Zamorano Pan-American Agricultural School

Department of Environment and Development

Environment and Development Engineering

Graduation Special Project

Development and evaluation of a water treatment prototype based on electromagnetic induction

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Honduras, august 2023

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Abstract

The average person requires at least 2.5 L of water per day to maintain a functional and stable physical health. Although this number is considered quite low, many communities face challenges in obtaining this amount of drinking water. Surface water resources are often polluted by industrial, chemical, and biological waste that pose a risk to human health. In response, there are a variety of water treatment systems with varying costs, such as ceramic filters, the use of chemical compounds, reverse osmosis, and quantum dots. There are also existing technologies that have the potential to be used as water treatment alternatives, such as electromagnetic induction and eddy currents, which generate heat from moving magnetic fields and highly conductive, non-magnetic materials. In response, a small water treatment system was designed and prototyped using electromagnetic induction to provide thermal treatment to the water. This was done through the implementation of Design Thinking methodology. The operating system of the plant was composed of three main parts: the filtration system, the thermal treatment, and the water flow control systems, which includes automation mechanisms to control the flow of water through the different stages. The performance of the prototype was evaluated by testing the rate of temperature increase of the water, resulting in a maximum temperature of 32.34 °C over a two-hour period. The construction and operating costs of the prototype were also calculated, resulting in USD 265 for its construction and USD 0.5 per each operating hour. After an evaluation of the obtained results, it was determined that the constructed prototype in its current state did not meet the required performance, being an ineffective alternative for water treatment.

Keywords: Biological contamination, design thinking, drinking water, innovation

Resumen

El ser humano promedio requiere un mínimo de 2.5 L de agua al día para mantener una salud física funcional y estable. Aunque esta cifra se considera baja, muchas comunidades se enfrentan con desafíos para obtener esta cantidad de agua potable. Los recursos hídricos superficiales suelen estar contaminados por desechos industriales, químicos y biológicos, que suponen un riesgo para la salud humana. Como respuesta, existen diversos sistemas de tratamiento de agua con costos variables, como los filtros de cerámica, el uso de compuestos químicos y la ósmosis inversa entre otros. También existen tecnologías que tienen el potencial de ser utilizadas como alternativas de tratamiento de agua, como la inducción electromagnética y las corrientes de Foucault, que generan calor a partir de campos magnéticos en movimiento y materiales no magnéticos altamente conductores. En respuesta, se diseñó y prototipó un sistema de tratamiento de agua a pequeña escala que utiliza inducción electromagnética para proporcionar tratamiento térmico al agua. Esto se hizo mediante la implementación de la metodología de Pensamiento de Diseño ("Design Thinking"). El sistema operativo de la planta constó de tres partes principales: el sistema de filtrado, el sistema de tratamiento térmico y el sistema de control de flujo de agua, incluyendo mecanismos de automatización para controlar el flujo de agua a través de las diferentes etapas. El rendimiento del prototipo se evaluó mediante pruebas de la tasa de aumento de temperatura del agua, logrando alcanzar una temperatura máxima de 32.34 °C en un período de dos horas. También se calcularon los costos de construcción y operación del prototipo, resultando en USD 265 para su construcción y USD 0.5 para cada hora operacional. Después de una evaluación de los resultados obtenidos, se determinó que el prototipo construido en su estado actual no cumplió con el desempeño requerido, siendo una alternativa ineficaz para el tratamiento de agua.

Palabras clave: Agua potable, contaminación biológica, innovación, pensamiento de diseño

Introduction

Water is a vital resource necessary for the development and survival of all living organisms. Its quality plays a crucial role since our health depends on it. However, approximately 2 million people worldwide lack access to safe drinking water due to various factors such as scarcity, contamination, and socioeconomic challenges. Despite the fact that the average adult requires only 2.5 L or half a gallon of water daily for their consumption (Heinz & Gorman, 2002), there still are individuals who must endure long and arduous journeys spanning hours and miles to obtain this precious resource, particularly when seeking safe drinking water. One study found that by the middle of this century it is estimated that between 2,000 and 7,000 million people will suffer from a clean drinking water shortage (Fernández Pardo, 2004). The World Health Organization (2011) recognizes access to safe drinking water as a fundamental to health, a basic human right and an essential component of effective health protection policies.

Water sources are very vulnerable to microbiological contamination, especially if the resource is close to human settlements. Surface water sources can be affected when communities don't have a good waste treatment system (liquid or solid) and dispose of it directly into rivers, lakes, and oceans, further contaminating them with feces or other pollutants. This situation jeopardizes the overall health of the people who benefit from these water sources, as some authors note that, most diarrheal diseases are associated with untreated water and poor hygiene and sanitation practices (Brown & Sobsey, 2010).

To determine the water quality, focusing solely on microbiological standards, the presence of microbial indicators must be evaluated. According to Saxena et al. (2015), the main indicator organisms of water quality are Total coliforms, Thermotolerant coliforms, *Escherichia coli*, coliphages, enteric viruses and intestinal enterococci. These microorganisms should not be present in the water, for it to be considered drinkable. Therefore, water intended for human consumption must be treated.

When it comes to water treatment for human consumption, various techniques are employed, and among these is the utilization of chemical agents. Chlorine gas proves to be highly efficient in eradicating harmful microorganisms present in water. Other chemicals such as sodium and calcium hypochlorite are also commonly used. Despite the effectiveness of these products, most of them aren't that popular thanks to their corrosive nature or their carcinogenic by-products. According to Padmaja et al. (2014), there are some less harmful disinfection methods that are equally effective such as ozonation (use of ozone), ultraviolet radiation, solar disinfection, sonication, and filtration systems. Filtration systems are commonly used in developing countries due to their low implementation cost and their efficiency in reducing water impurities and harmful bacteria.

There are many technologies that combine the various methods mentioned above but they tend to be quite large and require an equally large investment. One existing technology that addresses both of these issues while still being able to produce potable water is WesTech Trident HS 2100 compact drinking water treatment plant (Annex A). This relatively small water treatment plant uses filtration, sedimentation, chlorine, and UV disinfection to treat water. Even though it is effective, its use, operation, dependence on fossil fuel and financial investment poses a challenge for some communities (SPENA GROUP, 2016).

In this context, there is a need for new technologies that don't require human interaction, a high level of technical knowledge for operation and are able to rely solely on renewable energy sources. Already existing technologies can provide such services but most of them aren't commonly used in this area and can be further developed for this purpose, a good example is the use of electromagnetic induction.

Electromagnetic induction is a process by which a rotating magnet can generate an electric current through its magnetic field, which is later used to generate heat. This process is rarely used/implemented in drinking water treatment systems. According to Lin et al. (2020), the use of electromagnetic fields in water treatment systems has been controversial, specially the use of its anti-scaling properties although it has reportedly proven effective for numerous industrial applications.

Eddy or Foucault currents, named after 19th century physicist Jean-Bernard-Léon Foucault, are, According to MAGCRAFT (2015) currents that circulate within conductors like swirls in a stream, they are induced by changing magnetic fields, perpendicular to the plane of the magnetic field. "Leon Foucault (1819-1868) discovered eddy currents produce heat when a permanent magnetic is placed at the edge of a rotating metal disk." (Createx Studio, 2015). The thermal effect created by these currents combined with a highly conductive material, could be used to raise the water temperature to a point where most harmful bacteria can be eliminated.

Innovation is critical to addressing the challenges facing the developing world, particularly lack of access to safe drinking water, water efficiency, utility operations, monitoring and treatment, and data and analytics (Viola, 2020). One effective approach to driving innovation is through the Design Thinking methodology. This method focuses on understanding the needs and experiences of people who need and will use water treatment solutions. It involves empathizing with their situation, defining the problem, generating ideas, creating prototypes, testing them and if needed, and iterating on previous steps as needed to produce an effective and fully functional solution. By embracing innovation and design thinking, we can design and create effective and affordable ways to provide safe drinking water to communities, improving their quality of life and contributing to a more sustainable future.

Considering the need to innovate and develop appropriate technologies to improve drinking water treatment processes, the main objective of this study is to evaluate the applicability of electromagnetic induction as an alternative for water disinfection through the following specific objectives: 1) Develop an electromagnetic induction water treatment prototype applying the design thinking methodology. 2) Evaluate the performance of the electromagnetic induction-based prototype and 3) Estimate the construction and operating costs of the tested prototype.

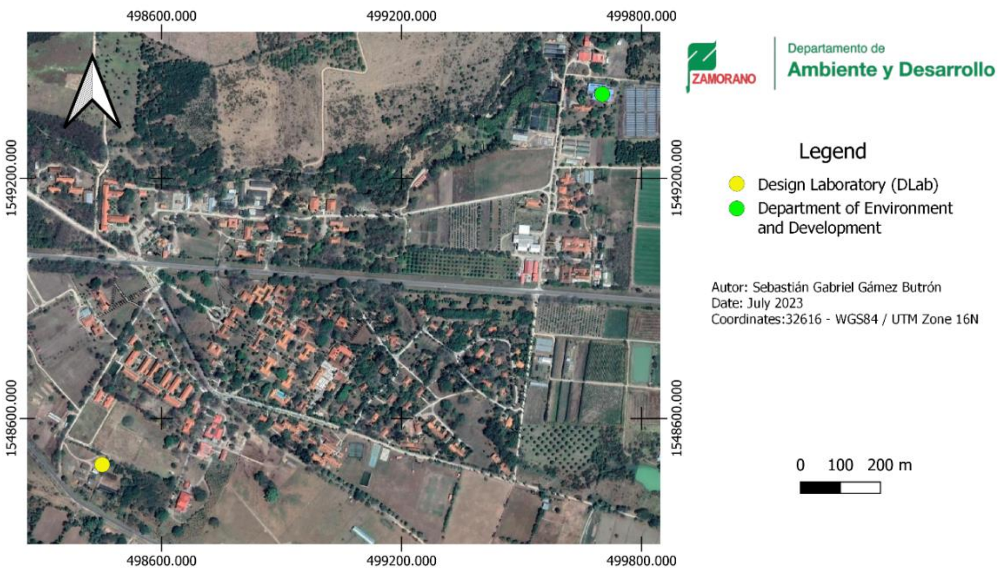
Materials and Methods

Study Site

The construction of the prototype was conducted at the Design Laboratory (D-Lab) (14°0'24.7"N and 87°0'51.5"W) located in the forestry unit and the testing of the prototype was conducted at the Department of Environment and Development (14°0'55.0"N, 87°0'10.0"W), both located at the Pan-American Agricultural School, Zamorano (Figure 1).

Figure 1

Location of the prototype development and evaluation sites



Electromagnetic Induction Water Treatment Prototype Development

To address the issue of limited drinking water access, a small water treatment unit was designed, constructed, and validated. This unit uses a combination of filtration and heating systems. The filtration system aims to reduce turbidity and negative organoleptic factors in the water, while the electromagnetic induction heat treatment aims to raise the temperature in the water to a point where *E. Coli* and other harmful bacteria are killed. During this process, a working prototype has been developed.

Prototyping is the process of bringing an idea or concept to life. It allows the designer/creator to interact with the model prior to its final version. Problems and strengths can be identified, leading to better models and ultimately a final working product that incorporates all the information learned from the other models into one. The development of this prototype followed the design thinking methodology. According to Woolery (2019), this methodology can be broken down into five different components, empathize, define, ideate, prototype, and test (Frame 1).

Frame 1

Design Thinking methodology

Component	Scope and definition	Application
Empathize	The "empathize" phase is the first stage of the Design Thinking methodology, which involves gaining a deep understanding of the needs and perspectives of the people who will use the product or service being designed. Understanding the target´s expectations and needs will allow us to create a better product/solution.	This stage helped to determine the acceptance level of the technology in the community, considering factors such as pricing, existing technologies, and problems that might arise while using the technology. An empathy map (Annex B) was used to comprehend the user's perspective by exploring their thoughts and feelings regarding water quality in their community, their surroundings, and how they might interact with the suggested technology.
Define	The "define" stage is the second stage of the Design Thinking process. It involves synthesizing and analyzing the information gathered during the "empathize" stage to define the core problems and challenges that we are aiming to solve.	In this stage, we consolidated the information obtained through the empathy map. This helped us define and create a clear and specific problem statement that guided us through the rest of the design thinking process, ensuring that we focused on creating an effective solution.
Ideate	The "ideate" stage is the third stage of the Design Thinking process. It involves generating a wide range of ideas and potential solutions to the problem or challenge identified in the "define" stage, using brainstorming and creative thinking techniques to explore multiple possibilities.	In this stage, the most promising ideas were evaluated and selected to further develop and refine in the next stage "prototype". Here we focused on creativity and exploration, which helped us come up with innovative and unexpected ideas that could lead to breakthrough solutions. The quality of the ideas was not important; what mattered the most was the quantity, which allowed us to identify different issues and come up with a unified proposal that didn't have all the identified issues (Figure 1)

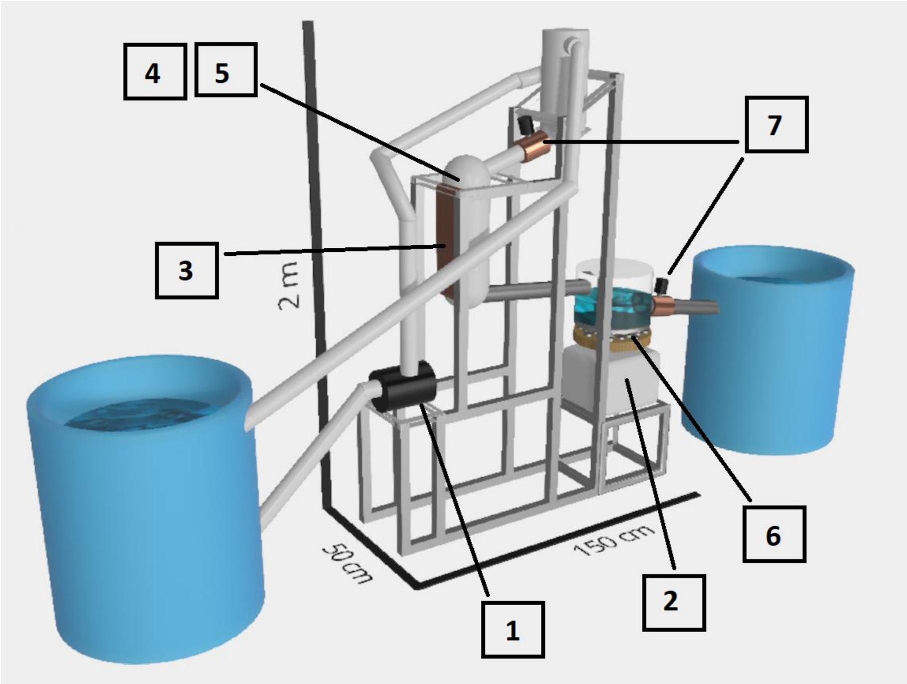
Component	Scope and definition	Application
Prototype	The "prototype" stage is the fourth stage of the Design Thinking process, which involves creating a low-fidelity representation of the most promising and relevant idea generated in the "ideate" stage.	In this stage, we created the proposed solution designed to meet the user needs. The creation of a final working prototype was the main focus. If the prototype didn't work, it would compromise the next stage "test," rendering the previous stages useless and requiring a do-over from the "ideate" stage. The Prototype (Figure 2) was built and developed in the D-lab, which belonged to the environment and development faculty.
Test	The "test" stage is the fifth and final stage of the Design Thinking process, which involves testing the final prototype created in the "prototype" stage in a real-life scenario to evaluate the effectiveness of the solution in meeting and solving the identified needs and problem.	The prototype was tested at a laboratory level, which allowed us to identify any usability or functionality issues and make the necessary recommendations or adjustments to ensure that the final solution was effective, user-friendly, and met the needs of the target audience.

Prototype´s Design and Construction

A prototype that aimed to work as a water treatment system dependent on electromagnetic induction, was designed with three main systems in mind, filtration, control and induction treatment system. The filtration system is composed of a -micron nylon filtration mesh and activated carbon; the water flow control system works with two solenoid valves and a water pump as the main control mechanism. Also, the electromagnetic treatment system consists of an electric rotor with variable speed, on which a plate with neodymium magnets is mounted. The components are signaled and identified in the following design. Taking the main components into consideration, and a desired water capacity of 500 mL per treatment cycle, the following design was developed with an online 3D modeling tool called Vectary (Figure 2).

Figure 2

Prototype design and dimensions



Nota. 1) Water pump (127 volts), 2) Motor (120 volts), 3) Water flow temporizer (Arduino), 4) Nylon Water Filtration mesh (10 microns), 5) Activated carbon, 6) Neodymium magnets, 7) Solenoid valves.

Evaluation of Prototype's Performance

The performance of the prototype was evaluated by testing its ability to heat 500 mL of water from an initial temperature of 24 °C within a 2 hours time frame (Frame 2). The initial temperature was measured with a thermocouple before the test began. With the system running, subsequent readings were taken at 5 minutes intervals until the two-hour period was reached. After the last reading was taken, the prototype was allowed to cool for a few minutes; the water was discarded, another water sample was collected, and the testing began again for another two hours. The test was repeated a total of five times; the results were later plotted to produce temperature rise curves for each repetition (Figure 4).

Frame 2

Testing method

Testing method	Parameter	Unit	Description	Equipment
Recording the temperature increase of the testing sample	Temperature & Time	Degrees Celsius (°C)	The temperature was recorded every 5 minutes	FLUKE Thermocouple with laboratory accuracy of (0.05% + 0.3 °C)

The test method used a 500 mL water sample with an initial temperature of 24 °C, these initial values were chosen to maintain consistency of the experimental setup. The water volume was the controlled variable, and water temperature and time were the response variables. The data obtained from the five repetitions were used to calculate mean and standard deviation. The prototype´s heat generation efficiency compared to the target temperature was calculated using the Equations 1, 2 and 3:

$$Target\ temperature - \ Starting\ temperature = temperature\ difference \qquad [1]$$

$$Temperature\ reached - \ Starting\ temperature = Degrees\ increased \qquad [2]$$

$$\left[\frac{Degrees\ increased}{Temperatrure\ difference}\right] \times 100 = Efficiency \qquad [3]$$

The target temperature that was used to evaluate the prototype´s efficiency was 70 °C, this is the temperature at which *E.coli* and most bacteria don't survive. According to the World Health Organization (2018), *E.coli* is destroyed by heating/cooking consumables until they reach a temperature of 70 °C or higher. Therefore, the closer the temperature got to the target the better and more efficient.

Estimation of the Operation Costs of the Validated Prototype

In order to determine the total investment for the prototype´s construction, a 3D design was used as a guide for the selection of materials and their dimensions, which were later searched in hardware stores to determine its cost. The prices of all the materials were multiplied by the quantity needed to build the prototype. Since the prototype was built on a laboratory scale within a limited time frame, information such as maintenance and repair costs were not taken into consideration, nor were human labor hours, since it's a fully automated prototype, therefore only material costs were considered. However, the energy consumption during the operating period was calculated, considering each individual component of the system (energy dependent); this was achieved by the Equation 4:

$$Electrical\ power = Voltage \times Current \quad [4]$$

Based on the power capacity of each component, the electricity consumption in kWh was calculated. The data was later summed up to obtain the total energy consumption of the prototype, which later was later used to estimate the energy cost per 500 mL of water heated (using this technology). To do this, the equation 5 was used:

$$E = \frac{\mathrm{P \times T}}{\mathrm{Vol \times 1000}} \quad [5]$$

Where:

E = Energy consumed (kWh/ L)

P = Total power consumed per hour (kWh)

T = Treatment time (Hrs)

Vol = Water volume (mL)

Once the value of the energy consumed was obtained, it was multiplied by the actual energy cost in Honduras (USD 0.18), taking the volume of water of the sample into consideration. The cost was calculated for the 2 hours testing period.

Results and Discussion

Electromagnetic Induction Water Treatment Prototype Development

Through the application of an empathy map canvas for the first stage of the Design Thinking methodology, an empathy map was created (Annex B). Tool that gave as a result, knowledge of the problem, the target user, and their needs. Resulting in the understanding that a solution needed to be developed for rural communities with access to contaminated water and lack of appropriate technology for its treatment and purification.

The gained knowledge from the Empathize stage was later used to define the action framework, where the challenges and understanding of the user's background were synthesized into the following problem statement that needs a solution: The presence of biologically contaminated water in underdeveloped communities and the need for innovative, user-friendly and fully automated water treatment solutions for water consumption.

From the identified and defined problem statement, an innovative, automated, and user-friendly solution was ideated to solve the problem and improve the lives of the target users, resulting in a 3D design for a water treatment system based on electromagnetic induction designed for a working capacity of 500 mL and to reach a temperature of 70 C° for 15 minutes (Figure 2), paving the way for the next stage which is prototyping.

During the Prototyping stage, the solution was built. To achieve this, the required materials were identified, listed, counted, and classified into six main categories according to their use and function; these are: main frame construction, Internal piping, filtration system components, electromagnetic induction thermal generator, water pump and control system components. The dimensions of the materials were established in order to produce a prototype at scale, taking the design as reference (Figure 2). The price of the materials was also researched, multiplied by the quantity needed and converted from the local currency (Honduran Lempira) to the US dollar, a total cost of the prototype was also calculated using this information.

A structural support for the water treatment components was built (Annex C) followed by the electromagnetic induction system, which required the adaptation of the ceiling fan motor as a base for the magnets. A circular piece of wood was cut to hold the 20 neodymium magnets (Annex D), and this piece was placed over the rotor. Above the wooden stand, a copper plate connected to a circular metal container was placed and held one millimeter over the magnets to ensure that the necessary eddy-currents were generated (Annex E).

After that, the PVC (polyvinyl chloride) piping and filtration system were installed, first the water supply and relief container was cut, and drilled into size to make room for the water inlet and relief pipes, a PVC pipe was also connected to the supply container to connect the water flow from it to the filtration system which consisted of 3 4-inch PVC connectors, a 10 micron nylon filtration mesh was placed between the first and second connectors and 1 kg of activated carbon was placed in between the second and third connectors (Annex F) and (Annex G). The filtration system was later sealed with two 4-inch PVC caps and connected to the circular metal container in the electromagnetic part of the prototype, from which the water outlet of the system came out.

Once the main frame, internal piping, filtration, and electromagnetic system were constructed, the electrical component of the prototype was worked on, to do this the two solenoid valves were connected to a two-channel relay system and a switching power supply (which connected to the electrical outlet), the two-channel relay was the connected to the Arduino compatible development board (Mega 2560) (Annex H). In order for the electronics to work properly the development board was coded using the Arduino IDE coding software (Annex I), which allowed it to control the solenoid valves that were mounted, one was mounted in the PVC pipe that connected the water feeding container to the filter and the other in the water outlet, which allowed us to control the water flow within the prototype. Lastly, a 127 V water pump was installed to supply water to the system through the water supply container.

Despite facing challenges and making essential design modifications due to budget constraints, the prototype was built. The resulting prototype closely resembled the original design in terms of size, measuring 1.8 m in height, 1.5 m in length, and 0.5 m in width. Notably, its height was 20 cm shorter than the designated design height.

Figure 3

Final working prototype and Automated electronic water flow control system

Once the prototype was built, the testing phase began to evaluate its overall performance. The insights and feedback gathered during testing were used to consider the need to iterate and refine the prototype. This may involve going back to earlier stages, such as redefining the problem, generating new ideas, or creating updated prototypes. The successful construction and evaluation of a working prototype serves as evidence that innovation and prototyping is facilitated by the Design Thinking methodology.

Evaluation of the Prototype´s Efficiency.

In order to assess the effectiveness of the prototype in raising the sample temperature, the average temperature increases obtained from the testing phase (Annex J) were computed using data gathered from the five repeated trials (Frame 3). It can be observed that the greatest increase in temperature is obtained during the first hour of operation, registering an average increase of 6 °C. During the second hour of operation, less than a 2 °C variation was registered, reaching an average increase of 8.34 °C over the entire 2 hour period of operation.

Frame 3

Water temperature data

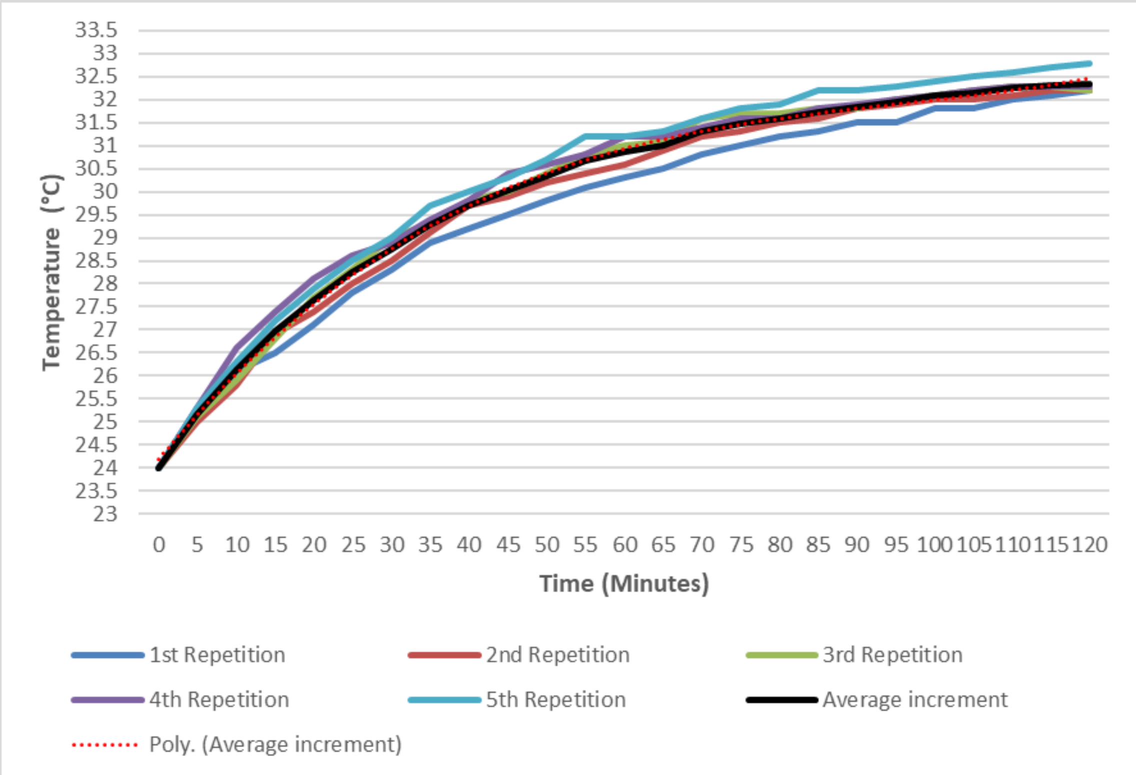
Time (minutes)	Water Temperature (°C)					
	Repetition 1	Repetition 2	Repetition 3	Repetition 4	Repetition 5	Average
0	24	24.0	24	24	24	24
5	25.1	25.0	25.1	25.3	25.3	25.16
10	26.1	25.8	25.9	26.6	26.3	26.14
15	26.5	26.9	26.8	27.4	27.2	26.96
20	27.1	27.4	27.7	28.1	27.9	27.64
25	27.8	28.0	28.3	28.6	28.5	28.24
30	28.3	28.5	29	28.9	29	28.74
35	28.9	29.1	29.3	29.4	29.7	29.28
40	29.2	29.7	29.8	29.8	30	29.7
45	29.5	29.9	30	30.4	30.3	30.02
50	29.8	30.2	30.4	30.6	30.7	30.34
55	30.1	30.4	30.8	30.8	31.2	30.66
60	30.3	30.6	31	31.2	31.2	30.86
65	30.5	30.9	31.1	31.2	31.3	31
70	30.8	31.2	31.6	31.4	31.6	31.32
75	31	31.3	31.7	31.6	31.8	31.48
80	31.2	31.5	31.7	31.6	31.9	31.58
85	31.3	31.6	31.8	31.8	32.2	31.74
90	31.5	31.8	31.8	31.9	32.2	31.84
95	31.5	31.9	32	32	32.3	31.94
100	31.8	32.0	32.1	32.1	32.4	32.08
105	31.8	32.0	32.2	32.2	32.5	32.14
110	32	32.1	32.3	32.3	32.6	32.26
115	32.1	32.2	32.3	32.3	32.7	32.32
120	32.2	32.2	32.2	32.3	32.8	32.34

The results obtained from these equations give the overall efficiency that the prototype had, showing that only 18.13% of the target temperature increase is achieved. This means that the prototype at its current state is lacking the capacity to generate or induce enough heat (Eddy-currents) through the copper plate, translating to a poor performance.

The temperature rise during the test period is visually displayed for each repetition performed (Figure 4). This visual representation also provides insight into the variability of the temperature, showing a discernible pattern within the graph. In simple words, the changes in temperature are caused by how long the 500 mL of water is in contact with the copper plate, which is influenced by electromagnetic effects. While there are other factors that could have influenced this data, such as friction and heating of the rotor, preventative measures were taken to mitigate most of them. The tests were conducted in a controlled environment and there was no direct contact or friction between the copper plate and the rotating magnets. The rotor temperature rise factor was also eliminated because motors heat up after long periods of operation, and the fastest rate of temperature increase was in the first minutes of operation instead of the second hour of the testing procedure.

Figure 4

Water temperature increment graph



Even though there is a clear correlation between the variables of time and temperature, the graph also shows a fast decrease in the rate at which the prototype was heating the water, this can be seen after the 60-minute mark, where the curve begins to flatten. This can be attributed to either one or a series of factors, such as the low RPM´s (Revolutions per minute) of the rotor we have been working with, the strength of the magnetic field or the combination of the magnets that compose it, and the dimensions of the copper plate that’s being subjected to the generated Eddy-currents. It is most likely that the two factors that influenced the results and the performance of the prototype were the motor and the copper plate because its dimensions can alter the Eddy-currents generated, since the magnets that were used are made out of neodymium and fall under the N52 category. Neodymium is renowned as the most potent rare earth magnet material, and N52 represents one of the top-tier grades within the neodymium category. As a result, N52 magnets are regarded as some of the most powerful magnets globally (Dura Magnetics, 2014).

As a result, the prototype underperformed and did not reach the desired temperature of 70 °C and it is expected that the presence of this microorganisms in the samples would not be affected Hence, the purpose for which the prototype was designed has not been achieved, and it could not be an alternative to other water treatment technologies, such as ceramic filters, reverse osmosis or traditional boiling water means.

Construction and Operation Costs of the Prototype

To determine the cost of building the prototype, a list of materials with their respective dimensions and quantities was created. Prices were checked online, including the materials that were readily available at the D-Lab. The total materials used for the construction, their quantity, their costs, and the total cost of construction of the prototype are shown in Frame 4.

Frame 4

Prototype material categories and components

Category	Components	Quantity	Price /Unit (HNL)	Price (HNL)	Price (USD)
Main Frame Construction:	150-cm square metal pipe (1-inch x 1-inch)	2	90	180	7.2
	180-cm square metal pipe (1-inch x 1-inch)	2	108	216	8.64
	170-cm square metal pipe (1-inch x 1-inch)	2	102	204	8.16
	40-cm square metal pipe (1-inch x 1-inch)	2	24	48	1.92
	30-cm square metal pipe (1-inch x 1-inch)	2	18	36	1.44
	100-cm square metal pipe (1-inch x 1-inch)	2	60	120	4.8
	70-cm square metal pipe (1-inch x 1-inch)	4	42	168	6.72
	50-cm square metal pipe (1-inch x 1-inch)	10	30	300	12
	25-cm metal rod	4	15	60	2.4

Category	Components	Quantity	Price /Unit (HNL)	Price (HNL)	Price (USD)
Interior Piping:	150-cm of 1-inch PVC piping	1	115	115	4.6
	40-cm of 6-inch PVC piping	1	153	153	6.12
	1-1/4 in to 1-inch PVC adapters	4	15	60	2.4
	2.2 meters of 1-inch hose	1	100	100	4
Filtration System Components:	Connectors of 4-inch PVC piping	3	20.6	61.8	2.47
	4-inch piping caps	2	77	154	6.16
	Nylon filtration mesh (10 Micron, 5-inch diameter)	1	10	10	0.4
	Activated carbon (kg)	1	200	200	8
Electromagnetic Induction Thermal Generator:	N52 neodymium magnets (40x10x4mm)	20	70	1400	56
	Wooden stand for magnet housing (16 cm diameter x 1.5 cm)	1	30	30	1.2
	Ceiling fan motor	1	200	200	8
	Copper plate (16 cm X 16 cm x 0.5mm)	1	104	104	4.16
	Circular metal container (15 cm diameter, 20 cm height)	1	20	20	0.8
Water Pump:	127-volt water pump	1	910	910	36.4
Control System Components:	Solenoid valves (1/2-inch, 12V)	2	375	750	30
	Relay module (5V, 10A, 2 channels)	1	170	170	6.8
	Switching power supply (24V, 2A)	1	180	180	7.2
	Arduino compatible development board (Mega 2560)	1	680	680	27.2
	Arduino IDE coding software	1	0	0	0
Total costs				6,629.80	265.19

Considering the cost of the developed prototype (in its current state) and comparing it to another technology, such as ceramic filters, whose main objective is also to treat water and eliminate harmful bacteria. According to the Centro de Investigación de Tecnología Apropiada and Centro Nacional de Hidrología y Calidad de las Aguas (CNHCA) in (2003), filters with an average filtration capacity of 7 to 10 liters have an approximate cost of USD 22. The developed prototype has a much higher cost, USD 265: about 12 times higher than the cost of a ceramic filter.

Another important aspect of the prototype is its electricity consumption (Frame 5). Although the prototype has a significant cost compared to other alternatives, it is important to determine the operation cost because it allows to assess if the benefits of the prototype outweigh the costs and if it can be sustained in the long run. Also, by analyzing the costs, we can find ways to optimize resources and make operations more efficient.

Frame 5

Electricity consumption per hour

Component	voltage (V)	current (A)	W	kWh
Arduino compatible development board (Mega 2560)	5	0.1	0.5	0.0005
Switching power supply	24	2	48	0.048
Relay module (2 channels)	5	10	50	0.05
Solenoid valves (1/2-inch)	12	0.3	3.6	0.0036
Solenoid valves (1/2-inch)	12	0.3	3.6	0.0036
Ceiling fan motor	120	1.5	180	0.18
Total energy consumed/hour			285.7	0.2857

After calculating the energy consumption of each electrical component, they were later summed to obtain the total energy consumed per hour by the prototype, obtaining a value of 0.2857 kWh for the total electricity consumption of the final prototype. Using this information, the estimated energy consumption per 0.5 L of water heated to 32.38 °C was calculated using Equation 6. The electricity consumed by the prototype in its current state to increase the water temperature of a 500 mL sample by 8.34 °C or to reach 32.34 °C in a time frame of 2 hours is 0.5714 kWh. Considering that the electricity cost in Honduras in July 2023 is USD 0.18/kWh, will obtain the total cost of the 2 hours of operation.

$$Energy\ cost = kWh \times\ USD/kWh \qquad [6]$$

The cost of increasing the water´s temperature by 8.32 °C in a two-hour span, at the prototypes current state is of USD 0.10, the being exclusively associated with the energy consumption. This factor can also be a barrier to technology adoption, as alternatives such as ceramic filters do not require electricity to operate. In addition, rural communities use low-cost fuels for activities such as cooking food and heating water.

Conclusions

An electromagnetic induction water treatment prototype by applying the design thinking methodology was constructed. The design thinking methodology was applied to complete the first version of the prototype. The constructed prototype has a working capacity of 500 mL, with a filtration mechanism and automated water feed and discharge flows. The feedback and readjusting required to the final phase of this methodology were not completed, so the prototype could not be validated against the desired specifications.

Evaluation of the prototype's efficiency in raising the water temperature revealed a very low performance. Although the prototype is operational, it did not meet functional expectations. The prototype, in its current state, lacks the ability to generate sufficient heat necessary to remove total coliforms and heterotrophic bacteria from the water.

The total construction cost of the prototype was determined to be USD 265, which is significantly higher compared to the cost of other water treatment alternatives like ceramic filters. At its current state the price could pose a challenge for communities under development and with a low income, it would be complicated for them to attain it.

Recommendations

Given that the developed prototype did not perform as intended, it is crucial to recognize the need to go back in the design cycle and iterate on the prototype, continuously refining and improving the prototype will contribute to achieving the desired results.

Replace the rotor motor with higher RPM capabilities or optimize the existing motor for improved performance through rewinding, aiming to increase the efficiency of heat generation.

Test alternative magnet configurations to enhance the magnetic field strength and improve the heat generation and effectiveness of the prototype.

Further research should be conducted to test copper plates with varying thicknesses or dimensions, aiming to identify the optimal size that maximizes the transfer of eddy-current-induced heat to the water.

Application of mechanisms to enhance the transfer of the generated heat to the water such as insulation, increasing the rate at which the water temperature rises.

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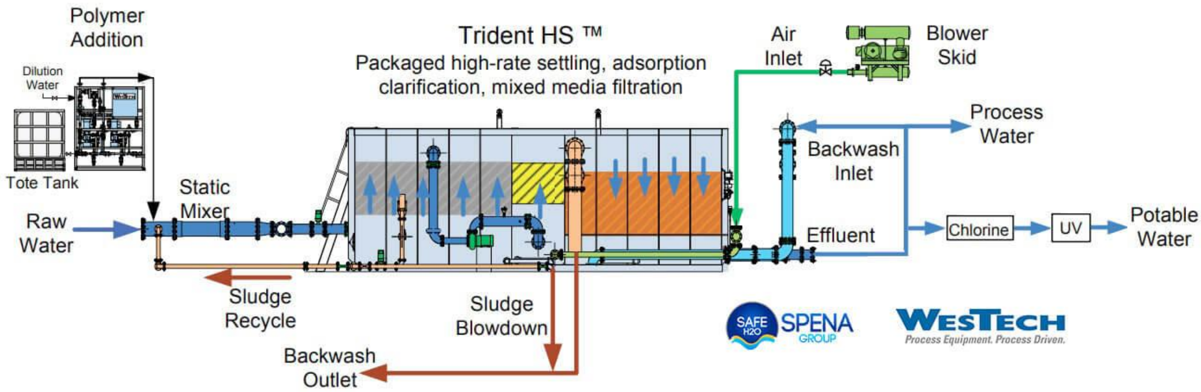
Annexes

Annex A

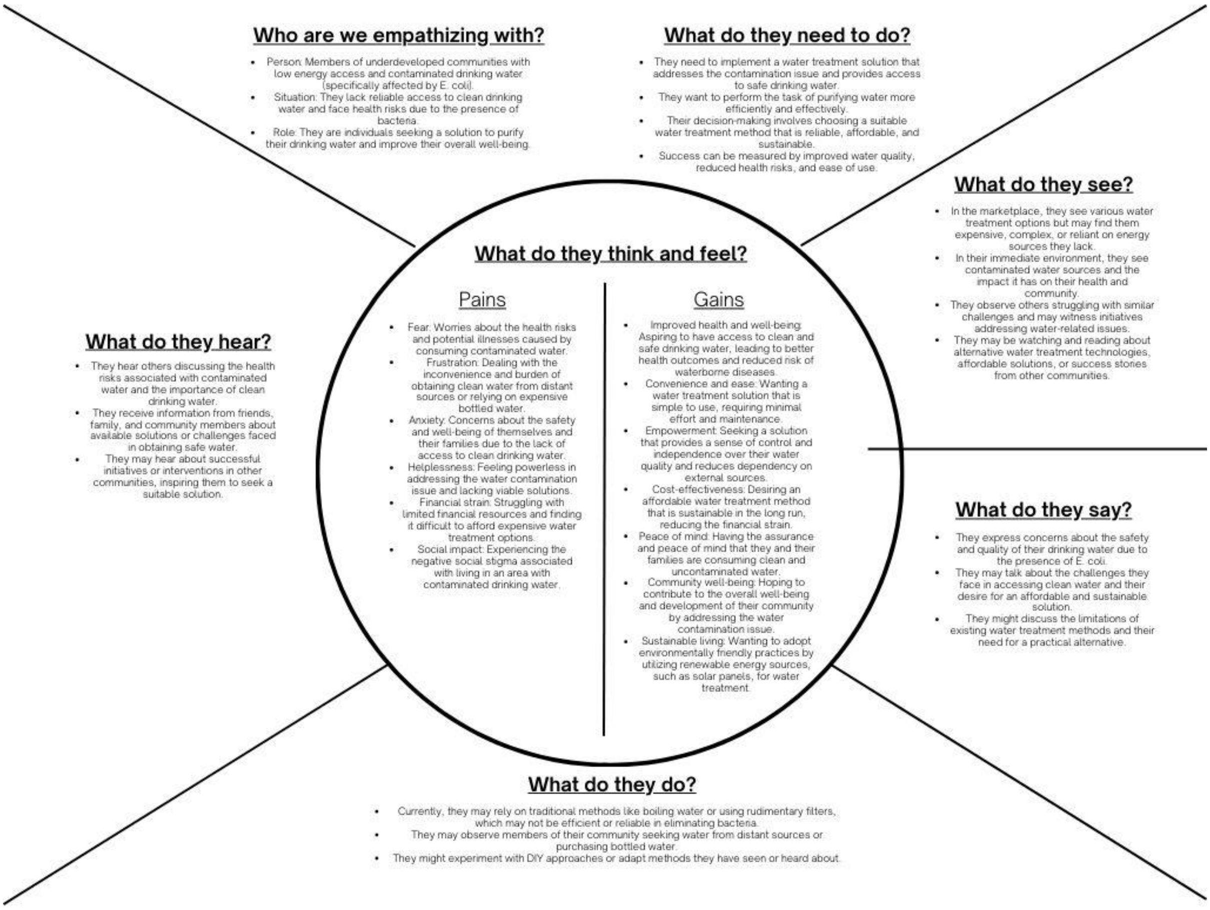
Compact drinking water treatment plant model Trident HS 2100



(SPENA GROUP, 2016)

Annex B

Empathy Map



Annex C

Main frame construction

Annex D

Circular wooden stand housing 20 neodymium magnets

Annex E

Electromagnetic Eddy-current induction system construction

Annex F

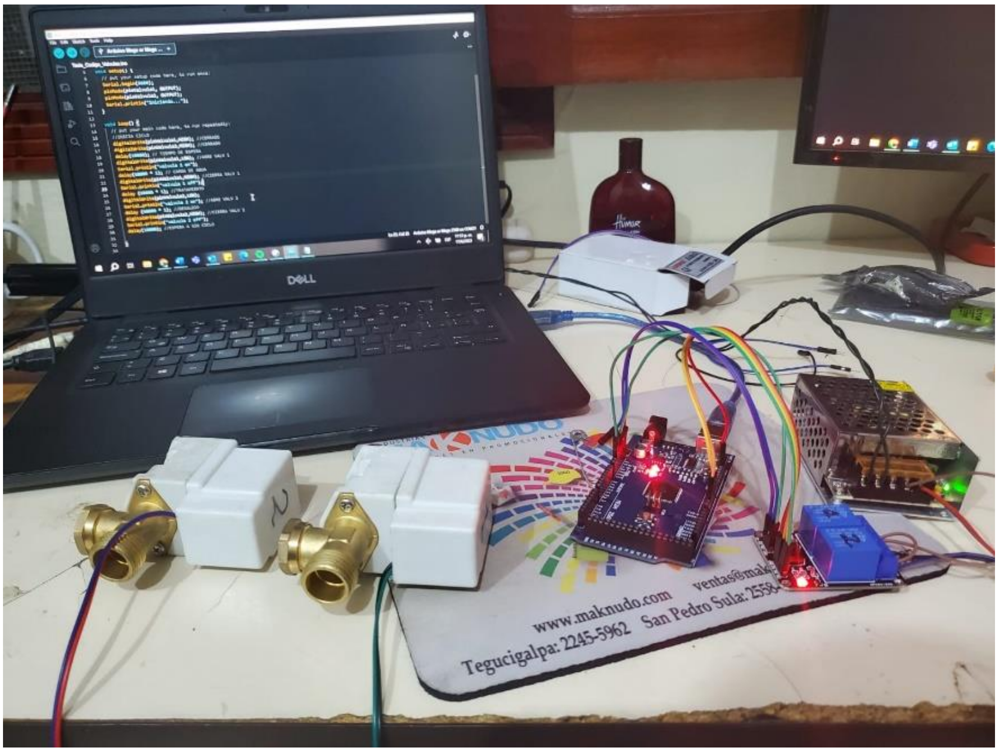
Filtration system construction

Annex G

PVC piping and filtration system mounting

Annex H

Electrical control system construction



Annex I

Electrical control system working code

```
const int pinValvula1 = 2;
const int pinValvula2 = 3;


void setup() {
// put your setup code here, to run once:
Serial.begin(9600);
pinMode(pinValvula1, OUTPUT);
pinMode(pinValvula2, OUTPUT);
Serial.println("Iniciando...");
}

void loop() {
// put your main code here, to run repeatedly:
//INICIA CICLO
digitalWrite(pinValvula1,HIGH); //CERRADO
digitalWrite(pinValvula2,HIGH); //CERRADO
delay(10000); // TIEMPO DE ESPERA
digitalWrite(pinValvula1,LOW); //ABRE VALV 1
Serial.println("valvula 1 on");
delay (60000 * 3); // CARGA DE AGUA
digitalWrite(pinValvula1,HIGH); //CIERRA VALV 1
Serial.println("valvula 1 off");
delay (60000 * 1); //TRATAMIENTO
digitalWrite(pinValvula2,LOW);
Serial.println("valvula 2 on"); //ABRE VALV 2
delay (60000 * 10); //DESALOJO
digitalWrite(pinValvula2,HIGH); //CIERRA VALV 2
Serial.println("valvula 2 off");
delay(10000); //ESPERA A SIG CICLO

}
```

Annex J

Prototype´s heating efficiency testing