Cornell Engineering World Health

EWH Design Competition Entry

Passive Cooling Device for Vaccine Transportation

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Problem Definition

Over 1 million children die each year from vaccine preventable diseases. Measles, and influenza still take their toll in remote villages across developing countries, where access to vaccines is limited. Even when these areas are able to get a hold of vaccines, they don't have the access to reliable electricity to maintain a properly functioning vaccine refrigerator, nor will they have on site medical personnel to administer the vaccines. These two limiting factors are the reason why those who live remote rural African villages are the most disadvantaged population when it comes to immunization.

A village with a population less than 500 doesn't need a constant large supply of vaccines onsite, especially after a round of vaccine administrations by healthcare workers.[1] Therefore, a constant overstock of onsite vaccines would result in greater incidences of spoilage than actual vaccine administrations.[2] This is true since onsite vaccines would have no stable source of refrigeration in remote villages. This is why healthcare workers typically retrieve vaccines from larger cities equipped with more advanced healthcare centers sustained by adequate electricity. The health care workers will load a batch of vaccines into a cooler with a few fresh packs of ice and deliver them to remote villages. To reach these remote villages, health care workers often motorbike or walk, but many have to "hike mountains or cross log bridges" in order to reach their target village, carrying a heavy cooler the entire time. Setting up shop to administer the vaccine can take hours or days down the road. Thus, vaccine spoilage remains a prevalent problem in the cold chain distribution.

Overall, the solution to this vaccination problem in rural areas of developing countries is not a permanent fixture to store the vaccines, but a device that can help make the jobs of vaccine outreach teams and health care workers more efficient by maximizing vaccine coverage of rural populations. The focus of our project is to construct a low-cost, portable, and durable refrigeration device that provides multiple doses of the basic vaccines (polio, tetanus, measles, influenza, etc.) to infants and adults in remote villages with limited access to electricity.

Impact on Developing World

Our Technology (PCD)

The current method of vaccine transportation to remote locations in Africa can take hours to days. This is where our vaccine cooler comes into play, with a light 3-D printed plastic shell lined with silica-aerogel vacuum insulation, our refrigerator is not only lighter, but also significantly more thermal resistant than a regular cooler. The sleek cylindrical design with a cooling core filled with cool gel beads or chilled water will allow for the optimal storage of vaccine vials while maintaining a small size for increased portability. The vaccine vials will sit on cylindrical shelves as seen in Fig 3. Standing at 16 inches with a diameter of 8 inches, our passive cooling vaccine refrigerator should be small enough for health care workers to easily fit into a backpack (fig.1). In total, this vaccine cooler can carry approximately 138 doses of vaccines or 18 single dose vials and 12- ten dose vials.

Currently, most coolers have a cubic design, a much less thermal resistant shape than that of a cylinder. The combination of a cylindrical shape, cooling core, and aerogel insulation can guarantee a temperature of 2-8 degrees Celsius for approximately a day, thereby expanding the distance that vaccines can be taken from a center and thus the radius of coverage by traveling NGOs (fig.2). The cooling core can be filled with chilled gel beads or more available water, to maintain the internal temperature around 2-8 degrees Celsius. With our passive cooling device (PCD), outreach teams can carry and keep cool enough vaccines to administer multiple villages in a row without having to return to the larger city to restock each night. Volunteer doctors and health care workers can save room in their cramped mobile clinics and vehicles that are already jammed packed with people, medical supplies and testing equipment.[4]

Figure 1

Figure 2

Figure 3

Competitors

Currently, the most prominent devices on the market used to prevent vaccine spoilage in the developing world are the SuperCooler sponsored by the Bill and Melinda Gates Foundation and the Sure Chill vaccine refrigerator. The SuperCooler and Sure Chill Refrigerator can passively keep vaccines between 2-8 °C for approximately one and ten months, respectively. Though both devices exhibit impeccable insulation capabilities, their size and weight make them inconvenient for transport through rough terrains on 100CC motorcycles which is how most vaccines are transported to remote villages in countries such as Uganda.[5] In terms of price, The SuperCooler and Sure Chill cost \$1000 and \$2600 respectively, significantly more than the \$400 cost of our Vaccine Cooler.

Table 1

	Price	Service Remote Villages	Hand Portable
Passive Vaccine Cooler	<\$500	✓	✓
SuperCooler	\$1000	◐	✗
Sure Chill vaccine Refrigerator	\$2,600	✗	✗

Compare Ninja table

Required Performance Specifications

- Maintain an inner chamber temperature of 2-8 degrees for at least 12 hours
- Insulation with thermal conductivity less than styrofoam (0.01 W/m*K)
- Weight: less than 20 lbs.
- Vaccine Capacity of 100 doses.

Implementation of Prototype

Design

The focal point of the prototype designing process was mitigating heat loss while maintaining portability. To account for radiative, conductive, and convective heat loss, the prototype was made to be a cylinder since for all three types of heat transfer, energy loss is directly proportional to surface area. A cylinder is the most efficient shape for reducing surface area since for a rectangular prism of approximately the same dimensions (8" x 8" x 16"), the surface area is reduced by about 20%. Similarly, HDPE plastic was chosen for the construction of the outside of the cooler due to the combination of its relatively small thermal conductivity constant (0.45 W/m*K), larger heat capacity (1.67 kJ/kg*K), and tensile yield strength (3800 to 4800 psi). Plastic was chosen over metal in order to reduce conductive heat loss and to resist temperature change. The insulation chosen was an aerogel composite that had a thermal conductivity constant significantly smaller than that of air (0.0014 W/m*K). In order to increase the efficiency of the insulation by increasing the thickness used, the size of the cooler was expanded to have an 8 inch diameter.

Continuing the focus on heat loss reduction past material selection and into the design of the cooler itself, to reduce exposure with the hot environment, a screw top lid was implemented. As seen in Fig.2, the center core that houses the vaccines is surrounded by two and a half inches of insulation on either side and can only be accessed by removal of the insulated lid on top. Removal of the lid only exposes the top of the core and each vaccine is housed inside a shelf (Fig. 3) whose top seals the tube it is stored in. Thus the removal of a vaccine will only expose the top vaccines in the shelf it is being taken from, reducing heat exposure to the other vaccines being stored. To prevent heat from entering from the bottom, the vaccine housing chamber sits atop a solid plastic stand to prevent direct contact with the bottom of the cooler. The inside of the vaccine storage compartment can then be filled with coolant (either with coolant beads or more easily accessible chilled water) so that each storage tube can be evenly chilled.

Construction

The cooler was also designed to be easily constructed with only a small number of pieces that required assembly. Most of the cooler was constructed from raw stock material. The outside casing of the cooler and the inner vaccine storage compartment were both tubing that was simply cut to the right height. The lid and bottom of the container were laser cut from plastic slates to the right proportions. For the insulated lid and bottom stand, both were cut to the proportions from the CAD model on the lathe out of solid HDPE plastic. The top lid was then threaded to allow it to be able to screw in and out of the cooler. The containment tubes inside the cooler were PVC pipes that were bored to the correct inner diameter and shaven to the correct outer diameter. These were then placed inside the inner cylinder, held with slots at the bottom, and filled with the 3D-printed vaccine shelves, designed to precisely hold single-dose or multiple dose vaccines. The lids, outside container, and bottom stand were then drilled and screwed together and the insulation was tightly wrapped around the inside of the cooler until it was fully packed.

Mode of Operation

Operation of the cooler is meant to be as simple as possible for users. After assembly, only a single fill of coolant is needed. One coolant that may be used includes the cooling beads found commonly in therapeutic sports ice packs. These beads are pliable and self-contain all the liquid coolant, making them ideal for cooling the vaccines. However, an easier option is to simply use chilled water. Since the shelves housing the vaccines are fully isolated from the coolant, there is no worry of contamination from the water being used.

After the coolant is added to the cooler, it should be stored in the same refrigerator where the vaccines are stored or another refrigerator that is at the correct temperature. Whenever NGOs or healthcare workers intend to make a trip to a remote village, the cooler can be quickly filled with vaccines and the entire contraption is then taken to its destination. Due to its sturdiness and relatively lightweight, it can easily be transported on the back of a motorcycle or by hand using the handle on the lid. At its destination, the cooler can be left anywhere since it was designed to resist high temperatures (although its cooling lifetime increases if left in the shade). Once used, the cooler is to be taken back to the main center and cool down in the main refrigerator again, ready for its next use. This way, the PCD is easily reusable with the only needed changing of parts being the quick refilling of vaccines for each use.

Proof of Performance

Testing Methodology

To accurately assess the performance of the cooler under realistic scenarios, the cooler was tested under a simulation of our proposed mode of operation. After filling the cooler with insulation, coolant and vaccine vials, temperature logger probes were placed inside the cooler to monitor temperature change at every 1 minute interval. The entire cooler was then chilled to 2°C for 24 hours. After being brought down to temperature, the cooler was placed in a temperature controlled oven at approximately 82°F (28°C) for 24 hours. Afterwards, the data was taken from the temperature probes as seen below.

Performance

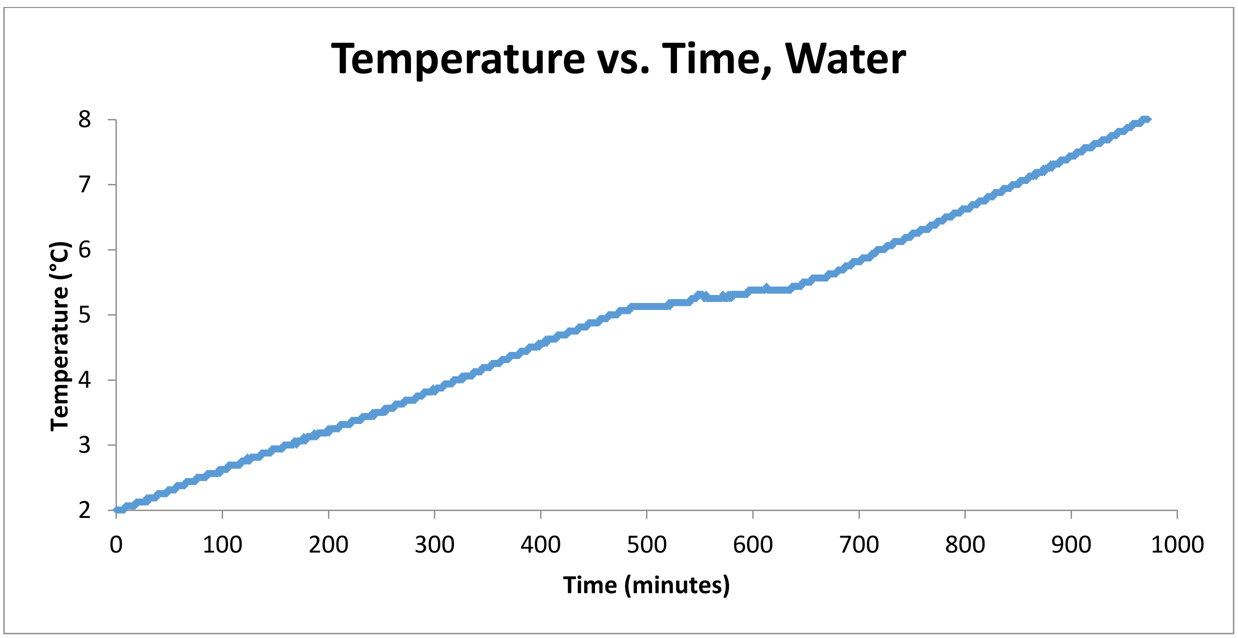

Figure 4

Using water as a coolant seeing as it is a more readily available resource in our target regions, the PCD was able to maintain a temperature between 2°C and 8°C for 973 minutes or 16.2 hours with an average ambient temperature of 25°C (Fig 4). The total weight of the cooler including insulation and coolant was roughly 16 pounds, still light enough to make it portable. In total, 30 vaccines were easily stored, for a total of 138 doses. Furthermore, the aerogel composite used had a thermal conductivity value of 0.0014 W/m*K, almost ten times lower than that of Styrofoam. Heat distribution between the middle of the container and the top showed some variation with the top of the container reaching the maximum temperature threshold (8°C) about an hour (55 minutes) before the middle of the container.

These results demonstrate the usefulness of the PCD in comparison to other existing vaccine coolers. Not only is it easy to use and refill vaccines with, but being able to last 16.2 hours on average with a single refrigeration cycle, it greatly expands the range of NGOs and health workers on trips to distant villages. Compared to the 4 hours provided currently available vaccine coolers in the same weight range, the PCD can expand the coverage of health care workers by the additional 12-16 hours of travel time gained.

In the plethora of available vaccine coolers, there are only a select few that can be passively cooled while maintaining a portable size. However often require constant refills of more than a kilogram of ice a week while costing more than $700.[6] Also, as the time to keep the device cool increases, the weight and size of the cooler grow in proportion, thus limiting their ability to be easily transportable[6]. Instead, our PCD extends the reach of the current vaccine distribution chain by taking advantage of the most readily available modes of transport to quickly deliver needed vaccines to those who are often the hardest to reach.

Business Plan

Customers

Volunteer Networks and Mobile Clinics

Direct delivery and administration of vaccines to remote regions of sub-Saharan Africa are primarily carried out by mobile clinics and traveling healthcare workers. Deploying mobile clinics is currently one of the popular initiatives taken by volunteer organizations such as African Impact and US Doctors for Africa in "delivering basic primary healthcare" including immunization.[6] US Doctors for America, alone plans to "deploy two-hundred mobile health clinics and two-thousand medical professionals in communities throughout Sub-Saharan Africa over the next ten to fifteen year", starting with first deployed to Senegal in 2009.[7] The vehicles used as mobile clinics will already be carrying doctors and volunteers, along with loads of medical and testing equipment, and therefore can't spare too much room for a large vaccine refrigerator, nor will they have the sufficient electricity to support it.[4] Thus, our compact passive vaccine cooler is the ideal addition to a mobile clinic's vehicle.

Aside from volunteers, remote villages rely heavily on full time traveling healthcare workers. The workers frequently, if not exclusively, travel on foot and in some cases on a motorbike. Making them our customers that would benefit the most from a light and compact vaccine cooler that one can easily carry with ease.

Non-Government Organizations

Non-government organizations (NGOs) such as Medic Sans Frontieres and The Red Cross frequently launch vaccination campaigns to countries and remote areas with low vaccination coverage.[8] The Red Cross is not only known for its measles and Rubella initiative in which they provided not only vaccines, but also technical support to local governments and communities. With them as a customer, they can purchase our vaccine coolers and distribute them during this campaign. Additionally on a smaller scale, the Red Cross also provides "door to door" vaccination services in which our vaccine coolers will also prove to be useful.

Government and Health Departments

We hope to eventually target local governments and health departments to help implement our passive cooling device as a standard tool used in local vaccination campaigns to remote villages and communities.

Distribution

Distribution will be split up into three phases:

Phase I: This will be our first phase of distribution as well as a test phase. At this point we will only have manufactured a few prototypes of the vaccine cooler and distribute them to Health center 4 in Uganda where our contact there will have their healthcare workers use them for an extended period of time in their vaccine campaigns to remote villages. We will also collect feedback during this phase and improve upon our product.

Phase II: Once Phase I is completely successfully, we will use the success at Health Center 4 to start selling our product to small scale NGOs and volunteer organizations that specialize in deploying mobile clinics and vaccine (or general health) campaigns to remote regions of Africa. Small scale organizations such as ASCOVIME based in Cameroon would be the perfect target for implementation of our product.

Phase III: We will use the success of our product with small scale organizations to sell our product to larger NGOs such as Medic Sans Frontieres and the international Committee of Red Cross. Both of these NGOs frequently launch mass vaccination campaigns to countries all over the world that consist of remote regions with low coverage of immunization. We will also attempt to distribute to governments and health centers by using NGOs and foundations, who donate medical equipment, as our middlemen. Eventually, we aim to be able to distribute directly to local governments and health centers as we increase the mass production, which will additionally drive down the cost.

Funding

Initially, we will need outside funding to make the first few prototypes to use in phase I of our distribution (see above in Distribution). This, we hope to acquire through grants and crowd funding initiatives. Once the first few prototypes are sold, we will still need to rely on outside funding in addition to the profits made from the first few sales, in order to improve upon the product and manufacture more vaccine coolers. Once we have received enough funding, we will start buying raw materials in bulk which will drive down the cost of these vaccine coolers. Eventually, the sales of the vaccine coolers should begin to cover its manufacturing costs and outside funding won't need to be relied on heavily. After we have achieved phase II of distribution (see distribution section), the amount of vaccine coolers sold should cover all raw material cost, eliminating the need of an outside funding source. There will be no labor cost because construction of these devices will be carried out by volunteers, such as Cornell EWH members or any trained volunteer wishing to contribute.

Manufacturing

Construction of the first few vaccine cooler prototypes to be used in the primary phase of distribution will be carried out by veteran and trained EWH members. After the completion of phase I, Cornell EWH will recruit trained members to form a sub-team solely devoted to manufacturing vaccine coolers. These volunteers will be rewarded university credit as an incentive to join and manufacture vaccine coolers for distribution. Using this manufacturing system will eliminate labor cost and Cornell EWH can keep the cost of vaccine coolers low.

Legal Issues

Since our technology is intended to be implemented in developing countries with little to no regulations regarding medical devices, FDA and CE approval is not necessary. However, since our major target customers are organizations that were founded and headquartered in the United States and Europe, we will seek FDA and CE approval. These approvals not only increase our marketing appeal, but also limits the liability of our organization from getting sued should the product fail in any way.

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Appendix

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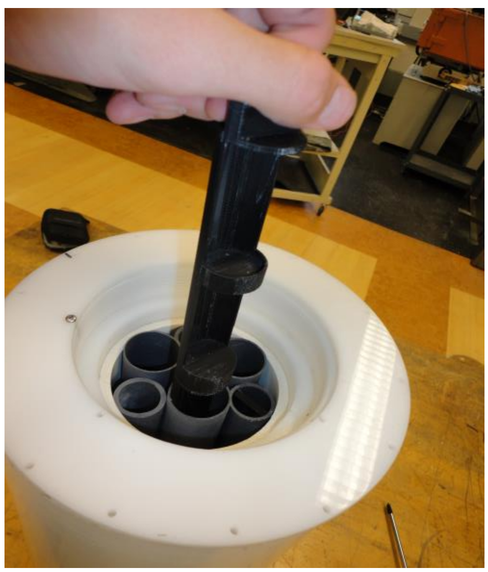

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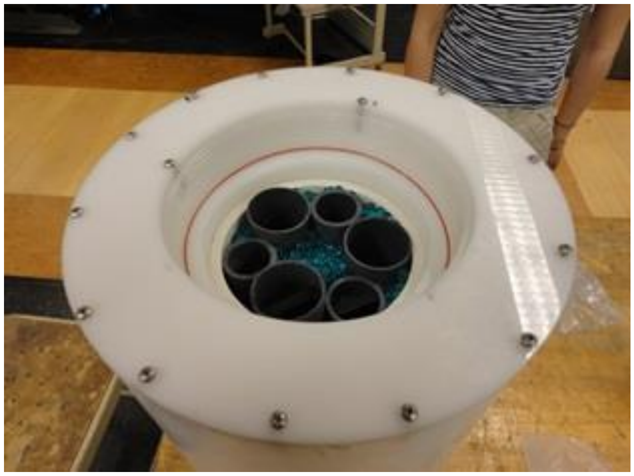

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