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Design of Solar Powered Vaccine Backpack

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ABSTRACT
Covid-19 Pandemic effects rural and indigenous area that is hard and far to reach by vehicles. Most of the medical deliveries to this remote area is done on foot and taken days to reach destination. Vaccine consistency is affected by their ambient temperature and duration of exposure to adverse temperature in their deliveries. In this research, the development of a reliable personnel backpack that provides self-sustainable energy for vaccine cold storage is proposed. This vaccine storage should support the ambient and stable temperature with at least between 2° – 8° Celsius. The problem on the transportation infrastructure in rural and remote area need to be addressed. Most of delivery is done by foot through the jungle or footpath that cannot be crossed by vehicles. Multi modal of power source is needed to accommodate the lack of electricity along the route in rural and remote area. Ergonomics and lightweight are also important for the personnel to bring the vaccine.

Keywords: *vaccine carrier, cold storage chain, solar*

1. INTRODUCTION

Current Covid-19 epidemic has worldwide impact with more than 9 million cases where 49000 cases are in Indonesia. National Research institute and bio pharmacies companies around the world are competing to find as so called the only solution to end the pandemic, vaccine for Covid-19. As the vaccine research is racing, the distribution of vaccine itself, especially in rural and remote area is having bigger challenge.

The successful vaccination program requires high immunization coverage in large population. The vaccine market is reaching developing countries and remote area due to the efforts of global immunization programmes. [1] As encouraging at it seems, the increase of immunization programs and the new vaccines introduction is putting in the problems on delivery systems that does not changed in decades. Unfortunately, only 31% of vaccines are stockouts and 55% of vaccines deliveries does not follow cold chain recommendation form WHO [2]. This is because of neglected and lack of basic vaccine handling policies, standards and quality management practices in vaccine cold chain. In 2014 alone, WHO estimated 67% vaccine deliveries are prone to be damaged and wasted [3].

Instability of vaccines often emerges as a key challenge during clinical development as well as commercial distribution. A lack of infrastructure, cold chain equipment particularly in developing countries, can lead to 75–100% of vaccines being exposed to during dissemination [4]. One of these challenges is that live, attenuated vaccines are more heat sensitive to potency loss during storage and distribution [5,8]. Most of the vaccines is made by weakening, attenuating of infectious viruses and/or bacteria that can be replicated in vivo. In terms of stability, these attenuated versions of viruses and/or bacteria should be lyophilized before administered by parental injection, nasally or orally.

The administration of vaccines through rural and remote area are prone to this challenge. Energy resources limitation and lack of transportation infrastructure are some obstacles of delivering vaccine to the rural area. Improperly maintenance or outdated cold storage equipment, lack of compliance on cold chain procedures and poor monitoring are some of the direct consequences in rural and remote area, especially in hot climate [6,7].

2. VACCINE COLD CHAIN

The common practice to deliver vaccine and preserve the temperature is by using box filled with ice pack. Also, if the area has facilities such as freezer and refrigerator then they manage to store the vaccine in that storage. Unfortunately, both practices, even with

refrigerator or freezer compartments of the household-grade combination storage units do not perform as well as recommended by WHO cold chain practice [9]. Research in one of developed Europe countries, shows that only one-third of the refrigerators fulfilled the cold chain requirements, and more than 15% threatening vaccine potency [10]. There is a gap of cold chain equipment providing a promising avenue for new technological research [6,11].

This research proposed reliable vaccine storage to support the cold chain especially in remote and rural area. This vaccine storage should support the ambient and stable temperature with at least between 2° – 8° Celsius. The problem on the transportation infrastructure in rural and remote area need to be addressed. Most of delivery is done by foot through the jungle or footpath that cannot be crossed by vehicles. The reliable vaccine storage should be carried easily by healthcare personnel. Ergonomics and lightweight are also important for the personnel to bring the vaccine.

The proposed vaccine storage should also accommodate sufficient space for air to circulate around them. The compartment should accommodate to bring any vaccine vial size with order of vial amount. The flow of air around the vaccine vials should equally distributed within the compartment [16]. This is to minimize the risk of warm air exposed when the storage is open and to prevent the defrost [17,18]. The right shape of compartment is needed for the vaccine to be stable and air equally distributed.

Multi modal of power source is needed to accommodate the lack of electricity along the route in rural and remote area. The design of solar powered TEC has been proposed by [19] for the deserts remote parts. It could be one of the renewable energy modalities of the proposed portable vaccine. Several parameters such as High electrical conductivity, low thermal conductivity, and a high Seebeck coefficient are desirable for thermoelectric materials. Therefore, knowledge of the relation between electrical conductivity and thermal conductivity is essential to improve the efficiency of Solar generated power on TEC properties [20,21]. The utilization of renewable energy as alternative source could coop with the challenge in the energy infrastructure.

The personnel spend whole day to bring the vaccine storage backpack that may make them suffer from musculoskeletal disorders due to carrying non-ergonomic and through the obstacle roads. The vaccine storage has weight that could give uneven spinal loading and lead this to injuries in the long usage [22,23]. The ergonomic parameters and the shape of backpack should be considered to prevent spinal disorders.

The personnel vaccine storage should also be equipped with remote monitoring to monitor the temperature and condition of the compartment. Method of communication protocol for the rural and remote area has been explored by [24,25] by using mesh protocol network with large coverage rural area. The usage of multimodal communication that can be automatically handover could solve the problem of telecommunication infrastructure in rural area [26].

3. BACKPACK DESIGN

The contexts of vaccine storage were divided into 3D design model as the scenario for personnel backpack and also the selection of performance and characteristic of each module. As shown in figure 1, conceptual isometric view of the proposed vaccine backpack is integrated with multiple sources of power. The current stage of development, all values for every associate performance and characteristic are defined into the functional bound based on the quality metrics. This 3D design will be subjected for the thermodynamic and Multiphysics analysis for the next steps.

Vaccine is distributed to remote areas that are still not reached by two-wheeled and four-wheeled vehicles. Usually during this distribution, the vaccine can be damaged or exposed. To overcome this, the solution we can offer is to use a cooler box that is combined with the backpack / backpack function, so that the delivery will remain safe and secure. The cooler box is also equipped with GPS to be able to find out the position and path when the delivery is made. In addition, it is also equipped with a solar panel that functions to charge what the cooler box needs

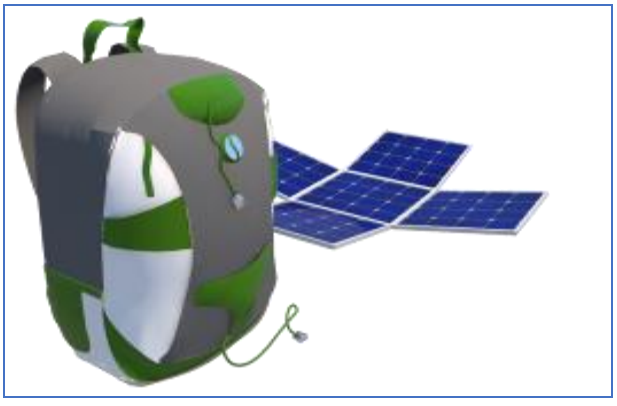
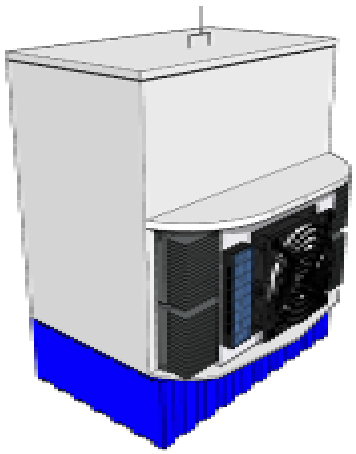


Figure 1 Conceptual isometric view of the proposed vaccine backpack.

Several solutions were made to assist in the distribution of vaccines and to ensure that there is no vaccine being wasted. The solutions we offer include in the process of delivering the vaccine, where the location is tracked and the journey process will also be recorded. Stability of the vaccine temperature and the low energy usage should be considered within the design.



(a)

(b)

(c)

Figure 2 Cross-section design from inner part of vaccine backpack. (a) Outer layer of cold storage box (b) Vaccine vial placement and air flow steering parts (c)

Figure 2 shows the cross-section design from inner part of the backpack. The thermoelectric cooling (TEC) has been widely used for the compact, portable, low voltage and lightweight cooling device. TEC could be the solution for cooling component of our proposed portable vaccine storage. The COP is the ratio between the refrigeration load and electrical power consumption, where the calculation was based on equation below

$$COP = \frac{Q^T}{W_e}$$

Where Q^T is the total rate of heat gain inside the storage, and W_e is the power consumed by the TEC unit.

However, there are several challenges such as extremely low coefficient of performance (COP) than compression system [12]. Figure 2.c shows additional heat-sink arrangement that could increase the TEC effectiveness. Configuration of heat sink increase the COP by finding optimum model of heat capacity rate of cooling fluid in the heat sink [13,14]. Several methods to modified mini-channel heat sinks and array configuration of TEC has also been proposed to increase the COP [15]. The best configuration array TEC and right shape of heat sink are needed to achieve the stable ambient temperature of portable vaccine storage.

As in Tabel 1, the proposed specification of vaccine backpack should generate enough power to fulfil the standards of cooling storage temperature of vaccine. Recommended storage for most of the vaccines are between 2° – 8° Celsius with the shelf lives for more than 1 year. The vaccines life could be reduced to less than hours when expose to heat within certain duration.

Table 1. Proposed specification of vaccine backpack

Specifications	Descriptions
Cooling Power QcMax (W)	7 Watt
Running Current	2 Ampere
Nominal Voltage	5 Volt
Max Voltage	6.5 Volt
Power Input	10 Watt
Operating Temperature	2°C – 10°C
Weight	2.5 Kilograms
MTBF (fans-hrs)	10,000
Performance tolerance	±10%

4. CONCLUSION

As 30% of population in developing countries are stayed in the remote area, the deliveries of the vaccine through remote area could be done correctly following the requirement of cold chain recommendation from WHO.

The current market of cold storage is still in the big and bulk box with compressor involved as cooling unit. There is no product that can be easily carried by personnel and reliable to keep the ambient temperature of vaccines.

At large, the result of proposed backpack will give significant output for the vaccine cold chain landscape, as it solves the vaccine distribution to the remote area and reducing the wastage of vaccine deliveries. It will be useful not only within this pandemic, but also the medical deliveries in long term.

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