheel.

It has been analysed for one minute for each different speed, which derives in various results that are reflected below.

u (m/s)	u (rpm)	Q (L/min)	Q (L/d)
0,753982	16	0,207	298,08
0,753982	16	0,217	312,48
0,801106	17	0,179	257,76
0,801106	17	0,595	856,8
0,84823	18	0,825	1188
0,942478	20	1,35	1944
1,036726	22	2,858	4115,52
1,178097	25	2,931	4220,64
1,272345	27	3,984	5736,96
1,272345	27	4,018	5785,92
1,319469	28	4,408	6347,52
1,460841	31	4,955	7135,2
1,507964	32	5,382	7750,08
1,649336	35	5,923	8529,12

Table 1: Data test results

With these data, a diagram can be made using a spread sheet. This diagram will relate the amount of drinking water produced (in litres per day) and the wheel velocity (m/s) that has been applied to the wheel in each case.

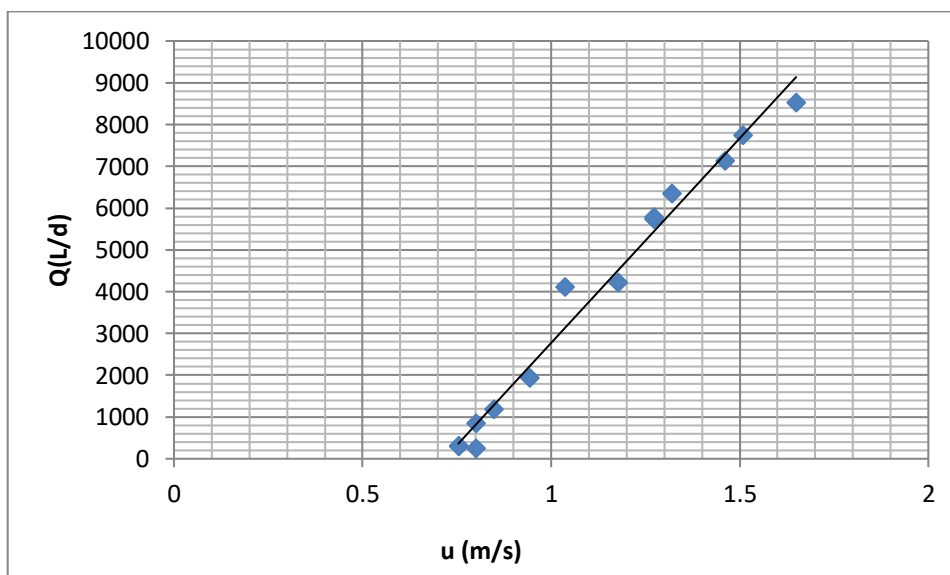


Figure 42: Diagram Q-u Test

As it can be observed, the amount of drinking water required (1700 L/d) will be achieved at a minimum wheel velocity value of approximately 0.9 (m/s), which is not far away from the value obtained during the theoretical calculation. This is compared and explained in greater depth in the chapter where the conclusions are reflected in this thesis.

6.5. CALCULATION

As part of this Thesis and in addition to the test carried out, it has been estimated as well in a theoretical way the velocity that the river should have in order to achieve the initial aim of production: 1700 litres per day.

To achieve this goal, it is required taking into account the factors that affect the wheel and its movement, and both its production.

The factors to take into account are the force (pressure), which the water applies with its movement on the part of the wheel that is submerged in it, and the moment that it produces. This force is exerted on the midpoint of the paddle (the part of the wheel that is submerged).

Both factors are affected by the velocity of the river (v) as well as the velocity at which the wheel rotates (u), so a relation between them is established giving a new parameter that is reflected later as λ .

On the other hand, another relation between those velocities will be achieved, which means the difference between velocities and will be representing as w .

The introduction of the different values of each parameter must always be taken into account in units of the International System to avoid errors.

For this calculation, several mathematical expressions have been needed, the combination of which results in the objective of the minimum speed to reach the demanded daily production. They are explained in the following paragraph:

$$F_w = \frac{1}{2} \times C_w \times \xi \times A \times v \times w$$

$$w = v - u$$

Where:

F_w = Force at the middle point of the paddle in the wheel

C_w = Flow coefficient (*dimensionless*)

ξ = Water density $\left(\frac{Kg}{m^3}\right)$

A = Under water paddle area (m^2)

v = Velocity of the river $\left(\frac{m}{s}\right)$

u = Scope velocity of the wheel $\left(\frac{m}{s}\right)$

w = Difference of velocity $\left(\frac{m}{s}\right)$

$$M = \frac{1}{2} \times C_w \times \xi \times A \times (1 - \lambda) \times v^2 \times L_t$$

$$\lambda = \frac{u}{v}$$

Where:

M = Moment made by the force

C_w = Flow coefficient (*dimensionless*)

ξ = Water density $\left(\frac{Kg}{m^3}\right)$

A = Under water paddle area (m^2)

λ = Relation between velocities (*dimensionless*)

v = Velocity of the river $\left(\frac{m}{s}\right)$

L_t = Radius of the paddle (m)

Once the formulas needed to carry out these calculations are determined, the values of each parameter are introduced. Some of these parameters, in the case of using water as liquid of work, can be considered constant, so that the calculations will be carried out with the following constant values:

➤ $C_w = 2,3$ (*dimensionless*)

➤ $\xi = 1000$ $\left(\frac{Kg}{m^3}\right)$

➤ $A = 0,105$ (m^2)

➤ $L_t = 0.375$ (m)

On the other hand, there are some parameters in these expressions that are not constants and should be determined by other methods. That is the case of both velocities and, as result, of its relation and difference.

By means of information about the pump that is being used (which is a piston pump, the model APME 28/40/4) it can be find the valour of the velocity of the wheel (u) and the other parameters' valour in consequence.

The information provided by the manufacturer and a previous Master thesis allows knowing data about the required moment for the pump (M), the cm³ per rotation that the pump provides (q), and the line (curve) of operation of the pump:

$$\checkmark M = 30,315 \left(\frac{Kgm^2}{s^2} \right)$$

$$\checkmark q = 66,14 \left(\frac{cm^3}{U} \right)$$

With these data, it is possible to obtain the number of rotations per day that the wheel should perform to reach 1700 litres of drinking water per day simply by dividing the litres that are required per day by the number of cm³ per rotation provided by the pump:

$$\frac{1700000}{66,14} \approx 25703 U/d$$

The final objective of these calculations is to determine the minimum velocity of the river, and for this the relation between it and the velocity of the wheel will be used as a tool, for that reason the velocity of the wheel should be calculated first.

By definition, velocity means the unit of space between units of time; therefore, it is needed calculate the space that the wheel has to travel to complete that number of rotations.

For this calculation, the concept of circumference length is used, which is represented by the following expression:

$$L = 2\pi \times D$$

Where:

L = circumference length (m)

D = Wheel diameter (m)

Rotation means the length of the circle. Once the necessary number of rotations is determinate, it is possible to obtain the meters that the wheel should travel without more than multiplying the number of rotations needed

per the number of meters that the wheel travel per rotation. It is suggested to apply conversion factors for adjust the units of measurement to the International System.

In that way, the calculation is carried out following the steps shown below:

$$L = 2\pi \times 0.9 \text{ m} = 2,83 \text{ m}$$

This means that the wheel travels 2,83 meters per each rotation.

$$\frac{25703 \text{ U}}{1 \text{ d}} \times \frac{2,83 \text{ m}}{1 \text{ U}} \times \frac{1 \text{ d}}{24 \text{ h}} \times \frac{1 \text{ h}}{3600 \text{ s}} = 0,842 \left(\frac{\text{m}}{\text{s}}\right)$$

The result reached is the scope velocity of the wheel, called “u” during the calculation, but what is demanded is the speed of the flow (v), so it is necessary to use the relation between both velocities that is mentioned in previous paragraphs.

This relation, λ , always has values between 0 and 1, then in a spread sheet these values have been introduced and different possible values of flow velocity as well. The range of this velocity will vary between 0,6 and 2,2 meters per second.

In this way, it can be shown the minimum flow velocity value that allows the system produces the 1700 litres per day that are demanded.

This is possible to be achieved by simply calculating the necessary wheel velocity for each flow velocity value by applying the relation between both. Thus, for each flow velocity, v, we will obtain 10 different values of u (plus another one that will always give us 0 when entering the value 0 as λ).

As it is known the minimum velocity of the wheel to reach the specified production goal, (since it has been previously calculated: $u_{\min} = 0,842$), it is possible to compare u values.

So it is selected the value of u within those calculated in each flow velocity that is greater than or equal to the minimum value needed: $u_{\min} = 0,842$.

Thereby, it has been obtained that the minimum flow velocity necessary to reach the goal of 1700 litres of drinking water production per day with this pump will be $1 \left(\frac{\text{m}}{\text{s}}\right)$.

For the flow velocity $v = 0.8 \left(\frac{\text{m}}{\text{s}}\right)$ all the u values obtained are below the minimum wheel velocity needed.

The following table shows the data obtained for $v = 1$. The information that has outcome for the other speeds and with which they have been compared

can be find out in the tables and diagrams attached in the chapter of annexes exposed at the end of this thesis.

v	1	1	1	1	1	1	1	1	1	1	1
u	0	0,1	0,2	0,3	0,4	0,5	0,6	0,7	0,8	0,9	1
w	1	0,9	0,8	0,7	0,6	0,5	0,4	0,3	0,2	0,1	0
λ	0	0,1	0,2	0,3	0,4	0,5	0,6	0,7	0,8	0,9	1
M	0	0,407	1,459	2,852	4,347	5,660	6,520	6,656	5,796	3,667	0

Table 2: Results $v=1\text{m/s}$

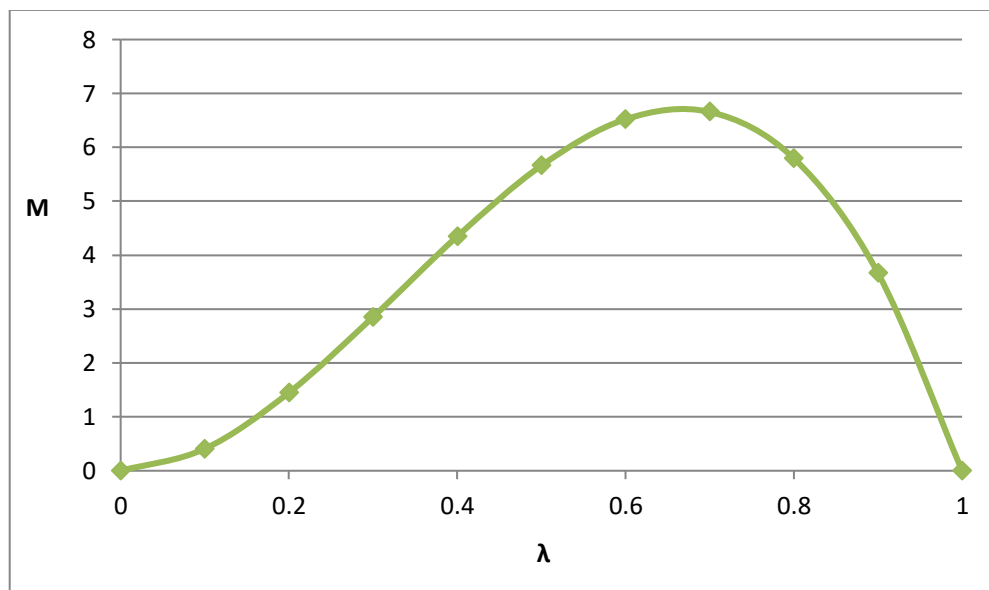


Figure 43: Theoretical diagram M-λ

The aforementioned and explained calculation is compared with the results obtained in the real test that is carried out in this thesis, throwing the conclusions which are exposed in the following chapter.

7. SUMMARY AND CONCLUSION

There are several points to take into account when summarizing or deducing conclusions about this thesis.

One of them is the results obtained during it. After comparing the results obtained in the test with those developed in the calculations, different conclusions and/or observations can be reached:

The result of minimum velocity that the wheel must carry to achieve the initially required goal of 1700 litres of drinking water per day is very similar in both cases.

While in the theoretical calculations a value of $0.842 \left(\frac{m}{s}\right)$ was obtained, after carrying out the tests and their subsequent implementation in spread sheet, a value of approximately $0.9 \left(\frac{m}{s}\right)$ for the same velocity was obtained.

It can be considered that the error between those results is not appreciable, since the conditions in which the tests were carried out were very far from the ideal ones:

- The force is applied by hand on the wheel, knowing exactly what force is being subjected to the wheel as well as the velocity that is induced on it is unachievable.
- It should be noted that the test must be done in a longer time interval than the one that has been done (one minute) because what is needed to test is the production in a day, not in a minute. These tests have been carried out at intervals of one minute and then the conversion has been made to how much it would produce in a day.
- The pressure of the system also affects the final result of the test. It has realized that the lower was the velocity applied to the wheel; the harder it was to start up the entire system to produce drinking water. This is due to the internal pressure that is created in the system.

On the other hand, it is worth mentioning and comparing the design developed to obtain the objective initially demanded with some of the devices that exist today in the market and that have been exposed in the Chapter called State of art.

One of these devices is the Ultraviolet Water Filter. This device has a shape very similar to that of a filter, unlike that in it the energy used to decontaminate the water to be treated is solar.

It does not require a pump or non-renewable energies; as a consequence it is a device that is getting a great reception and use nowadays, even though it

does not provide the effectiveness that can be achieved with the Reverse Osmosis process that has been applied during this thesis.

Moreover, it should be noted about this filtration system the fact that the mineral filter replaces the standard post filter in 5-stage osmosis systems, whose connections can easily be used.

This characteristic provides the system with a compact design, one of the required specifications when the problem was exposed that during the realization of this thesis has been tried to solve.

8. PROPOSAL TO THE FUTURE

After developing the entire system according to the initial specifications, there is still one that seems to be unresolved: mobility.

In order to achieve a solution is developed the idea of introducing the whole system in a box. This operation gives it certain mobility while keeps it compact. So the solution, although not put into practice, is fully developed.

The ideal material for the aforementioned box is Aluminum, due to several reasons that are explained below:

- ✓ It is a light material, so it will provide greater ease for mobility and transport whatever the conditions in which it is going to be used.
- ✓ It is economic, which will be a positive aspect in the budget of the entire system and something to take into account as this system will be used in places where the economy is not well developed.
- ✓ It is easy to find, which should be considered as an important aspect. In case of having to replace or change it, will be easily supplied.

To achieve these characteristics, it is possible follow one of these procedures: look for the solution by searching and buying a metal box already designed with specific dimensions; or purchase the necessary material to design and manufacture a specific and customized solution for the system developed in this thesis.

Both options present advantages and disadvantages those have been taken into account and are exposed in the next paragraph.

On the one hand, a suitable option is the solution offered below. It is a trolley-type box that provides all the required features as ideal to cover the system.

It is easily found in a few minutes by online purchase, with German manufacturer, which facilitates the supply.

In addition, as has been done up to now, the economic aspect is taken into account. It has been compared with other metal boxes and it presents a remarkably lower price.



Figure 44: Trolley Aluminum box solution

The disadvantages that present are the wheels with which it has been designed and the dimensions it presents. In principle they can seem great disadvantages or problems, but actually there is no complication in deal with it: the wheels are easily removable or changeable without simply dismounting the system by which they are attached to the base of the box that is also simple.

Regarding the dimensions, it can be possible to search for one of larger dimensions or even order one with the dimensions determined for the system, as long as the price is within an acceptable range.

On the other hand, the solution that consists in the construction of it is also viable. It would be necessary to buy the necessary material for this, but this is not a problematic situation since that material is easily found in any store dedicated to this area.

The disadvantage in this case is that calculate different variables that can affect the correct function of this box is needed as well as having a place, time and tools necessities for the construction.

9. REFERENCES

- [1] WHO (2016)
Diseases and risks associated with deficiencies in water and sanitation services.
URL: http://www.who.int/water_sanitation_health/diseases-risks/es/
Search date: 30/01/2018
- [2] Agrokenya
Report update of the streaming pump
Kenya, 2017
- [3] Reverse Osmosis technical center
URL: <https://www.freedrinkingwater.com/infocenter.htm>
Search date: 01/02/2018
- [4] Boyle, S.
Recirculating, purifying, disinfecting, cooling, decontaminating, feedback controlled water system for drinking water and other uses to improve health and well-being of animals and humans
URL: https://worldwide.espacenet.com/publicationDetails/biblio?II=0&ND=3&adjacent=true&locale=en_EP&FT=D&date=20180111&CC=US&NR=2018009686A1&KC=A1
Search date: 19/01/2018
- [5] Walter F.; Grabosch M.; Ritzka R.; Purmann S.; Groesche D.; Lohrberg M.;
Purification device and purification method for water utilizing filter cartridges
URL: https://worldwide.espacenet.com/publicationDetails/biblio?II=1&ND=3&adjacent=true&locale=en_EP&FT=D&date=20180111&CC=US&NR=2018009680A1&KC=A1
Search date: 19/01/2018
- [6] Wistuba E.; Zink M.
Cleaning unit for water treatment
URL: https://worldwide.espacenet.com/publicationDetails/biblio?II=2&ND=3&adjacent=true&locale=en_EP&FT=D&date=20140214&CC=ES&NR=2442903T3&KC=T3
Search date: 21/01/2018

- [7] Castagnino Larriera, A.
Compact water treatment plant for the production of drinking water
URL:https://worldwide.espacenet.com/publicationDetails/biblio?II=3&ND=3&adjacent=true&locale=en_EP&FT=D&date=20080312&CC=AR&NR=059189A1&KC=A1
Search date: 21/01/2018
- [8] Zwinger V.
Device and method for the preparation of drinking water
URL:https://worldwide.espacenet.com/publicationDetails/biblio?II=4&ND=3&adjacent=true&locale=en_EP&FT=D&date=20170314&CC=ES&NR=2605474T3&KC=T3
Search date: 21/01/2018
- [9] Mitchell M. D.; Collias D. I.
Water filters and methods incorporating activated carbon particles and surface carbon nanofilaments
URL:https://worldwide.espacenet.com/publicationDetails/biblio?II=5&ND=3&adjacent=true&locale=en_EP&FT=D&date=20101103&CC=ES&NR=2347691T3&KC=T3
Search date: 21/01/2018
- [10] Katz G. P.
Apparatus, Method and System for Desalinating Water
URL:https://worldwide.espacenet.com/publicationDetails/biblio?II=6&ND=3&adjacent=true&locale=en_EP&FT=D&date=20171207&CC=US&NR=2017349455A1&KC=A1
Search date: 21/01/2018
- [11] Nava Sanjuan, J. I.
Domestic water filter and purifier
URL:https://worldwide.espacenet.com/publicationDetails/biblio?II=7&ND=3&adjacent=true&locale=en_EP&FT=D&date=20040812&CC=MX&NR=PA01008798A&KC=A
Search date: 23/01/2018

- [12] Nowak, P.
Máquina expendedora de agua potable
URL:https://worldwide.espacenet.com/publicationDetails/biblio?II=8&ND=3&adjacent=true&locale=en_EP&FT=D&date=19970516&CC=ES&NR=1035755U&KC=U
Search date: 23/01/2018
- [13] DecRen water consult
Mobile, no energy, non-chemical Ultrafiltration water purification
URL:<http://www.dwc-water.com/technologies/filtration-systems/index.html>
Search date: 25/01/2018
- [14] DecRen water consult
Mobile water purification/desalination system
URL:<http://www.dwc-water.com/technologies/solar-reverse-osmosis/water-trailer/index.html>
Search date: 25/01/2018
- [15] Ontario Safety Standards
Ultraviolet water filters
URL: <https://ontariosafetystandards.com/smart-filter/>
Search date: 25/01/2018
- [16] Bouchekima B.
A small solar desalination plant for the production of drinking water in remote arid areas of southern Algeria
URL:<https://www.sciencedirect.com/science/article/pii/S0011916403900713>
Search date: 29/01/2018
- [17] Solaqua
Solar still
URL: <http://www.solaqua.com/solstilbas.html>
Search date: 29/01/2018

- [18] Daniels, B.; Mesner, N.
Drinking Water Treatment Systems / Ion Exchange
URL:<https://extension.usu.edu/waterquality/files-ou/Publications/Drinking-water-treatment-systems.pdf>
Search date: 31/01/2018
- [19] Torgerson, R.
Colorado company patents break through water purifying technology
URL:<http://eaglefordtexas.com/news/id/138365/colorado-company-patents-break-water-purifying-technology/>
Search date: 31/01/2018
- [20] Lyndon, B.; Johnson Space Center.
Filtering Water by Use of Ultrasonically Vibrated Nanotubes
URL:<https://www.techbriefs.com/component/content/article/tb/techbriefs/materials/5609?m=1393>
Search date: 31/01/2018
- [21] Spy Ghana
Photocatalytic Water Purification Technology Developed
URL:<http://savethewater.org/2015/01/01/photocatalytic-water-purification-technology-developed/>
Search date: 01/02/2018
- [22] Zhang, A.
Advancements in Water Purification Technology: How Straws Can Save Lives
URL:<http://triplehelixblog.com/2014/09/advancements-in-water-purification-technology-how-straws-can-save-lives/>
Search date: 01/02/2018
- [23] Water is life
Bucket filter systems
URL: <https://waterislife.com/impact/clean-water#bucket-filter-systems>
Search date: 01/02/2018
- [24] Gillert, J.
Bachelor Thesis: "Konstruktion eines Testandes für mobile Trinkwasseraufbereitungsanlagen", 2017

- [25] Heizung-Solar24
Schmutzfänger mit Edelstahlsieb 1/2" product data sheet
URL:<https://www.heizung-solar24.de/Heizung-Wasser-Installation/Schmutzfaenger-mit-Edelstahlsieb-1-2::534.html>
Search date: 22/01/2018
- [26] Osmofresh
Anschlüsse product data sheet
URL:<https://www.osmofresh.de/zubehoer/ersatzteile/anschluesse/#?p=1>
Search date: 22/01/2018
- [27] Purway Crystal Group
Fcps 5mcr "melt blown" polypropylene sediment filter membrane
URL:https://shop.purway.de/public/catalog_xmlslproductsearch.aspx?q=5908311098257&art=SetSearch&SearchButton=Absenden&uid=7618&zid=72771dbe-b2ce-41ed-bc47-3575965437e1
Search date: 22/01/2018
- [28] Purway Crystal Group
PLA 2600L/H 10" carbon patrone granulataktivkohle wasserfilter aktivkohleblock
URL: <https://shop.purway.de/WASSERFILTERPATRONEN-PLA-2600L-h-10-CARBON-Patrone-Granulataktivkohle-Wasserfilter-Aktivkohleblock.html>
Search date: 22/01/2018
- [29] Purway Crystal Group
PCB 10MCR carbon block aktivkohleblock aktivkohle wasserfilter kalk chlor osmose
URL:<https://shop.purway.de/WASSERFILTERSYSTEME-Brunnen-Wasserfilter-PCB-10mcr-Carbon-Block-Aktivkohleblock-Aktivkohle-Wasserfilter-Kalk-Chlor-Osmose.html>
Search date: 22/01/2018

- [30] Purway Crystal Group
DP 10 TRIO 1" OT TS Dreifach filtergehäuse hauswasserfilter
trinkwasserfilter
URL: <https://shop.purway.de/WASSERFILTERGEH%C3%84USE-DP-10-TRIO-1-OT-TS-DREIFACH-Filtergehaeuse-Hauswasserfilter-Trinkwasserfilter.html>
Search date: 22/01/2018
- [31] Purway Crystal Group
W3 - Wandhalter (blau) für dreifach-filtergehäuse Purway
URL:<https://shop.purway.de/WASSERFILTERGEH%C3%84USE-W3--Wandhalter--blau--fuer-DREIFACH-Filtergehaeuse-purway.html>
Search date: 22/01/2018
- [32] Osmofresh
Schlauch 3/8 Zoll weiß
URL:<https://www.osmofresh.de/zubehoer/ersatzteile/schlaeuche/schl auch-3/8-zoll-weiss>
Search date: 24/01/2018
- [33] Osmofresh
Membran 600 GPD
URL:<https://www.osmofresh.de/membrane/membran-600-gpd?number=MB600N>
Search date: 24/01/2018
- [34] Osmofresh
Membrangehäuse 600 GPD
URL:<https://www.osmofresh.de/zubehoer/ersatzteile/gehaeuse/membrangehaeuse-600-gpd?number=ETMB600N>
Search date: 24/01/2018
- [35] Osmofresh
Aktivkohle Nachfilter
URL: <https://www.osmofresh.de/ersatzfilter/aktivkohle-nachfilter>
Search date: 24/01/2018

- [36] Osmofresh
Mineral Nachfilter
URL:<https://www.osmofresh.de/ersatzfilter/mineral-nachfilter?number=FIMIN>
Search date: 24/01/2018
- [37] Osmofresh
Klammer
URL: <https://www.osmofresh.de/search?sSearch=klammer>
Search date: 24/01/2018
- [38] Purway Crystal Group
S1-DP / F Schlüssel für die x-serie dp und f filtergehäuse von purway in schwarz
URL: <https://shop.purway.de/WASSERFILTERZUBEH%C3%96R-S1-DP--F-SCHL%C3%96SSEL-fuer-die-X-SERIE-DP-und-F-Filtergehaeuse-von-purway-in-schwarz.html>
Search date: 24/01/2018
- [39] Purway Crystal Group
PCG1 Flow meter durchflussmessgerät messung von flüssigkeiten wie wasser
URL:<https://shop.purway.de/WASSERFILTERZUBEH%C3%96R-PCG1-Flow-Meter-Durchflussmessgeraet-Messung-von-Fluessigkeiten-wie-Wasser.html>
Search date: 24/01/2018
- [40] Müller, M.

Master Thesis: “Untersuchung, Auslegung und experimentelle Überprüfung von Pumpenbauformen für eine mobile Wasserkraftanlage, sowie Erarbeitung und Validierung einer Auslegungsvorschrift für Spiralpumpen.”, 2018
- [41] Adolph,U.; Grabow, G.; Heinrichs, K.; Kriegel, G.; Will, D.

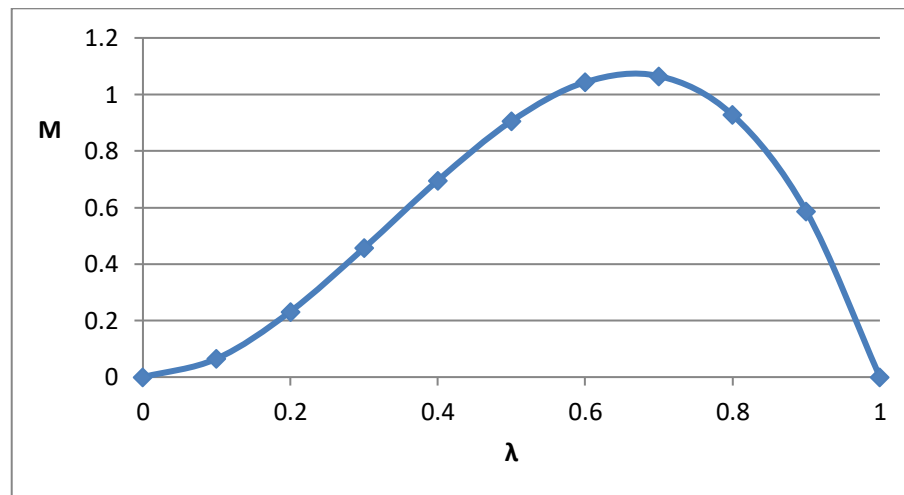
“Pumpen für Flüssigkeiten”, 1984

10. APPENDIX

APPENDIX A: CALCULATION RESULTS DATA

For a flow velocity (v) of **0.4** meters per second:

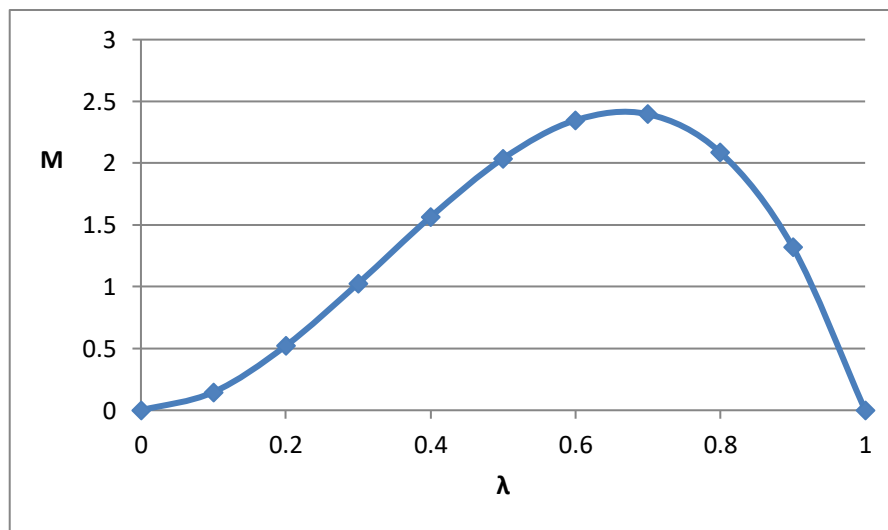
v	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4
u	0	0,04	0,08	0,12	0,16	0,2	0,24	0,28	0,32	0,36	0,4
w	0,4	0,36	0,32	0,28	0,24	0,2	0,16	0,12	0,08	0,04	0
λ	0	0,1	0,2	0,3	0,4	0,5	0,6	0,7	0,8	0,9	1
M	0	0,065	0,231	0,456	0,695	0,905	1,043	1,065	0,927	0,586	0



APPENDIX B: CALCULATION RESULTS DATA

For a flow velocity (v) of **0.6** meters per second:

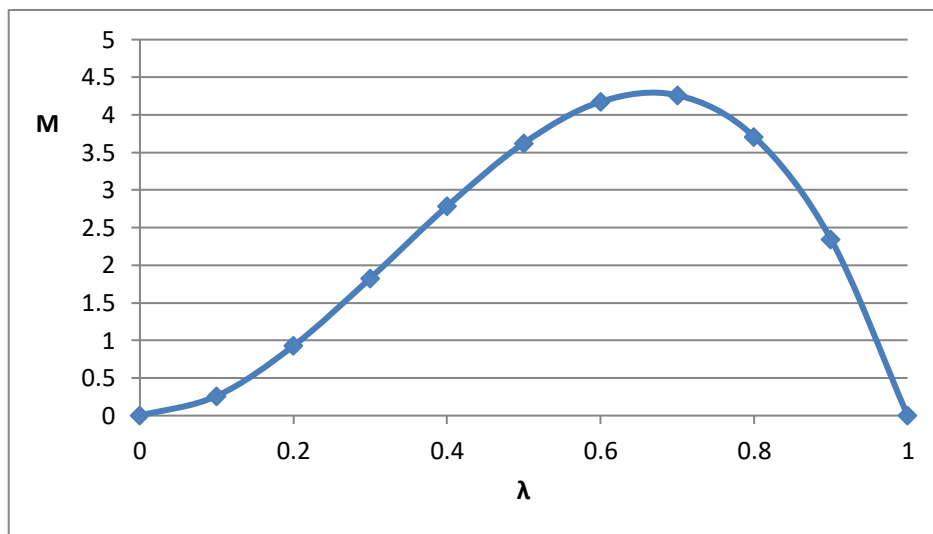
v	0,6	0,6	0,6	0,6	0,6	0,6	0,6	0,6	0,6	0,6	0,6
u	0	0,06	0,12	0,18	0,24	0,3	0,36	0,42	0,48	0,54	0,6
w	0,6	0,54	0,48	0,42	0,36	0,3	0,24	0,18	0,12	0,06	0
λ	0	0,1	0,2	0,3	0,4	0,5	0,6	0,7	0,8	0,9	1
M	0	0,146	0,521	1,026	1,564	2,037	2,347	2,396	2,086	1,320	0



APPENDIX C: CALCULATION RESULTS DATA

For a flow velocity (v) of **0.8** meters per second:

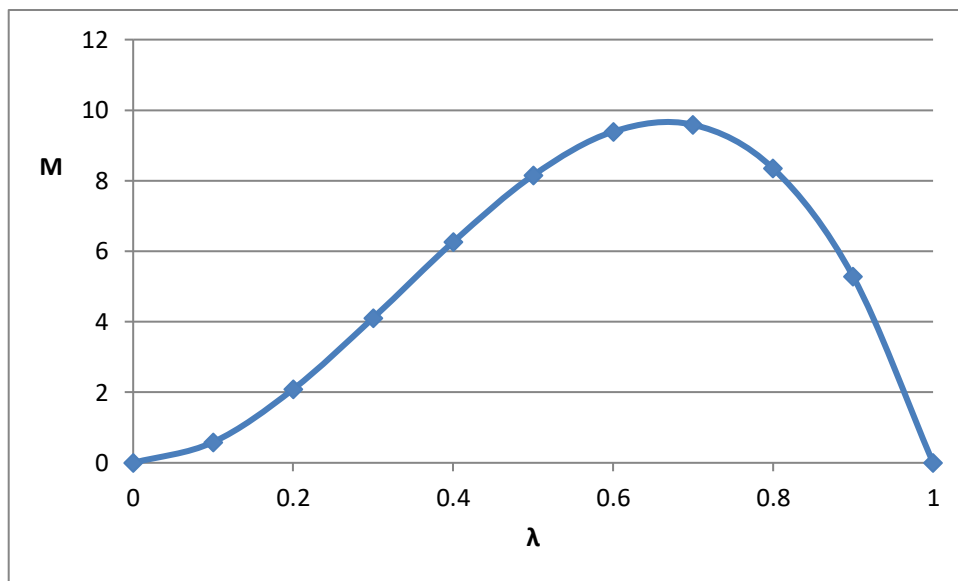
v	0,8	0,8	0,8	0,8	0,8	0,8	0,8	0,8	0,8	0,8	0,8
u	0	0,08	0,16	0,24	0,32	0,4	0,48	0,56	0,64	0,72	0,8
w	0,8	0,72	0,64	0,56	0,48	0,4	0,32	0,24	0,16	0,08	0
λ	0	0,1	0,2	0,3	0,4	0,5	0,6	0,7	0,8	0,9	1
M	0	0,260	0,927	1,825	2,782	3,6225	4,173	4,260	3,709	2,347	0



APPENDIX D: CALCULATION RESULTS DATA

For a flow velocity (v) of **1.2** meters per second:

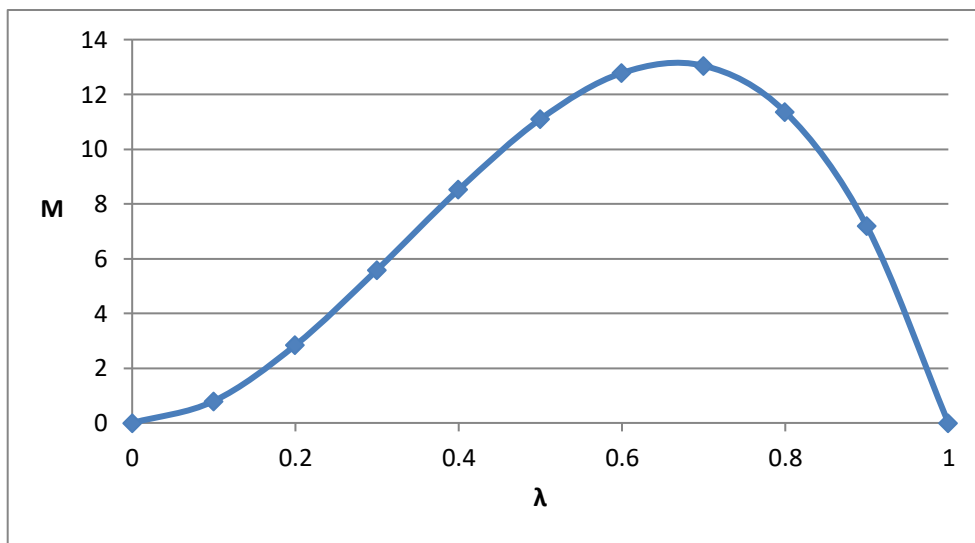
v	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2
u	0	0,12	0,24	0,36	0,48	0,6	0,72	0,84	0,96	1,08	1,2
w	1,2	1,08	0,96	0,84	0,72	0,6	0,48	0,36	0,24	0,12	0
λ	0	0,1	0,2	0,3	0,4	0,5	0,6	0,7	0,8	0,9	1
M	0	0,586	2,086	4,107	6,259	8,150	9,389	9,585	8,346	5,281	0



APPENDIX E: CALCULATION RESULTS DATA

For a flow velocity (v) of **1.4** meters per second:

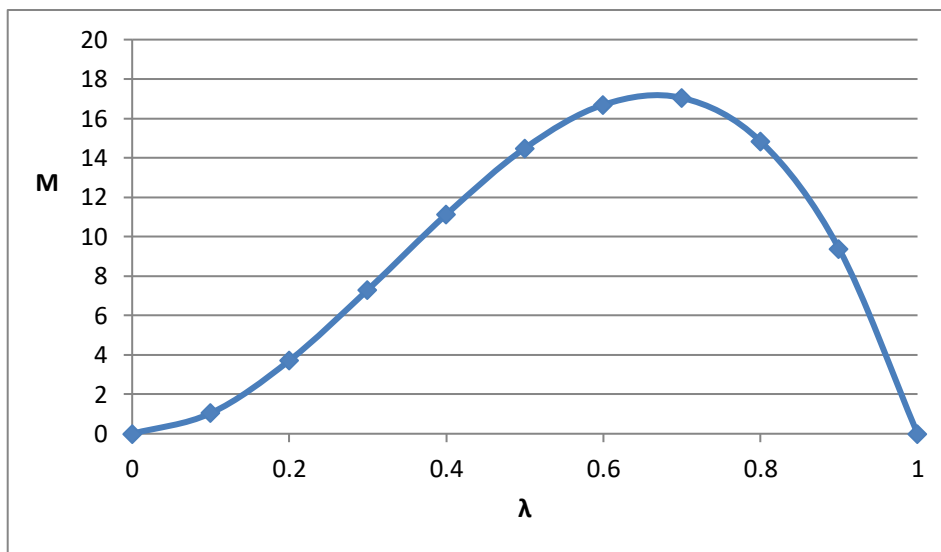
V	1,4	1,4	1,4	1,4	1,4	1,4	1,4	1,4	1,4	1,4	1,4
u	0	0,14	0,28	0,42	0,56	0,7	0,84	0,98	1,12	1,26	1,4
w	1,4	1,26	1,12	0,98	0,84	0,7	0,56	0,42	0,28	0,14	0
λ	0	0,1	0,2	0,3	0,4	0,5	0,6	0,7	0,8	0,9	1
M	0	0,798	2,840	5,591	8,520	11,093	12,780	13,046	11,360	7,188	0



APPENDIX F: CALCULATION RESULTS DATA

For a flow velocity (v) of **1.6** meters per second:

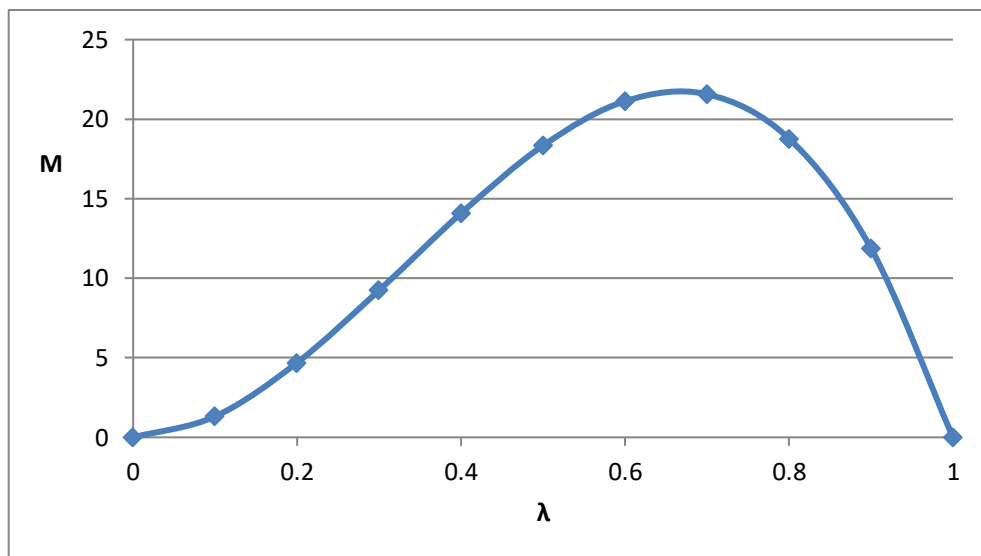
V	1,6	1,6	1,6	1,6	1,6	1,6	1,6	1,6	1,6	1,6	1,6
u	0	0,16	0,32	0,48	0,64	0,8	0,96	1,12	1,28	1,44	1,6
w	1,6	1,44	1,28	1,12	0,96	0,8	0,64	0,48	0,32	0,16	0
λ	0	0,1	0,2	0,3	0,4	0,5	0,6	0,7	0,8	0,9	1
M	0	1,043	3,709	7,302	11,128	14,49	16,692	17,040	14,837	9,389	0



APPENDIX G: CALCULATION RESULTS DATA

For a flow velocity (v) of **1.8** meters per second:

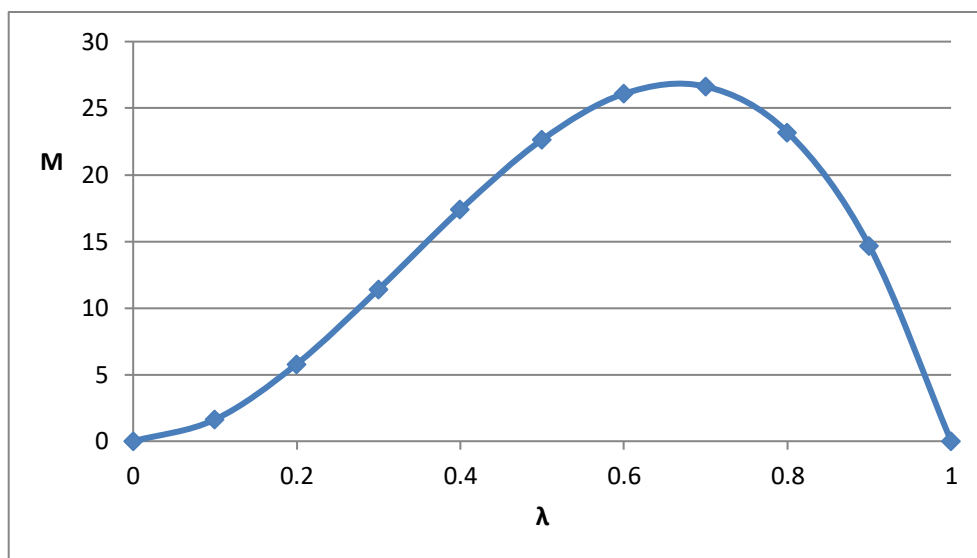
v	1,8	1,8	1,8	1,8	1,8	1,8	1,8	1,8	1,8	1,8	1,8
u	0	0,18	0,36	0,54	0,72	0,9	1,08	1,26	1,44	1,62	1,8
w	1,8	1,62	1,44	1,26	1,08	0,9	0,72	0,54	0,36	0,18	0
λ	0	0,1	0,2	0,3	0,4	0,5	0,6	0,7	0,8	0,9	1
M	0	1,320	4,694	9,242	14,084	18,338	21,126	21,566	18,779	11,883	0



APPENDIX H: CALCULATION RESULTS DATA

For a flow velocity (v) of 2 meters per second:

v	2	2	2	2	2	2	2	2	2	2	2
u	0	0,2	0,4	0,6	0,8	1	1,2	1,4	1,6	1,8	2
w	2	1,8	1,6	1,4	1,2	1	0,8	0,6	0,4	0,2	0
λ	0	0,1	0,2	0,3	0,4	0,5	0,6	0,7	0,8	0,9	1
M	0	1,630	5,796	11,410	17,388	22,640	26,082	26,625	23,184	14,671	0



APPENDIX I: CALCULATION RESULTS DATA

For a flow velocity (v) of **2.2** meters per second:

v	2,2	2,2	2,2	2,2	2,2	2,2	2,2	2,2	2,2	2,2	2,2
u	0	0,22	0,44	0,66	0,88	1,1	1,32	1,54	1,76	1,98	2,2
w	2,2	1,98	1,76	1,54	1,32	1,1	0,88	0,66	0,44	0,22	0
λ	0	0,1	0,2	0,3	0,4	0,5	0,6	0,7	0,8	0,9	1
M	0	1,972	7,013	13,807	21,039	27,395	31,559	32,216	28,052	17,752	0

