Development of A Low-Cost Solar Water Purifier Using Metaheuristic Process

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Abstract

The solar water purifier is an advancement of the current water purification system. It has been introduced to meet up demands of pure drinking water using renewable energy. It takes solar power as an energy source and stores it in a battery which is a free source of energy. Then using this energy, a low-cost heating coil heats water up to a certain temperature (below boiling temperature). After condensing cold water is further purified through the filtering chalk. In this stage, water is condensed again and gives water at room temperature. Through this process, we get pure drinking water. We followed almost all the phases of a product development process which started with collecting customer requirements and ended with finalizing the design. Cost analysis had also been done from the viewpoint of mass production of the product. We optimized the overall process using a metaheuristic approach for heating process, cooling process and purifying process. This product, if used properly, can eradicate the scarcity of pure drinking water.

Keywords
Solar Energy, Water Purification, Metaheuristic Process, Design Analysis, Cost Optimization.

1. Introduction

Water is one of the fundamental elements of human life. The need for fresh water is increasing day by day. Nowadays water purifiers are a must in our daily life. A water purifier purifies impure water. But as a driving force, it requires a source of energy. The most common energy sources used in such purposes are electricity, heat, chemical reactions etc. But in our water purifier, we have planned to utilize solar energy as the driving force. Solar energy is the most available renewable energy that is found in ample anywhere which is also inexpensive. We can create a voltage difference from solar energy by using solar cells. By accumulating several solar cells, we can create a solar panel. Then it is connected to a battery to store the energy in the absence of sunlight in case of cloudy weather. Then the energy is transmitted to a conductive coil to heat water as required and boils impure water to kill germs. We collect the hot water and after condensation, we pass this water through filtering chalk. Then finally we obtain pure drinking water. To develop a new product, we started with the customer survey so that we could find out the customer needs. After that, we performed QFD to convert those needs into technical requirements and prioritize them. We also performed functional decomposition using the black-box model. We designed our Solar Water Purifier using CAD software. Stress analysis was also done. After finishing the design, material selection, manufacturing process selection, and cost analysis were done. Thus, we built our prototype, run it and tested the water.

2. Literature Review

To improve product design there are four steps such as; assess the current performance using Fishbone Diagram, Pareto chart, FTA, RBD, FMECA; identify the stakeholders needs through customer survey; establish target specification performing QFD and HOQ to translate the stakeholders' requirements into product technical specification (TS) and testing and final specifications using design of experiments through analysis of variance tool ANOVA (Alsyouf et al. 2015). Product design can be defined as a set of constitutive elements of a product that consumers perceive and organize as a multidimensional construct comprising the three dimensions of aesthetics, functionality, and symbolism (Homburg et al. 2015). There is plenty of literature on the water purification process. Konda Reddy used nanotechnology for water purification and discussed different types of Nano-adsorbents with their advantages, disadvantages, and applications (Kunduru et al. 2017). A simple and inexpensive water purification method was developed using a natural coagulant (Moringa seed powder) and antibacterial agents (scallop powder) followed by bio-sand filtration (Zaman et al. 2017). Jun Yin prepared a thin-film nanocomposite (TFN) membrane containing graphene oxide (GO) nanosheets for water filtration (Yin et al. 2016). Kishor G. Nayara proposed electrodialysis (ED) over reverse osmosis (RO) for water purification in the urban area of India which outperforms RO and can achieve a recovery of 80%, producing 12 L/h of water at the desired salinity of 350 ppm from a feed salinity of 3000 ppm. The cost and size of the proposed system are also found to be comparable to existing in-home RO systems (Nayar et al. 2017). Shock electrodialysis (ED) can thoroughly filter micron-scale particles and aggregates of nanoparticles present in the drinking water. Shock ED can enable the disinfection of feedwaters as well, by combining these functionalities (filtration, separation, and disinfection) with deionization, shock ED has the potential to enable highly compact and efficient water purification systems (Deng et al. 2015). Sreenath Bolisetty Proposed inexpensive hybrid membranes made from protein amyloid fibrils and activated porous carbon for wastewater treatment (Bolisetty, S., and Mezzenga. R. 2016). Daniel S. Wendt developed a model in which a switchable polarity solvent forward osmosis (SPS FO) system was used for water purification. A thermally driven process SPS FO may be more cost-effective than electrically driven processes, such as reverse osmosis (RO), even if more energy is required (Wendt et al. 2015). Pankaj J. Edla provided a detailed review of different studies on the active solar distillation system in India. This paper discussed four different types of solar water purification methods such as; solar water disinfection, solar water distillation, solar water pasteurization and solar water purification (Edla et al. 2013). Manoj Phalak et al. proposed a solar-powered reverse osmosis portable water purifier which can be very useful in situations of floods (Phalak et al. 2017). Md. Z. H. Khan et al. developed a water purification and disinfection system by using solar energy. A compact water filter of five layers of filtrations was used for water purification as well as a solar collector was used in order to remove the rest pathogens, micro-organisms, some viruses and bacteria (Khan et al. 2015). A solar water purifier is designed using a black plastic sheet covered by a white glass window. The short wavelength, infra-red radiation from the sun is enlarged by entrapping between glasses which is directly absorbed by the water. Thus, the water gets hot and vaporizes (Ward 2003).

3. Methodology

The best way to help transform customer needs into engineering characteristics for a product or service is quality function deployment (QFD). Once the customers have been identified for a certain product, the next goal of the QFD method is to determine what is to be designed or which features can be attached to it. The key to this QFD step is collecting information from customers. First of all, we identified our target market those are urban residential sector, industrial sector, and rural residential sector. We carried out a survey on 88 people for developing customer needs for our solar water purifier in the above mention sectors through direct questionnaires, online surveys, and interviews over the phone. The requirements can be summarized in three categories. Following table-01 shows the categories:

Table 1: Customer requirements with preference

High Preference	Low cost
	Easy to clean
	Low maintenance cost
	Effective mechanism
Medium Preference	Easy to use
	Iron control mechanism
	Chemical-free water
	Multiple output line
	Alarm system in case of failure
	Compact design
Low Preference	A backup power system
	Temperature control system
	Odorless purified water
	Switching system instead of rotating tap

We convert this customer's needs to technical requirements and perform QFD (Figure 1).

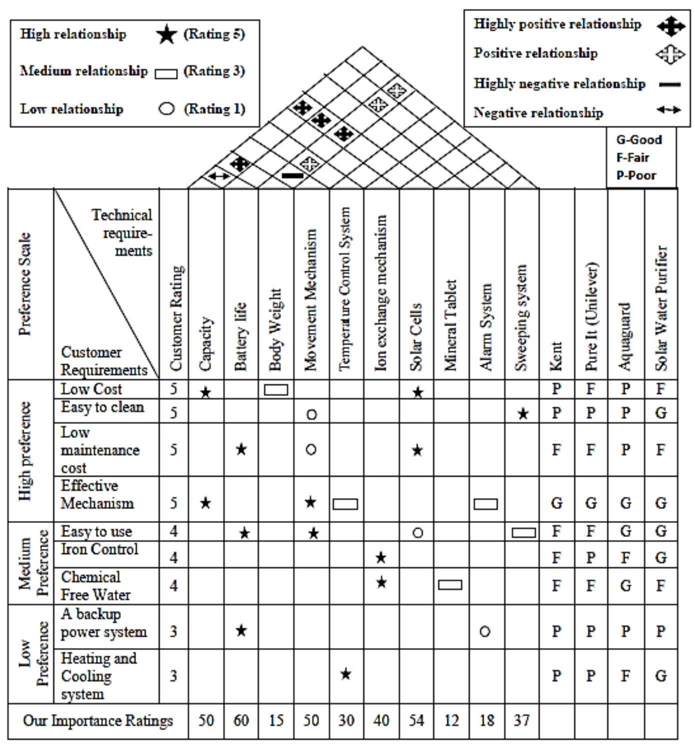


Figure 1: Product Planning Diagram (House of Quality) for Solar Water Purifier

From figure 01 we see that battery life, capacity, movement mechanism, and solar cells are the main technical requirements for our product. Then we perform functional decomposition where we break our product into smaller parts. We also conduct a black box design (Figure 2).

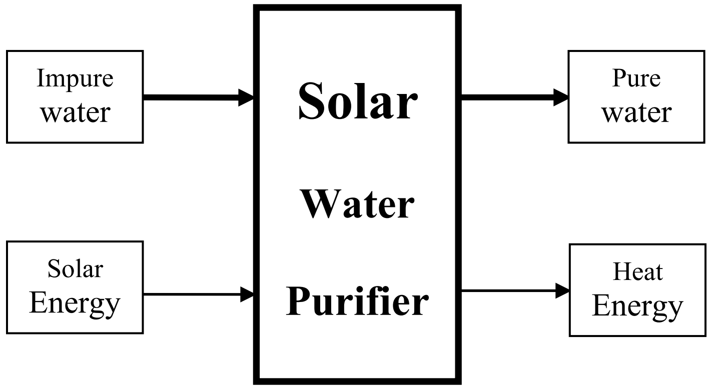


Figure 2: Black Box Model of the Solar Water Purifier

The component hierarchy of our Solar Water Purifier is shown in figure 3. Cluster Function of Solar Water Purifier is shown in figure 4. The first two stages of the product development process are planning stage and concept development stage which are followed by the system-level design stage. In the case of our product, we first developed a rough sketch and then considering its unique features and application, which lead us to a more detailed design.

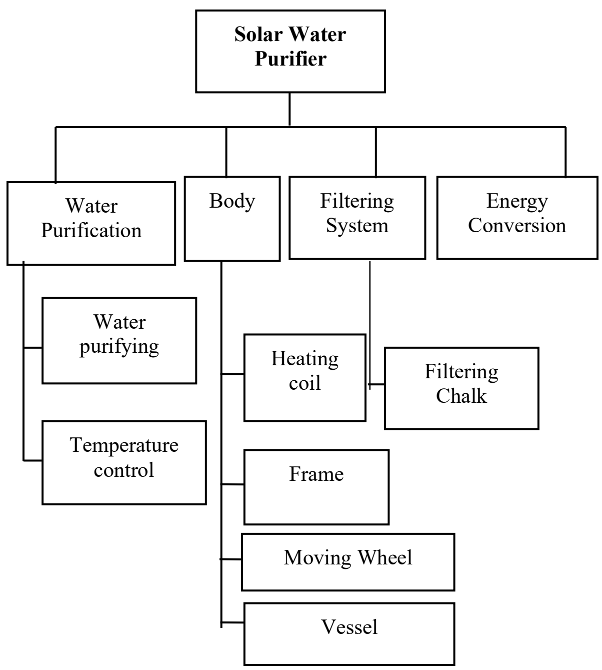


Figure 3: Component hierarchy of Solar Water Purifier

It is done on SolidWorks software shown in table 2. After the planning phase, we have developed the Solar Water Purifier physically. Besides we have shown stress analysis of the critical parts of the product in figure 6-8. After assembling all parts the final model is shown in figure 5. Our fabricated final product is shown in figure 9. We ran our product successfully and test the purified water. The results are shown in table 3.

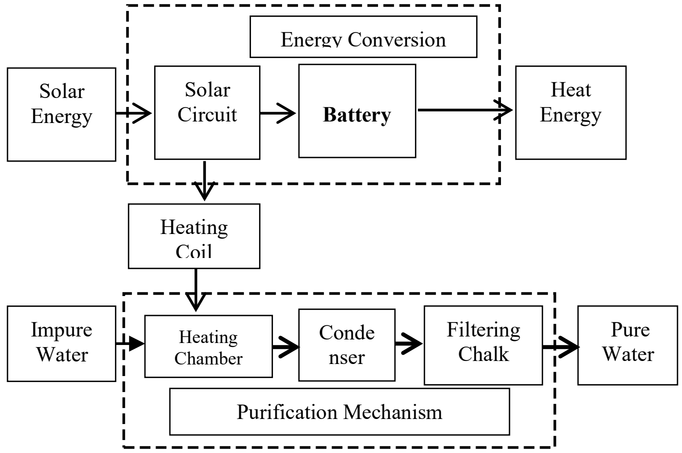
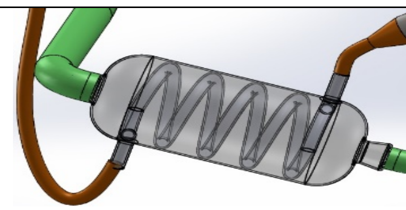
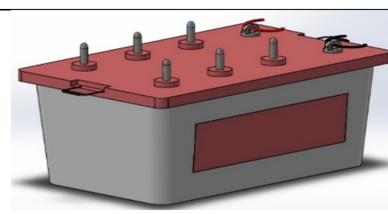
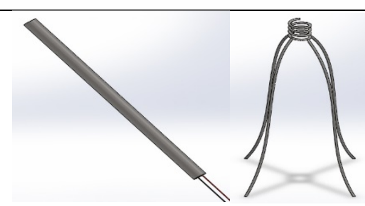
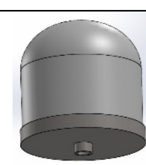
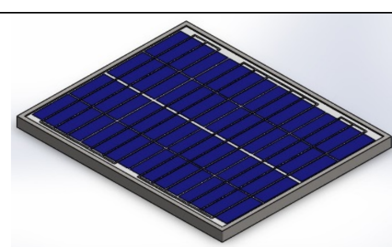


Figure 4: Cluster Function of Solar Water Purifier

Table 2: Parts of solar water purifier

Part Name	CAD Design
Condenser	
Battery	
Heating Coil & holder	
Chalk Filter	
Solar Panel	

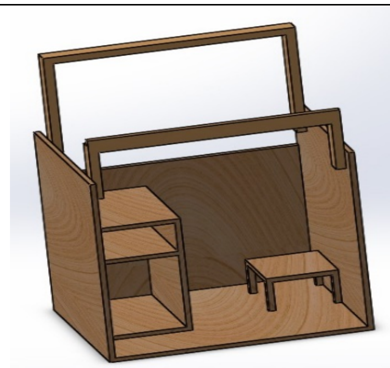
Body	

Figure 5: CAD model for Solar Water Purifier

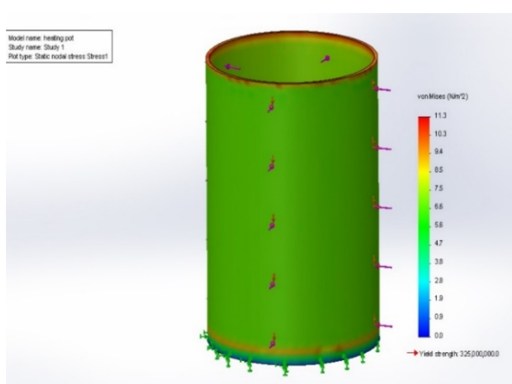


Figure 6: Stress analysis of heating vessel

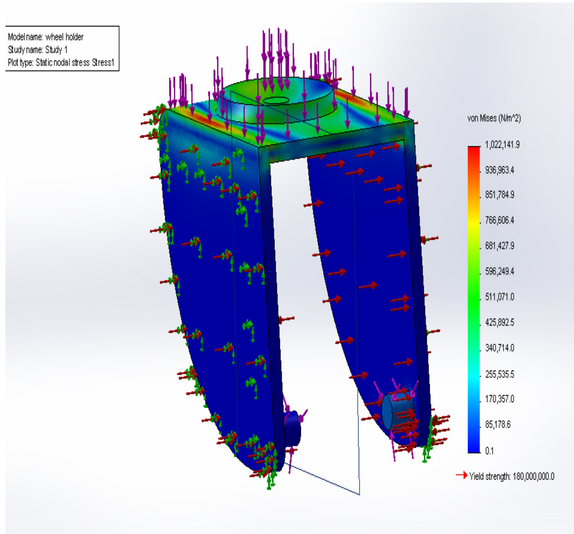


Figure 7: Stress analysis of wheel holder

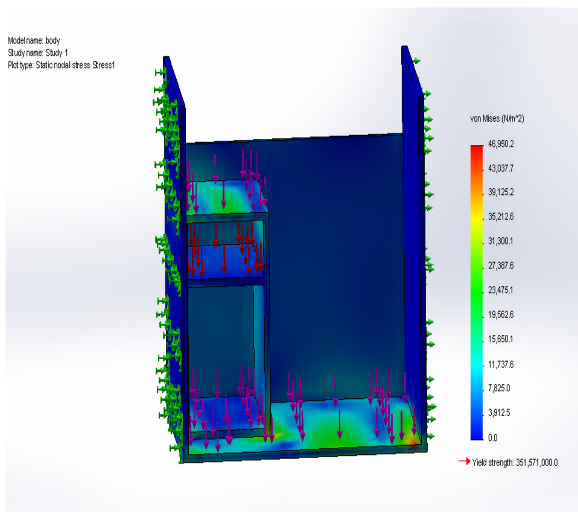


Figure 8: Stress analysis of body

Table 2: Results of the water test

Parameter	Before Purification	After Purification
pH	7.1	7.1
BOD	5.3 mg/L	4.9 mg/L
COD	8.5 mg/L	8.3 mg/L
Iron	0.02 mg/L	0.0195 mg/L
Dissolved Oxygen	5.8 mg/L	5.4 mg/L
Nitrate	0.05 mg/L	0.047 mg/L

Figure 9: Manufactured Solar Water Purifier

4. Conclusion

The scarcity of pure drinking water and scarcity of energy are two of the most booming problems of Bangladesh. Our solar water purifier offers a perfect solution for both of these problems. We followed all the steps of product design from customer surveys to the manufacturing processes. Afterward, the purified water quality was tested against different parameters and it was observed through the results that although the purification system does not have a significant impact on pH values, it decreases COD, BOD values and other parameters. However, the design is effective for only domestic uses. It needs to be refined and amended to increase its output for usage in industrial sectors effectively. We can also explore the possibility of removing arsenic from drinking water, which is a silent killer toxin in Bangladesh. Due to arsenic poisoning, hundreds of people are dying every year in Bangladesh and many water sources have been marked unusable due to this. If we can mitigate arsenic levels from water through purification, this can have a revolutionary effect in terms of social benefits. These can be scopes of future studies in this field. In Bangladesh, this type of water purifier is yet to be introduced in the market. So, we think our solar water purifier, if implemented efficiently by removing limitations, will attract customers of all sectors inhabiting in both urban and rural areas.

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Biographies

Sourav Kumar Ghosh is a lecturer in Industrial and Production Engineering at Bangladesh University of Textiles (BUTEX). He earned B.Sc. in Industrial and Production Engineering from Bangladesh University of Engineering and Technology (BUET) in 2017. He is a former lecturer in textile engineering at Primeasia University. He is currently enrolled in a Master's program in Industrial and Production Engineering at Bangladesh University of Engineering and Technology, Bangladesh. He has published two journal papers and three conference papers. S. K. Ghosh has completed several research projects under UGC. His research interests include machine learning, supply chain optimization, operation research, parameter optimization of CNC machines, renewable energy, and lean manufacturing.

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Fariha Kabir Torsha has graduated in the year of 2017. She earned her B.Sc. degree in Industrial and Production Engineering from Bangladesh University of Engineering and Technology (BUET). She has conducted her undergraduate thesis on process parameter stabilization using Artificial Neural Network and published a research paper in the same name, Proceedings of 1st International Conference on Industrial and Mechanical Engineering and Operations Management (pp. 62-69). Her research interests include Optimization, Operations Management, Operations Research, Statistics, Quality Control, Inventory Management, and Computer Aided Process Planning etc. She is currently working as supply production leader in a sports retail multinational company.

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