Detection of Pernicious Electrolyte Concentrations to Prevent Crop Failure

eConviction

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Abstract

The clean technology solution described in the following proposal focuses on measuring the impurities of water used in irrigation and for drinking through the use of a simple circuit that can quantify electrolyte concentration levels in water. By substituting the variably polluted water solution in place of a potentiometer, the resistance of the circuit can be used to numerically calculate the concentration of electrolytes. A proportionality equation based on levels of electrolytes found naturally in polluted water sources can be used to alert local farmers in remote rural communities of the possibility of crop failure resulting from the use of polluted water. By implementing an economically effective pollutant-detection device, nations can maximize the output of their farms and prevent crop failures without the financial strain on local farmers. The final product is a portable glass-covered box containing our circuit drawn onto a printed circuit board. Two metal leads are exposed on the outer surface so that the box can be safely placed into the water solution to complete the circuit. The processing unit includes a program to use the empirically derived proportionality equation to identify electrolyte levels using circuit conductance. The box functions on a solar-powered battery that can be easily replaced. The small solar panel, circuit board, and processing unit are all encased in the glass box. The solution is intended for use in central and south Asia, Eastern Europe, and central Africa, where water pollution levels are highest and where crop failures have been the most pervasive in recent years. The ultimate objective is to maximize agricultural output in order to reduce the food shortages in developing nations.

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Introduction

A stunning 45 percent of all deaths in children under five are caused by malnutrition. 3.1 million children die each year due to a lack of basic nutrients and edible food.[1] While investors and organizations work to help developing nations build sustainable farms and growing food supplies, an astonishing few devote time or resources to ensuring the quality of the yield these farms produce. The poor water quality in developing nations in Africa and Asia leads to crop failures and water-borne illnesses in the population that are transmitted through the consumption of these crops. Each year, more than 840,000 people die from these diseases.[2] The root cause of this serious problem is the inability of village and municipal government systems to ensure the quality of irrigation and drinking water. Polluted water due to runoff from factories in urbanized areas causes stunted growth in staple crops, dehydration and death of sprouting plants, and food-borne illnesses due to contamination. Nitrates and other electrolytes in the water pollute river mouths and irrigation systems in rural communities, contributing to the growing problem of hunger and food shortages in the growing population. Seemingly treated wastewater has chlorine, phosphates, and other substances harmful to both the plant and humans who consume it for sustenance.[3] The presence of pollutants in water can be detected by measuring the electrolyte concentration of the water supply. This will enable farmers and government programs to quantify the detriment of polluted water, and to take action to combat the problem.

Background Information

The most intuitive solution to world hunger is to maximize the production of nutritious and edible food. Local farms provide food supplies for a majority of the remote rural communities in developing nations, but farmers in third world countries cannot ensure the efficiency of their farming methods or the probability of sufficient crop yield. One crop failure can lead to the starvation of an entire village for months at a time. Crop failures result from weather shifts, plant diseases, and stunted plant growth. While the weather cannot yet be controlled on a large scale, plant disease and stunted plant growth can be minimized with clean water for irrigation. The most prevalent and dangerous water quality problem that the world faces today is eutrophication: the saturation of water with nutrients that are not beneficial in large quantities.[4] Nitrates, phosphates and other salts crowd out necessary minerals in the water supply and cause plant deaths, crop diseases, and dehydration of plant life on farms and in the wild.[5] Increases in such pollution are most prominent in parts of India and Southern Asia, Eastern Europe, and the central regions of Africa. By adopting measures to check the pollution levels in their irrigation water, farmers in these areas could save millions of lives each year.

Problem Assessment

While access to food in third world countries is the primary cause of world hunger, the abundant deaths and diseases that stem from hunger are more often the result of malnutrition, which is usually caused by infected crops. In third world countries, local farms rarely have the tools and technology necessary to ensure that the food they produce meets health standards. Infected crops and bad harvests add to the disease and hunger of the communities that rely on them. Oftentimes, crop failures result from impurities in the water used for irrigation. As salts work in humans to cause dehydration, they can work in plants to prevent the roots from being able to absorb water. Salts in water lead to stunted plant growth and plant deaths due to dehydration. Water with high salinity levels is said to contain electrolytes.[6] Desalination on a small scale can be easily accomplished by boiling the water, but local farmers cannot easily identify dangerous levels of salinity in their community water supplies. While the problem has been growing across India, South Asia, Eastern Europe, and Africa, we have an affordable and efficient solution to detect and quantify the impurities in water.

Scientific Approach

Water is absorbed into the roots of plants through osmosis, which is the diffusion of water—a passive process that requires no energy. The direction of osmosis is determined by the water potential (Ψ), which is the combination of the pressures from solutes in the water (Ψs) and the physical pressure (Ψp). Pure water has a water potential of zero. The formula for water potential is:

$$\boldsymbol{\Psi = \Psi p - \Psi s}$$

As a result, water moves from areas of higher potential to lower potential. In other words, water will move from areas with fewer solutes to those with more solutes. This can be harmful to plants if the water used to hydrate them contains various salts (solutes). If impure water is used to irrigate crops, there may be more solutes outside of the roots, in the soil, than inside the plant itself. Through osmosis, water will flow from inside the plant to the outside in order to equilibrate the water potentials. This further dehydrates the plant, causing poor quality crops with limited lifespan. Thus, the use of impure water to irrigate crops has a tremendously negative effect on both the plants and the people who rely on them for sustenance.

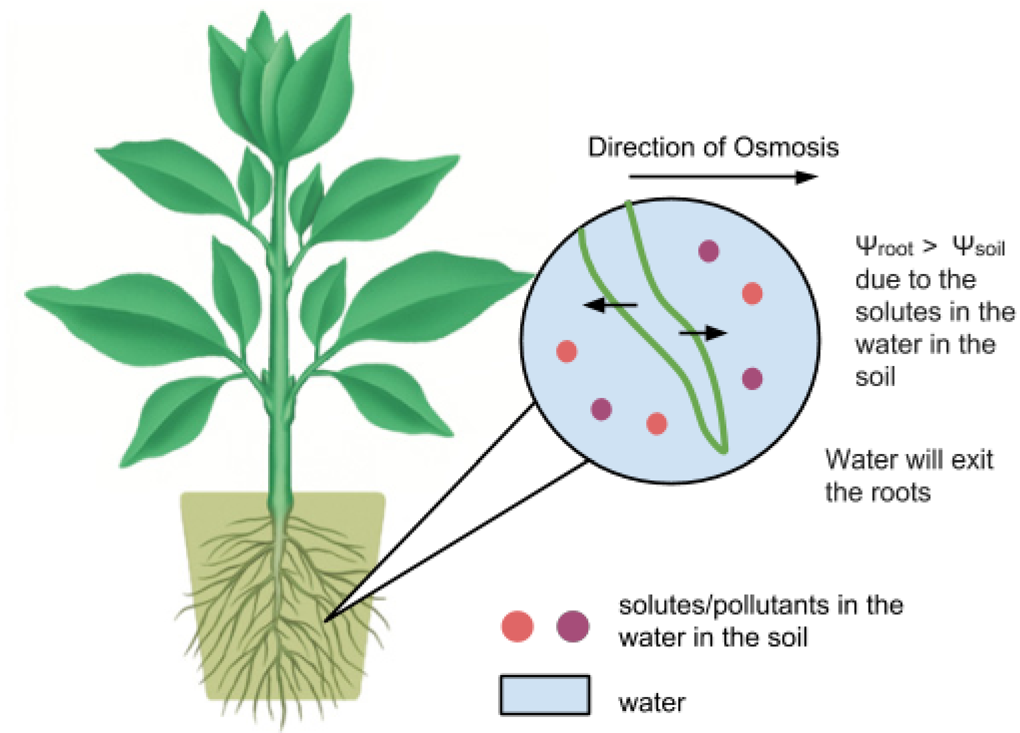

Figure 1. Diagram of osmosis when polluted water is used for irrigation of crops.

The solution entailed consists of a small enclosed open circuit that contains two live leads on the outer surface of the box. Designed to resemble parts of a miniature defibrillator, the two leads can be safely placed into the water solution to close the circuit. Depending on the electrolyte concentration of the solution, the conductance of the circuit varies. Salinity in water comes in the form of multiple ions that include chloride Cl^-, sulfate SO_4^{2-}, bicarbonate HCO_3^-, sodium Na+, calcium Ca^{2+}, magnesium Mg^{2+}, and in some cases, potassium K^+ and nitrate NO_3^-. By measuring the resistance of the electrolytic solution, the levels of salinity can be kept below the point of harm to crops.[7]

Simple circuits have three components that are related by Ohm's law: the current through any segment of the circuit *I* is directly proportional to the potential difference across that segment *V* by a constant of proportionality equal to the resistance *R* of the segment. Ohm's equation is provided below:

$$\mathbf{V = IR} \qquad \text{or} \qquad \mathbf{I = V/R}$$

Resistance *R* depends on the substance through which the current travels, which in electronic application is usually a metal electrically conducting wire. The resistance of the wire itself, for a given length, remains nearly constant throughout the process of electrical flow, and resistors added to the circuit in series increase the resistance of the total circuit.

A potentiometer is a resistor that can have variable resistance based on the voltage difference set by the user. As the resistance of a potentiometer changes, the total resistance of the circuit changes, consequently changing the circuit's conductance *G*, which is the reciprocal of resistance:

$$\mathbf{G = 1/R = I/V}$$

If a polluted water solution is used to complete the circuit in place of a potentiometer or other resistor, the varying resistance of the solution can be measured using an ohmmeter, which measures resistance, and an analog reader. The conductance *G* is proportional to the electrolytic concentration of the solution by a constant of proportionality, which can be empirically measured for combinations of different ion concentrations. The constant of proportionality between the conductance and the total electrolyte concentration will be measured empirically before the processing unit of the product is programmed so that an accurate equation may be used to display concentrations for local farmers who will use the product.

Technological Elements

This proposition uses clean energy technological elements to create a salinity calculator that has a sustainable power source and is affordable build for farmers in developing nations. The circuit board itself is a PCB (printed circuit board) with no wiring that can be disabled by external elements such as corrosion. The circuit board is connected to a small processing unit, about 2 cubic centimeters in volume. This processing unit controls the display board, visible from the outside of the small glass box. Our program uses the empirical equation derived from experimentation (see testing and redesign) to calculate the salinity levels to display. The power source for the apparatus is a small solar unit, similar to the one used by a solar calculator, connected to a replaceable battery. The metal leads are the only aspect of the surface of box that are not made of glass. The rest of the apparatus is enclosed by the glass box so that the solar component may function appropriately, and the dimensions of the structure is approximately $6 \times 3 \times 2$ centimeters.

To maximize the use of green technology, our product design uses a small, waterproof solar battery and an eco-friendly chemical resistant printed circuit board (PCB). This design is cost-effective as manufacturing one device could cost no more than twenty dollars, and this can be greatly minimized with mass production so that the board may be provided free of charge to local farmers in third world countries. The same technology can be sold to athletes and to research labs across the United States and other first world countries for positive cash flow to finance the free-of-charge water purification project in our targeted nations. The analog output can be connected to a micro-transmitter to alert local authorities and support groups so that the water source in question can be desalinated effectively. Our solution identifies the problem that exists on a large scale so that it can be solved through localized desalination techniques as efficiently as possible. With the flexibility provided by our breadboard design and simple circuit, improvements can be made in the future to excrete a catalyst for desalination from the device into the liquid itself.

Engineering Design

To simulate the functionality of the described circuit, an Arduino Uno breadboard with Grove LEDs and an ohmmeter to measure the electrical resistance of a salt-water electrolytic solution will be used.

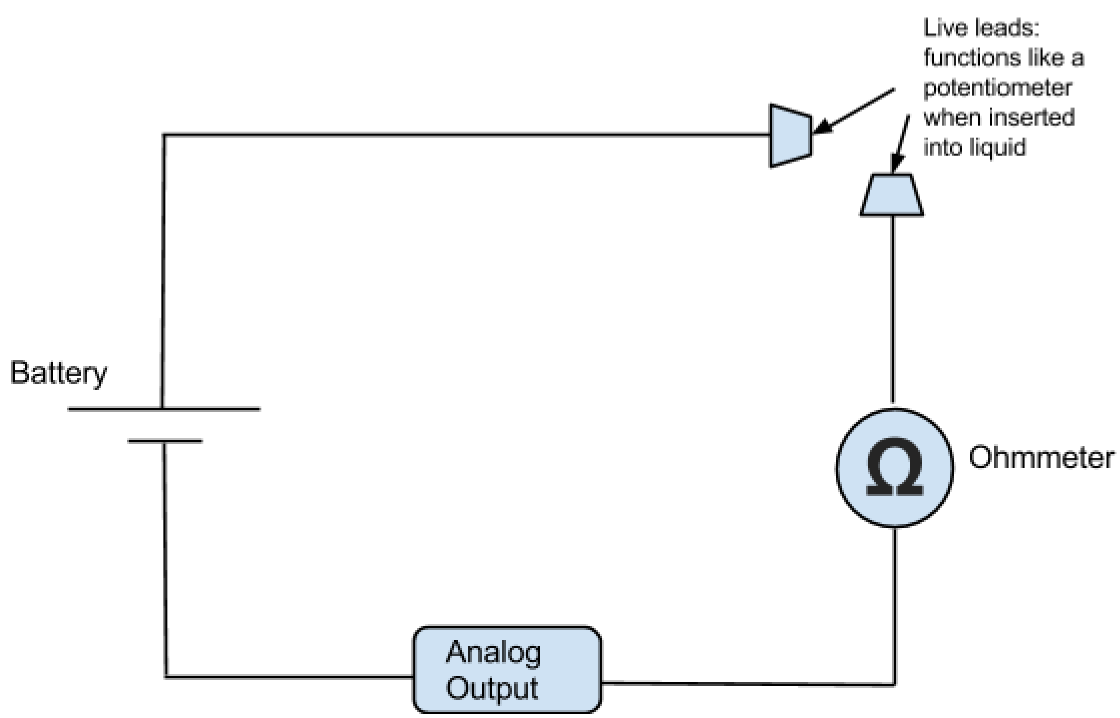

Figure 2. Diagram of the proposed circuit board.

The circuit is completed by inserting two live wires that would otherwise have been connected to the potentiometer into the electrolytic solution. The live wires in the product design have been replaced by metal leads located on the outside of the box. Depending on the resistance of the circuit, the brightness of the LED in our simulation changes. The LED in the product design has been replaced with a numerical analog indicator of the electrolyte concentration of the solution in question, and the wiring can be drawn onto a simpler breadboard for the final product so that only a distinct interface will interact with the electrolyte solution. The analog output will be programmed to display the electrolyte concentration using the proportionality equation derived through experimentation described below.

Testing and Redesign

Beginning with the null hypothesis that the solutes in the water will have no effect on the LED on the circuit board, i.e. neither the pure nor impure water will cause the LED to turn on, several processes will be carried out to test, and ultimately reject, this hypothesis. A simulating circuit will be constructed and tested with saline solution and an LED that will be replaced with an analog output in the final design. The prototype circuit will consist of a series of wiring that will include one opening that functions as a potentiometer when the live wires are inserted into the saline solution. Na^+ and Cl^- solutes will be added periodically to the water. As the electrolyte concentration of the solution increases, the LED should theoretically become proportionally brighter.

To numerically measure the resistance of the circuit, we will use an analog output ohmeter in place of an LED. By measuring resistance, R, we can calculate conductance G, and then find the proportionality equation relating the conductance and the electrolyte concentration for a solution containing dissolved NaCl. The experiment will be repeated with solutions containing SO_4^{2-}, HCO_3^-, Ca^{2+}, Mg^2, K^+, NO_3^-, and combinations of other pollutants that are found in similar quantities in polluted water sources. The pollutant proportions used for testing in the experiment will be based on local water pollution data from the environmental agencies of the respective target nations: India's Ministry of Environment, Forest, and Climate Change; Russia's Ministry of Natural Resources and Environment; the State Environmental Investment Agency of Ukraine; and the United States Agency for International Development which takes data on international water pollution across third world countries including the Republic of Congo.

Our design faces limitations due to the cost of efficiently shipping our device on a large scale to farmers in remote rural towns. With the help of volunteers from international environmental and hunger organizations, the devices can be more easily distributed, but the initial investment in our device will focus largely on distribution to farmers in need of our technology, where crop failures have been most prevalent.

To improve this design in the future, a desalination process catalyst will be added to the device itself. To begin the desalination cycle, we currently plan to experiment with solvents or various other solutions that can react with nitrates and phosphates to produce precipitates. Our device can discharge quantities of these solutions or catalysts to produce precipitates that can be disposed of with ease. Desalination automation is the next stage of improvement for our design. We are currently able to identify the problem and the level of need for public action, but hope to contribute to the desalination process as well in the future, so that we can lower costs of water cleaning procedures worldwide. Our primary objective, to reduce food shortages through the prevention of crop failure, can be accomplished through the implementation of our electrolyte concentration detector with the flexibility of added improvements as necessary.

Results and Conclusion

The ultimate objective of this solution is to detect the impurities in water used in irrigation and for drinking in order to consider the next phase of desalination. Having statistical evidence of these impurities will enable government authority to enact laws pertaining to the resolution of this issue. These laws will allow for the further implementation of desalination techniques on a mass scale.

The results of the initial experimentation should allow us to reject the null hypothesis that the electrolyte concentration of a solution would not be able to complete the circuit with significant resistance to be registered by an ohmmeter. Our experimentation with NaCl dissolved in water should theoretically produce a significantly resistant portion of the circuit which should be easily registered through the brightness of the LED. The voltage drop across the solution should increase as the NaCl concentration increases, which would indicate a positive relation.

Based on the results of the above experimentation, we propose to further experiment with water solutions that contain combinations of electrolytes most commonly found in polluted water. The results from this experimentation will allow us to develop an optimal proportionality equation to relate conductance and electrolyte concentration. We will then be able to program the CPU to display a more accurate electrolyte concentration value.

Based on the experiments and analyses, we should be able to conclude that a device built with this proposed design will clearly have variable resistance based on electrolyte concentration. Further experimentation will allow us to confirm the capacity of the ohmmeter to detect minimal changes in electrolyte concentration and the efficiency of the program used to control the display. The proposed materials used to create the prototype can be replaced with more cost-effective and size-efficient alternatives for the final design.

The proposal entailed above uses basic electricity principles to detect chemical disparities between pure water and polluted water. Added sensors and actuators can be added to alert the user to impurity levels that exceed water safety standards and to determine the specific form of water purification that would best ameliorate the problem based on localized concentration levels. By alerting local farmers in remote rural communities to the dangers of using polluted water for their crops, crop failures and food shortages can be minimized and avoided across the globe. In our target communities in Asia, Eastern Europe, and India, a solution to shortages could save thousands of lives each year. The solution described in this proposal is an economically- and environmentally efficient way to combat the problem of food shortages, and the inherent flexibility of the project will allow for further expansion and improvement through experimentation.

References

[1] "World Food Programme Fighting Hunger Worldwide." *Hunger Statistics*. World Food Programme, 2015. Web. 11 Feb. 2015. <http://www.wfp.org/hunger/stats>.

[2] Olness, Alan. "Water quality: prevention, identification and management of diffuse pollution." *Journal of Environmental Quality* 24.2 (1995): 383-383.

[3] Puckett, Larry J. "Identifying the Major Sources of Nutrient Water Pollution." *Environmental Science & Technology* (1995): 408A-14A. Print.

[4] Bernstein, L. "Effects Of Salinity And Sodicity On Plant Growth." *Annual Review of Phytopathology* 13 (1975): 295-312. Print.

[5] "Decade, Water for Life, 2015, UN-Water, United Nations, MDG, Water, Sanitation, Financing, Gender, IWRM, Human Right, Transboundary, Cities, Quality, Food Security." *UN News Center*. UN, 23 Oct. 2014. Web. 05 Mar. 2015. <http://www.un.org/waterforlifedecade/ quality.shtml>.

[6] Science Buddies Staff. "Electrolyte Challenge: Orange Juice Vs. Sports Drink" *Science Buddies*. Science Buddies, 18 Nov. 2014. Web. 5 Mar. 2015 <http://www.sciencebuddies.org/science-fair-projects/project_ideas/Chem_p053.shtml>

[7] Ott, Wayne R. *Environmental Indices: Theory and Practice*. Ann Arbor: Ann Arbor Science, 1979. 384. Print.