Introduction

Engineers Without Borders is a non-profit organization that supports community-driven development programs worldwide through the design and implementation of sustainable engineering projects. The EWB-UCSB team works in the Andean highlands of Peru where rural communities are required by the local government to chlorinate their water supply as a means of ensuring safe drinking water. Many rural areas around the world lack proper water sanitation and consumption of this water can cause illness. For this reason, rural areas often depend on chlorine, a low cost, readily available resource that safely and reliably sanitizes water. Unfortunately, the government provides these communities with a crude system that is neither reliable nor accurate at metering chlorine. At times, the chlorine level is too high and not pleasant to drink, which deters community members from chlorinating their water. At other times, the chlorine level is too low to properly disinfect the water, causing increased illness. The project’s purpose is to design a reliable chlorination system to sanitize water that maintains appropriate chlorine levels over a range of flow rates to ensure rural communities have a consistent supply of safe drinking water. Through the use of research, modeling, prototyping, testing and analysis, a system has been designed to meet the requirements listed in Table 1.

Design Process

The design process began by researching various methods of introducing chlorine into a water system that would be an improvement to the government-supplied device. From our research and analysis, it was concluded that a venturi injector would be the optimal system due to its accuracy, cost, and simplicity. Once this device was selected, extensive testing was conducted to model various flow rates and characterize the venturi system. We tested a similar system to the venturi chlorination system currently installed in Araypallpa. The test system used can be seen in Figure 2. Various modifications were identified, tested, and verified to improve the system. The chlorination device was placed before the water reservoir to ensure adequate contact time. A constant water-level chlorine solution tank was installed in the injection line to maintain a constant pressure and improve accuracy. A larger venturi was also utilized to make the system less sensitive and meet the minimum refill interval of the chlorine stock tank. These changes are highlighted in red in the system schematic as seen in Figure 1.

Test Methods

In order to verify that the chlorination system performs properly, a test system was developed to accurately model the conditions in Peru. The success of the design depends on the ability of the chlorination device to dispense chlorine, while positioned between 3.5 and 4.5 m below the water source, that results in a free residual chlorine level between 0.3 and 1.0 mg/L. The relationship between the total chlorine added to the water and the free residual chlorine depends on what is in the water. Information from previous EWB trips to Peru was used to calculate that the required total chlorine range to produce the desired free residual chlorine is between 2.0 to 6.0 mg/L. The test flow rate test results were used to calculate the theoretical chlorine stock solution concentration and the resulting total chlorine concentration range, which was between 2.29 to 5.72 mg/L. Therefore, the system successfully produces free residual chlorine levels within the 0.3 to 1.0 mg/L range.

The entire device can be fabricated for $195 using locally available materials, making it an affordable solution for rural communities. The minimum chlorine contact time of 30 minutes is achieved by positioning the device before the reservoir, since it stores approximately 2 days of water. The average flow rate ratio and average total water use were used to calculate the refill interval for the chlorine solution tank to be 2.37 weeks, which allows the community water quality lead to spend less time maintaining the system.

Results

The designed water chlorination system is robust and simple, can be readily manufactured using locally available tools and materials, and reliably meets the dispensing accuracy requirements. While it will be initially installed in Araypallpa Peru, the system is suitable for application in any rural community with similar conditions. A user manual has been developed, which includes safety, installation, calibration, and maintenance information. Worksheets are also included to take the user through the design process to develop a system for a similar community. Through the characterization of the system and the utilization of the manual, the system can be disseminated to rural communities in need of sanitary drinking water.

Sustainability

For the system to be a success, it also needs to be easy to install and maintain by non-technically trained people, since the community is running the system on their own for the majority of the year. In addition, it is our ambition for this system to be adaptable to different communities. The system is specifically designed to be implemented in Araypallpa, Peru, but instructions for adjustment are required so that it can work in communities with different needs and requirements.

Table 1: All of the performance requirements were met.

<table>
<thead>
<tr>
<th>Performance Criteria</th>
<th>Goal</th>
<th>Obtained Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum Unit Cost of Device</td>
<td>$200 (571 sol)</td>
<td>$195 (557 sol)</td>
</tr>
<tr>
<td>Adequate Contact Time for Disinfection</td>
<td>&gt;30 minutes</td>
<td>&gt; 2 hours</td>
</tr>
<tr>
<td>Total Chlorine Added to the Water</td>
<td>2.0 – 6.0 mg/L</td>
<td>2.29 – 5.72 mg/L</td>
</tr>
<tr>
<td>Interval for Refilling Chlorine Stock Tank</td>
<td>2 weeks</td>
<td>2.37 weeks</td>
</tr>
</tbody>
</table>

Figure 1: Design of Proposed System

Figure 4: The average flow rate ratios exist within the minimum and maximum ratio proving accuracy in dispensing for the three flow ranges.

Discussion

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