Young Stunners

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Introduction:

The World Health Organization (WHO) has reported that vaccine wastage may result in a global annual economic cost of up to **$10 billion**. In India alone, the vaccine wastage has resulted in an estimated loss of **₹2,300 crores** ($310 million) as of July 2021, encompassing direct and indirect expenses such as vaccine disposal, storage, and transportation. To avoid significant financial losses, particularly for expensive vaccines like those for COVID-19, it is essential to minimize wastage by carefully planning, efficiently distributing, and effectively managing vaccine supply chains. The attribute issues such as logistical difficulties, reluctance to receive vaccines, and insufficient preparation can be resolved with adequate cold-chain management.

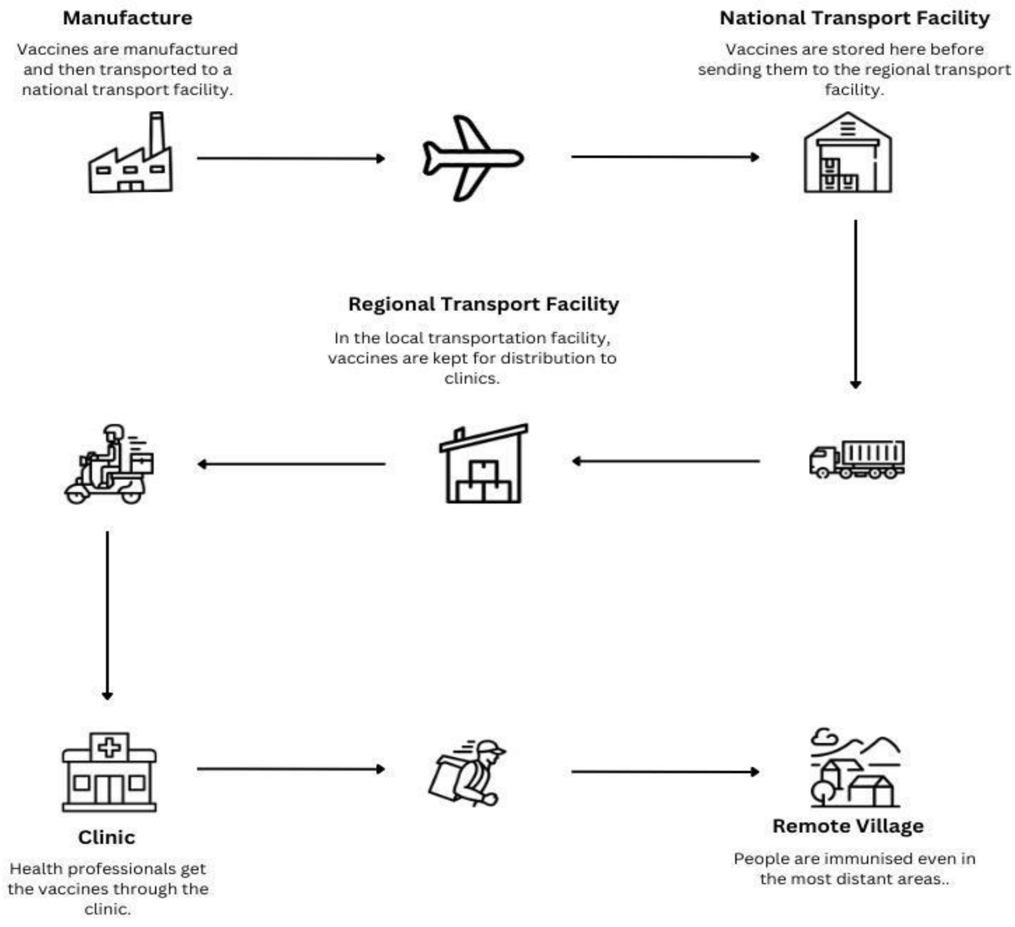


Fig-1: Vaccine Supply Chain

The pursuit of cold chain management is to maintain the product's quality and safety while ensuring that it stays within the required temperature range throughout its journey from manufacturing to consumption. Vaccines contain delicate biological materials that may degrade when exposed to certain range of temperature. Effective cold-chain management facilitates transportation to remote areas, prevents wastage, and ensures vaccine efficacy. Ultimately, it plays a critical role in reducing the spread of vaccine-preventable diseases and protecting public health.

Effective cold chain management is vital to maintain the efficacy of vaccines, but it comes with several challenges that can lead to significant vaccine wastage and compromise public health outcomes. One challenge is the lack of real-time temperature monitoring, a common problem in India, with only **35%** of temperature monitoring cold storage devices being functional. Inadequate cold chain management in vaccine logistics and distribution can result in up to **50% worldwide vaccine wastage**. A lack of proper storage facilities, inefficient transportation methods, and inadequate tracking systems compounds this issue. Outdated and poorly maintained refrigeration equipment in remote areas is another major issue, responsible for 25% of vaccine wastage in sub-Saharan Africa. Inadequate cold chain infrastructure is also a concern, with only 29,000 out of 70,000 vaccine storage points in India having proper refrigeration facilities as of January 2021. Addressing these challenges is crucial to ensure the efficient delivery of vaccines and safeguard public health.

Some alarming facts:

- Over **50%** of global vaccine wastage is caused by poor cold chain maintenance during transportation, says **WHO**.
- **71%** of **wasted vaccine** doses from unopened vials are due to unusable Vaccine Vial Monitors (VVM).
- Some countries have vaccine wastage rates as high as 25%, such as India, where it's estimated that **20-25%** of vaccines are **wasted annually**.
- According to a national assessment, vaccine wastage was high for most vaccines at the last cold chain point.

The COVID-19 pandemic has highlighted the importance of ensuring that vaccines reach every single person in the population. Reducing vaccine wastage is vital as it means saving precious lives and protecting vulnerable populations such as the elderly, those with pre-existing medical conditions, and essential workers who are at greater risk of severe illness. Every vaccine wasted implies one less person is protected against deadly diseases. Our innovation minimizes vaccine wastage and is just one small contribution to this larger effort. But we believe that every effort counts in pursuing a healthier and safer community for all.

Current Available Technology:

Ice Cooling Box:

Ice-packed Vaccine carriers are insulated containers that use coolant packs to keep vaccines and diluents cold during transportation. As the name suggests, the coolant packs contain ice. It is based on the physical process that the ice absorbs heat as it melts.

Cons:

- Ice packs only provide a limited amount of cooling time, and once they melt, they will no longer be effective in keeping the vaccines cool.
- The carrier must be refilled with new ice packs or recharged in a freezer, which may not be possible in remote or low-resource settings.
- Vaccines may freeze in case of an accidental direct contact with the Ice packs. This can damage the vaccines and render them ineffective.
- No alert System for abnormal temperatures outside the range of 2°C - 8°C.

Fig2: Ice Cooling Box

Emvólio:

Emvólio is a portable battery-operated refrigerator designed to carry vaccines and other payloads that require temperature-controlled storage and transport. The system provides a conducive environment for transport of vaccines and other thermally sensitive materials.

Cons:

- The rechargeable battery needs replacement every 10 hours, which is too short.
- Although it has a real-time temperature display, it is not connected to the cloud, rendering it useless.
- The outer layer is made up of Acrylonitrile butadiene styrene which is less durable and prone to physical damage, risking the vaccine's integrity.
- Its cost is prohibitively high at 1.3 lakhs rupees in India where the government's per capita expenditure on healthcare is only ₹1,815.

Fig 3: Emvólio

Our Solution:

Our solution (Vacsafe) is an active-cooling enabled vaccine transport box for long-distance vaccine transportation to the remote areas. We have used an endothermic chemical reaction with high enthalpy of reaction per mole of reactant. The dissolution of ammonium nitrate in water is used as the endothermic reaction to absorb heat from the vaccines.

- *Outer Insulated Box*
    - We have used a hard plastic box to provide physical protection to the vaccines and prevent the loss of heat through conduction.

- *Vacuum layer*
    - A 3mm thick vacuum layer is used between the outer hard plastic layer and the inner plastic water container, coated with aluminium on the inner side.

- *Water container*
    - An inner hard plastic container is used to hold water in contact with the inner vaccine container.

- *Entry and Exit pipe*
    - A pipe extending through the body of the container is equipped for refilling and cleaning purposes.

- *Vaccine container*
    - A lightweight aluminium vaccine container is used to hold the vaccines in contact with water and it also acts as a separator so that water spillage does not take place inside the vaccine vials. At the same time due to the high thermal conductivity of Aluminium, heat is transferred between the vials and the cooled-down water.

- *Temperature Sensors*
    - To constantly monitor the temperatures of the vaccine vials we are using ten NTC thermistors attached to the inner side of the vial containers with thermal paste. The microcontroller constantly checks the temperature of the vials.

- *Microcontroller*
    - The microcontroller is linked with temperature sensors and a solenoid mechanism. When the temperature reaches the higher threshold (which is 8°C for most vaccines), the solenoid mechanism is triggered, causing a specific amount of solute to dissolve in the water. It is operated by a 3.7 V battery.

- *Valve*
    - A solenoid valve is used for draining the water from the vaccine box and dropping a controlled amount of ammonium nitrate into water.

- *Ammonium Nitrate Container*
    - It is the circular box containing Ammonium Nitrate, with a volume of 1000 cm^3, which will hold up to 1.2 Kg of Ammonium Nitrate.

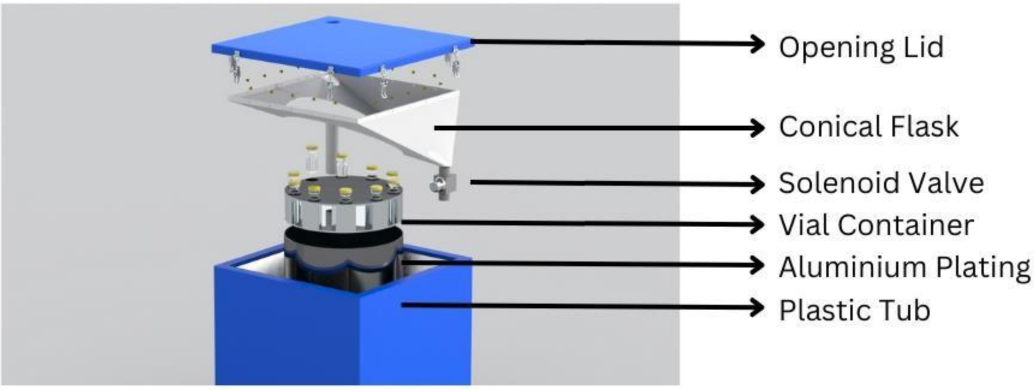


Fig 4: Explosion Sectional View of Our Solution

Design and Mechanism:

Hard plastic:
Our vaccine box features a 1 cm thick layer of hard plastic covered internally with a thin deposition of copper. Hard plastic was chosen after considering several materials based on thermal conductivity, weight and cost. The inner side of the hard plastic layer is covered with a thin deposition of aluminium which serves a dual purpose of providing a reflective layer to ward off radiative dissipation of heat and stops gassing of hard plastic that occurs when exposed to heat or vacuum.

Plastic tub:
The hard plastic tub will serve as the foundational layer for the inner vaccine box, which will hold water and provide stability for the ammonium nitrate box. Owing to the low thermal conductivity of plastic, the plastic tub will act as a thermal insulator, preventing heat transfer and preserving the water at its ideal temperature. The tub will also effectively prevent any leakage of water, which is crucial for temperature maintenance.

Water:
We use a simple reaction - dissolution of salt in water - to cool down our vaccine vials. We need to take one litre of water for the optimal case. The trade-off is that NH_4NO_3 has fixed solubility in water but with a higher amount of water it would need to cool down that volume of water. Running a solver, we arrived at one litre of water and 848g of ammonium nitrate.

Ammonium nitrate:
Ammonium nitrate consists of ionic bonds packed tightly together. When it comes into contact with water, the polar water molecules interfere with those ions and eventually make them disperse. It takes energy to do this, which is absorbed from the surroundings and makes the solution cold. While some heat is produced when the ammonium nitrate ions interact with the water molecules (i.e. an exothermic reaction), it is a lot less than what is needed for the water molecules to disperse the strong ionic bonds of the ammonium nitrate, so the overall process is an endothermic reaction, or one that absorbs energy from its surroundings. It's for this reasonthat solid ammonium nitrate is used in commercial cold packs, which are really just a mixtureof ammonium nitrate and water.

Solenoid valve:
We use a solenoid valve with a small form factor to fit in our vaccine box. Current is passed through the coil of the solenoid using a MOSFET driver that opens a ferromagnetic material used as a valve. The valve is opened for a specific time interval to allow a predefined amount of NH_4NO_3 to fall into the water container.

Controller:
We are using an ATMega8 to control the opening and closing of the solenoid valve. Each vial slot has a thermistor attached to it via thermal paste. We use a 10k Ohm NTC thermistor in resistive divider comunfiguration. There is one thermistor for each vial, hence 10 thermistors in total connected to the microcontroller through a 16:1 Analog MUX CD74HC-4067. A micro USB port is provided with a CP2102 FTDI USB to UART converter to upload code to the microcontroller. An N-channel MOSFET is used to drive the solenoid valve. A HC-05 Bluetooth module is used to provide error messages to the smartphone of the vaccine transporter over BLE 2.0 (Bluetooth Low Energy).

The microcontroller has a lookup table stored in EEPROM of amounts of NH_4NO_3 to be released into the solution for cooling based on the number of cooling cycles that has occurred. A state machine is implemented in the controller. There are two states: NORMAL and OVERTEMPERATURE. In the normal state the microcontroller reads the temperatures from the thermistors and stores them in an array. It also sends temperatures over BLE to the vaccine transporter. It checks each temperature to see if any vaccine vial has exceeded the upper temperature limit. If that condition happens an over temperature flag is set. On setting the 'ovt' flag, the state machine transitions to the OVERTEMPERATURE state where the solenoid valve is opened for a specific amount of time and the new height is computed. The microcontroller then returns back to NORMAL state and continues monitoring the temperature.

To save power, this entire process happens after every 15 minutes. For the rest of the time, the microcontroller is in power-down mode where it consumes 0.5 µA at 3V at 4 MHz clock speed.

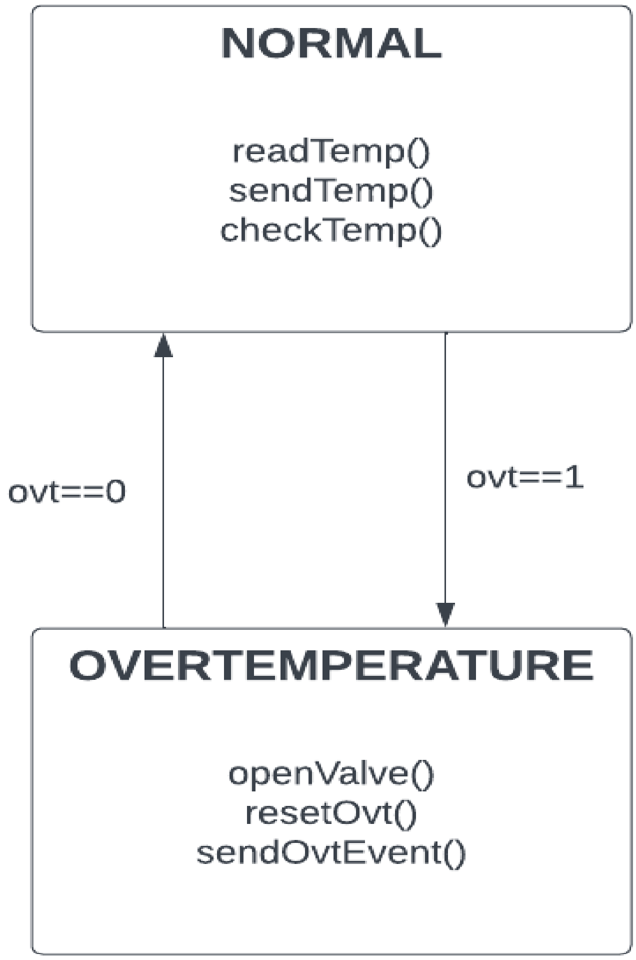


Fig 5 : State Machine of Controller

Product Specifications:

Category	Component	Function	Specification
Insulation Layers	Outer insulating layer	Structural protection, thermal insulation	1 cm hard plastic (polycarbonate)
	Vacuum chamber	Prevents conduction	3 mm thickness
	Aluminium plating	Prevents radiation of heat	PVD coating
	Inner insulating layer	Insulation, contains water	1 cm polycarbonate
Polycarbonate tub	Inner insulating layer	Base of inner layer	1 cm polycarbonate
	1L water.	Dissolves NH_4NO_3	-
Vaccine container	Aluminium container	Separation, conduction	2 mm 1000 series Al sheet, 14 cm dia, Length
Temperature sensors	10KΩ NTC thermistor	Measures temperature	10 KΩ nominal resistance
PCB	ATMega8	Microcontroller	-
	Solenoid valve	Opens orifice	3.7V, 9 Ω coil resistance
	HC-05	Bluetooth Module	BLE 2.0
	CD7D4HC4067	For 10 thermistors	16:1 analog mux
Salt	Ammonium Nitrate (NH_4NO_3)	Dissolution is endothermic	Enthalpy of dissolution = +25.7 kJ/mol
Lid	Hard plastic lid	Upper covering of box and insulation	1 cm hard plastic

Calculations:

The chemical reaction of Ammonium Nitrate when dissolved in water:

$NH_4NO_3 + H_2O \rightarrow NH_4^+ + NO_3^-$

ΔH (enthalpy of reaction)	25.7 KJ/mol
Molar Mass of Ammonium Nitrate	80 gm/mol
Specific heat capacity of water (c)	4.18 J/mol
Solubility of NH_4NO_3 in water (at 0° C)	118 g/100 mL
Vial water volume	25 mL

Our cooling system cools down the 10 vials of vaccines of 25 mL volume each by 5 deg C per cycle for a total of 8 cycles. Our calculation is based on the amount of heat absorbed versus the solubility of NH_4NO_3 in water. If we use more amount of NH_4NO_3 to make our product last more cycles, the amount of water needed to dissolve that amount of salt increases - we need to cool down more water and hence need more salt. We used a mathematical solver to find the optimal amount of salt and water needed.

Cycle No	Amount of salt in soln (g)	Amount of Salt Sent In (g)	Weight of Solution (g)	Energy for Temp Change (J)	Mol of Salt reqd (mol)	Amount of Salt Required (g)	
1	0	34.7927418	1284.792742	26852.1683	1.044831452	83.58651612	
2	84	37.21381157	1371.213812	28658.36866	1.115111621	89.20892969	
3	173	39.80335264	1462.803353	30572.59007	1.189594944	95.16759555	
4	268	42.57308818	1560.573088	32615.97754	1.269104185	101.5283348	
5	370	45.53555711	1665.535557	34809.69314	1.354462768	108.3570215	
6	478	48.70417087	1776.704171	37133.11717	1.444868372	115.5894698	
7	594	52.09327416	1896.093274	39628.34943	1.541959122	123.3567297	
8	717	55.71820983	2022.71821	42274.81059	1.644934264	131.5947411	
						848.3893382	g

Amount of salt needed = 848.39 g

Considering spillage, wastage, and operator error we consider amount of salt to be 1200 g.

Amount of surrounding water = 1000 mL

Number of vials in a box = 10

Energy Calculations:

Active mode :

Vop = 3.3V

I = 5 mA (3mA for microcontroller, from datasheet + 2mA for peripherals)

P = 16.5 mW

Operating time in active mode is for ~2s every 15 mins.

Energy in 96 hours = 16.5 * 4 * 96 = 0.768 J = 0.213 mAh

Sleep mode:

Vop = 3.3V, I = 0.5 μA (from datasheet) , P = 1.65 μW

Operating time is approximately all the time for every 15-minute sleep cycle.

Energy in 96 hours = 1.65 μW * 96 * 3600 = 0.57 J = 0.16 mAh

Opening of solenoid valve:

According to the amounts of ammonium nitrate to be dissolved every time, the time of valve opening can be calculated. The values are tabulated. The solenoid valve has a coil resistance of 9 **Ω**. We operate at 3.7 V. So the power needed for the solenoid valve is

P = V2R = 1.52 W

Cycle	**Time(s)**
1	0.39
2	0.50
3	0.63
4	0.78
5	0.95
6	1.2
7	1.53
8	2.01

Total time (in s) = 7.98

Total energy = 1.52 * 7.98 J = 12.138 J = 3.37 mAh

Total energy for 96 hours operation = 0.213 + 0.16 + 3.37 mAh = **3.734 mAh**

Cost Analysis:

	Unit cost (in Rupees)	Quantity	Total cost (in Rupees)
ATMega 8	45	1	45
PMV16XNR mosfet	9.77	1	9.77
16MHz crystal	17.52	1	17.52
CD74HC4067 16:1 MUX	52.00	1	52
HC-05 BLE module	189.00	1	189
SMD Capacitor	5.29	4	21.16
SMD Resistor	0.895	11	9.845
Relimate Connector	0.24	5	1.2
10K Thermistor	8	10	80
Thermal Paste	1.25/ml	1ml	1.25
Solenoid valve	169	1	169
CR2032 coin cell	9	1	9
Aluminum	450/kg	$V = \pi*(14.2^2 - 14^2)*19$ cm^3 $\varrho = 2.7$ g/cc W = 0.9 kg	405
Physical Vapor Deposition	1803/16-parts	1	112
Polycarbonate	25/kg	$V = 30^3 - 29^3$ cm^3 $\varrho = 1.2$ g/cc W = 3.1 kg	78
Ammonium nitrate	40/kg	1.2 kg	48
Total Cost of Production			**₹1250** (approx.)

Why our product ?

Climatic conditions also play a role in the cold chain logistics market. A large part of cold chain transport is seasonal in nature and requires multi-temperature fleets even on smaller vehicle platforms. Conventional units which are fixed on trucks need dedicated fleets making cold chain transportation unreliable or impossible for most products and package sizes in India. As we already know the fact that almost 70% of India’s population resides in Rural India Therefore, vaccine transportation is a hectic task in these distance-prone areas and this is well spread across the country due to this movement of small vehicles is not a feasible option and That’s why we came up with our idea of **Vacsafe** which offers a sustainable alternative to diesel-based transportation solutions and thereby reducing the overall impact on economy/environment. For example, Covaxin and Covishield require a temperature of 2-8 ^{0}C otherwise these vaccines will be affected by the Indian ambient conditions. Our solution allows enabling vaccine manufacturers and transporters to transport vaccines to the remotest corners of the country in dry ambient vehicles thereby helping make our country’s vision of inoculating every Indian a reality.

<u>USP:</u>

1) **Low wastage of vaccines:** A very accurate temperature range can be maintained by the device, which would reduce the number of vaccinations that are wasted as a result of poor temperature monitoring.

2) **Precise temperature control**: The device is designed to maintain a very precise temperature range, which is important for storing sensitive products such as vaccines, medications, or certain foods.

3) **Energy Efficiency:** The device is designed to be highly energy efficient, which would be appealing to businesses looking to save on energy costs and reduce their environmental impact.

4) **Durability:** The device is built to withstand tough environments and heavy use, which would be important for businesses that require a reliable and durable cold storage solution.

5) **Portability:** The device is designed to be lightweight and portable, which would be appealing to businesses that need to transport cold products from one location to other.

6) **Easy to Use:** The device is designed to be easy to use, with simple controls and intuitive interfaces, which would be important for businesses that need to train staff quickly and ensure consistent performance.

7) **Connectivity:** The device is designed to be connected to the internet or other devices, allowing for remote monitoring and control, which would be appealing to businesses that require real-time data on their cold storage operations.

Innovation:

The great majority of vaccinations are currently delivered in refrigerators between 20 and 80 °C, with a desired average of 50 °C. While UV light can harm many, it should also be adequately wrapped and protected from light. The issue we currently have, however, is that sometimes vaccine temperatures fall below the acceptable range due to human error, resulting in vaccine waste. To lessen the issue of wastage, we constructed a cold storage system where the vaccines' temperature is maintained through chemical reactions. It is an endothermic process that produces aqueous ions as by-products.

$NH_4NO_3 \rightarrow NH_4^+ + NO_3^-$

$NH_4^+ + NO_3^- + OH^- + H^+ \longleftrightarrow NH_4OH + HNO_3$

The temperature of the vaccines is kept constant thanks to this chemical process. Ammonium nitrate is once again released to maintain temperature as soon as it rises above the required range.

A special application – DTaP for infants:

The DTaP vaccine is administered to children from 6 weeks to 6 years of age to provide immunization against diphtheria, tetanus, and pertussis. It consists of diphtheria and tetanus toxoids (inactivated toxins) and acellular pertussis antigens. The tetanus component of the vaccine is about 5 to 10 levels of flocculation (Lf) units of manufactured tetanus toxoid. The diphtheria component is a manufactured diphtheria toxoid of about 15 to 25 Lf units. The acellular pertussis component of a DTaP vaccine consists of manufactured pertussis antigens called pertussis toxin, filamentous haemagglutinin, pertactin, and fimbriae type 2 and 3. Store diphtheria, tetanus, and pertussis vaccines refrigerated between 2°C and 8°C (36°F and 46°F). Temperature extremes may adversely affect resuspend ability of this vaccine. Store lyophilized vaccine packaged with a vial containing Diphtheria and Tetanus Toxoids Pertussis vaccine and reconstituted vaccine.

These infections can cause severe illness, long-term disability, and even death, particularly in infants and young children. Therefore, the DTP vaccine is crucial in preventing these illnesses and saving lives. Diphtheria is a bacterial infection that affects the respiratory system and can lead to heart and nerve damage. Tetanus is a bacterial infection that causes muscle stiffness, and spasms, and can be life-threatening. Pertussis, or whooping cough, is highly contagious and can cause severe coughing spells, difficulty breathing, and even pneumonia. The DTP vaccine is usually given in a series of five doses to children under the age of seven. The vaccine is also recommended for adults who may have never received the vaccine, or who need a booster shot to maintain their immunity.

If DTP vaccines are not properly transported, several consequences may occur. These are sensitive to temperature and light, and any deviations from the recommended storage conditions can lead to a loss of potency or even total vaccine failure. And it is extremely important in protecting individuals, especially young children, from life-threating bacterial infections that can cause severe illness and even death. It is an essential part of public health efforts to control and prevent the spread of these diseases.

Impact:

Overall, the benefits of using endothermic reactions in already existing technology system can include increased precision, maintains potency, extended shelf-life, prevention of degradation, long-term storage, and improved efficiency by controlling the reaction for sustaining the particular drop in the temperature range, which leads to reduced vaccine wastage which leads to reduced quality of life, patient safety concerns.

It's a major concern in today's world because World Health Organization reports over 50% of vaccine wastage around the world. The world's most extensive Universal Immunization Programme (UIP) in India targets 27 million infants and 30 million pregnant women every year.

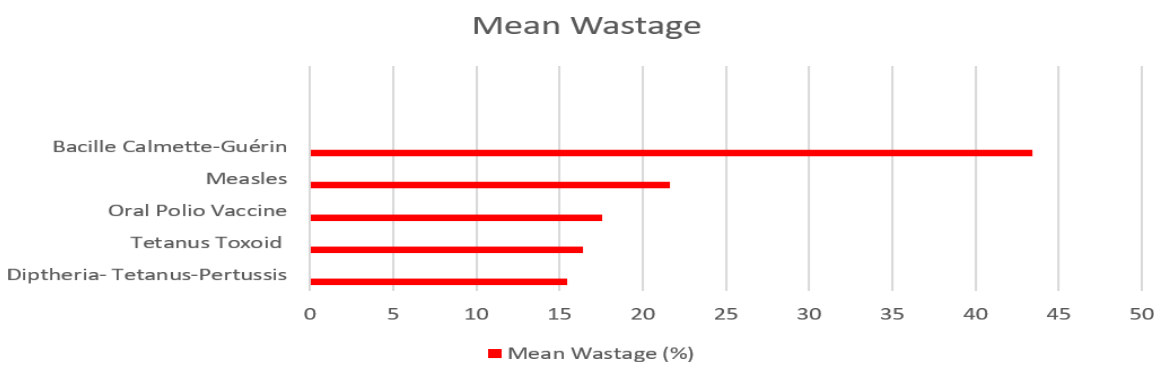
Vaccines are temperature sensitive and, therefore require refrigeration or freezing to maintain theirpotency and effectiveness. Additionally, refrigeration is not feasible in all conditions, such as remote or low-source areas which require a high amount of power consumption. Our solution consumes 6400 times less power than a standard refrigeration solution and can run on a small coin cell battery for 15940 hours on a single charge, subject to chemical refilling.

The coverage of UIP vaccines is more than 70% in 11 states; 50-70% in 13 states and below 50% in the remaining 8 states. One of the reasons for less coverage may be due to a programmatic error in terms of vaccine logistic management.

1. According to the WHO report, estimates 50% of vaccines get wasted, largely due to inefficiency in temperature control while storing & transporting. With this device, we can add up to 9-12 % of extra vaccines to the inventory which can potentially reduce 18-24 % of the waste produced.

2. For 96 hours, our product will cost 48 rupees, whereas the cost of refrigeration for the same volume using the refrigerator will be 57 rupees. Therefore, our product is 15.78 percent cheaper

3. Our Product keeps the temperature for 96 hours, 140% more than the original vaccine box which is 40 hours.



Future Enhancements:

1) Cold storage devices are used to keep products and materials at a specific temperature during transportation or storage. As technology advances, there are several potential ways in which our device can be used in the future.

2) **Vaccine storage:** Cold storage devices can be used to store vaccines at the appropriate temperature. As new vaccines are developed, they will likely have different temperature requirements, and cold storage devices will need to be adapted to accommodate these requirements.

3) **Food delivery:** Food delivery businesses might make use of cold storage equipment to keep their deliveries fresh. There will be a growing need for cold storage units that can keep food at a consistent temperature during transit as online ordering and meal delivery services continue to expand.

4) **Biopharmaceuticals:** Cold storage devices can be used to store biopharmaceutical products, such as antibodies and enzymes, which are highly sensitive to temperature fluctuations. As the biopharmaceutical industry continues to grow, there will be an increasing demand for cold storage devices that can maintain the temperature of these products during transportation and storage.

5) **Horticulture:** In horticulture, cold storage equipment can be used to preserve the freshness of plants and flowers while being transported. This may increase the products' shelf life and cut down on waste.

6) **Blood storage:** Cold storage devices can be used for the storage of blood and blood products. As the demand for blood products continues to grow, there will be an increasing need for cold storage devices that can maintain the temperature of these products during transportation and storage.

7) **Organ storage:** Three plastic bags and an ice box are currently the gold standard for donor organ preservation in clinical organ transplantation. The organ itself is enclosed in a preservation solution in the first plastic bag (e.g., Celsius). This bag is placed inside another one that has already been filled with saline, and the three of these are then placed inside an ice chest. This method's drawback is that the organ typically becomes overly chilly. It has been established that 4°C to 8°C is the ideal range for maintaining organs. Lower temperatures than 4°C increase the danger of cold injury with protein denaturation, whereas higher temperatures cause hypoxic impairment of the organ since the metabolism is not decreased effectively. In the current study, we investigated a device that keeps the organ temperature consistently in the desired range of 4°C - 8°C and can potentially decrease cold injury to donor organs.

ANNEXURE

Material Selection

Reflective covering for outer insulation:

	Density	Reflectivity	Cost	Availability
Aluminum	2.7 g/cc	0.86	180 Rs / kg	High
Copper	8.33 g/cc	0.9	900	Fairly common
Silver	10.49 g/cc	0.96	67000 Rs/kg	Common
Gold	19.32 g/cc	>0.97	5000 Rs/ gr	Rare

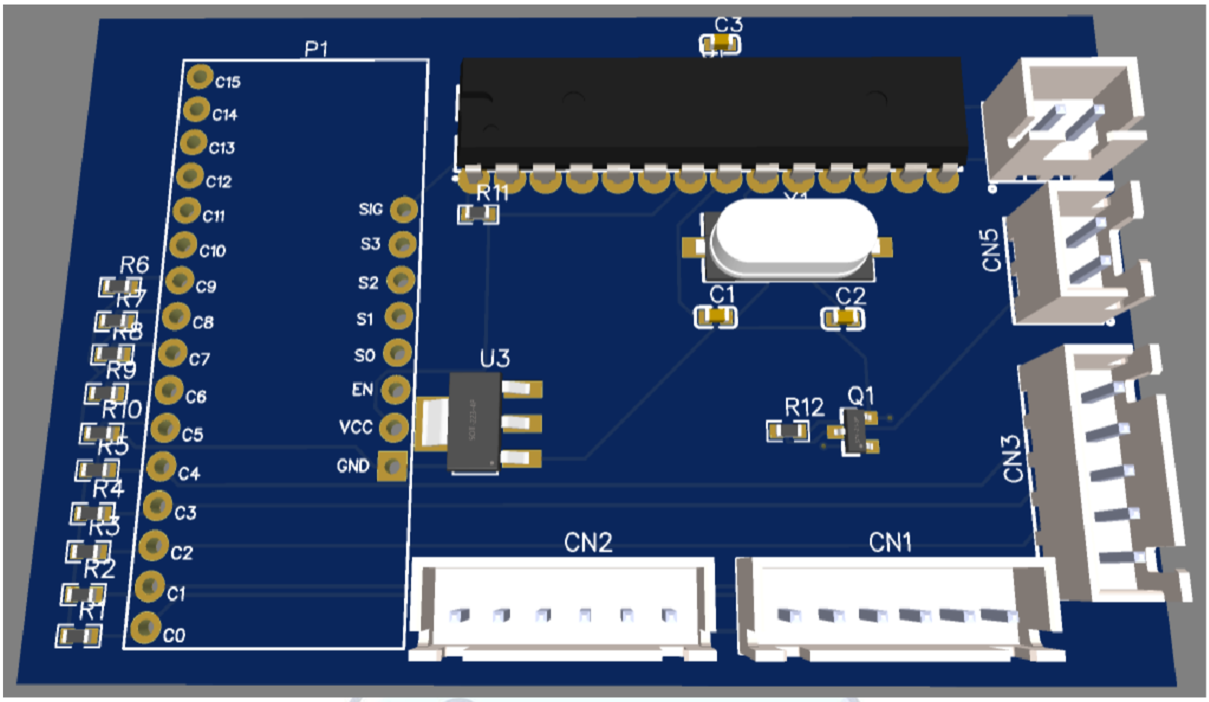
Materials for outer layer of box:

	Density (g/cm3)	Thermal conductivity (W/mK)	Young's modulus (Pa)	Cost (Rs/Kg)	Availability	Manufacturability
Brass	8.73	109	9e10	300	Yes	CNC
Polystyrene	0.96	0.150	0.12e10	85	Yes	Moulding
Hard plastic	0.9	0.19	0.24e10	25	Yes	Laser Cutter
Stainless steel	8	15	19e10	195	Yes	CNC
Aluminium	2.7	247	7e10	200	Yes	CNC

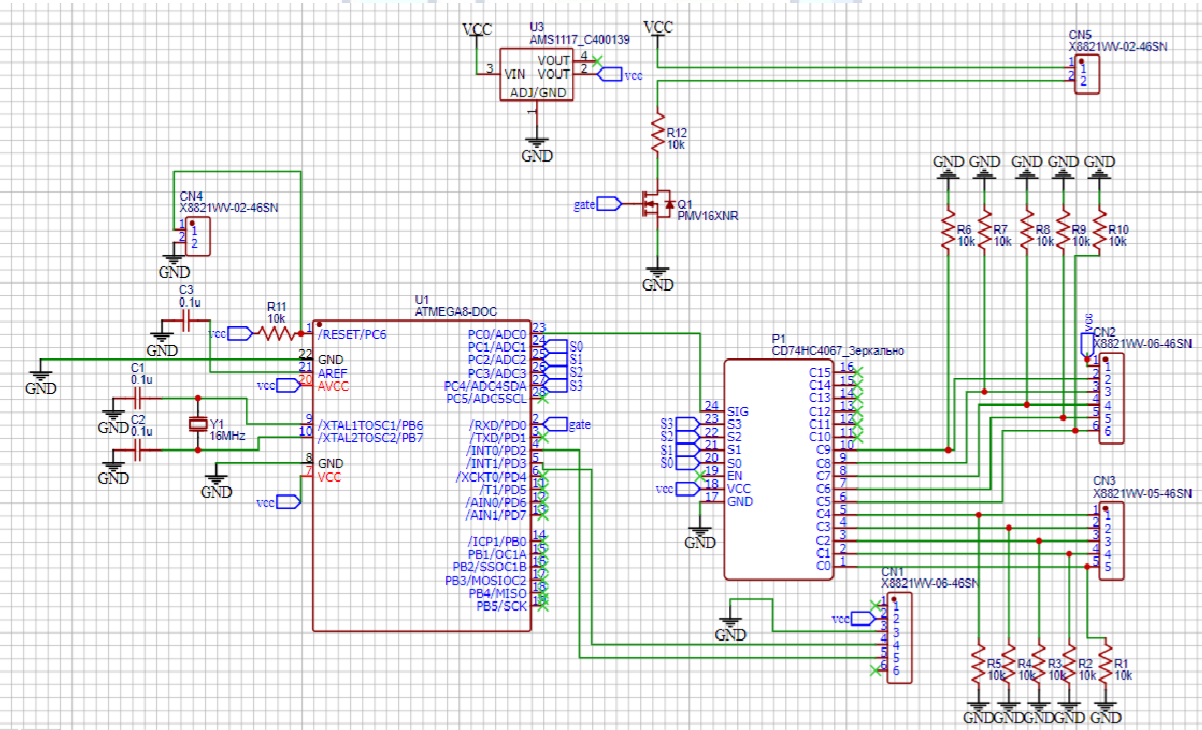
Materials for Vaccine container:

	Thermal Conductivity (W/m*K)	Cost (Rs/Kg)	Availability	Density (g/cm3)
Copper	398	900	High	8.33
Gold	315	4927441	Low	19.32
Aluminium	247	230	High	2.7
Tungsten	173	460	Low	19.25

PCB:



Schematic of controller:



Microcontroller

We selected the ATMega8 for our application. We had considered other microcontrollers like ATTiny85, ATTiny2313, and ATMega328P and more based on Program Flash, SRAM and EEPROM, ADC availability, Pinout requirements, and cost. ATTiny85 did not have enough pins to interface the HC-05 Bluetooth module using the Software Serial library. ATTiny2313 had enough GPIO ports but did not have any ADC. Instead, it had an Analog comparator, which could have been used but would have led to increased complexity. ATMega328P satisfiesall the criteria but we went with ATMega8 due to its low cost and exact match of other requirements.

It is an 8-bit microcontroller belonging to the AVR family of microcontrollers. It is built on RISC (Reduced Instruction Set Computer) instruction set architecture.
ATmega8 microcontroller consists of 1KB of SRAM, 8KB of flash memory, and 512 bytes of EEPROM.

Features-

- High-performance, Low-power Atmel AVR 8-bit Microcontroller
- Advanced RISC Architecture
    - 32 x 8 General Purpose Working Registers
    - Fully Static Operation
    - On-chip 2-cycle Multiplier
- High Endurance Non-volatile Memory Segments

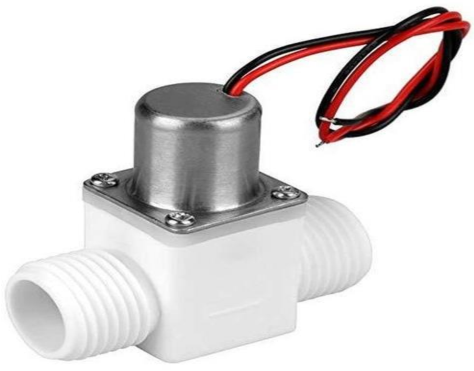
Another important selection criterion for ATMega8 was the availability of a power-down mode which consumes only 0.5 µA current at 3.3V at 4 MHz clock frequency.

Power Consumption at 4MHz, 3V, 25^0C

- Active: 3.6 mA
- Idle Mode: 1.0 mA
- Power-down Mode: 0.5 µA

Solenoid Valve

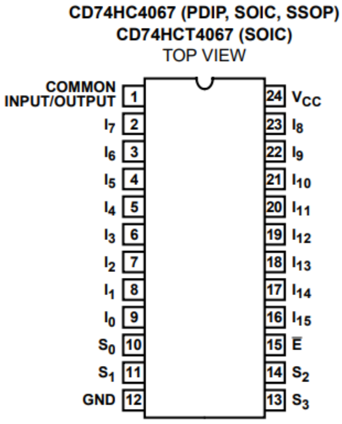
A solenoid valve is an on/off electromechanically operated valve which consists of an electromagnetic actuator (solenoid) and a valve body. The solenoid-plunger assembly is the valve actuator responsible for opening and closing the valve. This actuator can be arranged in such a way that the plunger action can either open or close only. There is no intermediate, or in-between position, so there is no way for a solenoid to throttle flow. The valve body consists of the pressure containing parts in-contact with the process fluid.



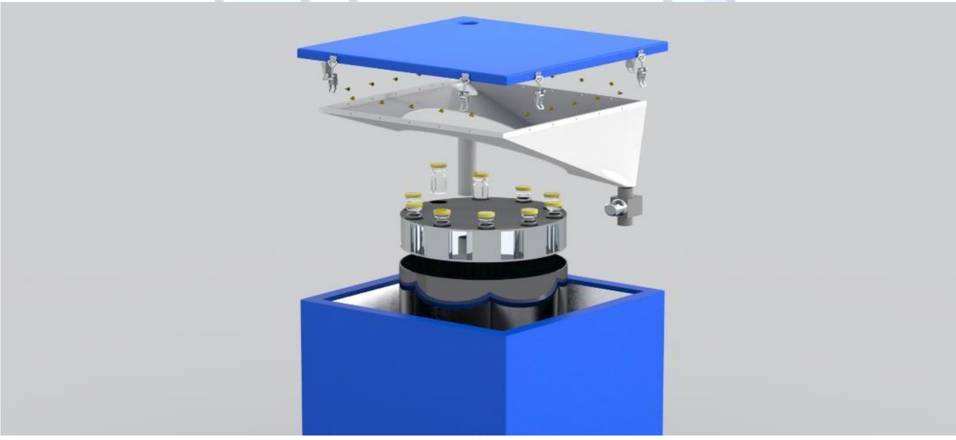
Multiplexer

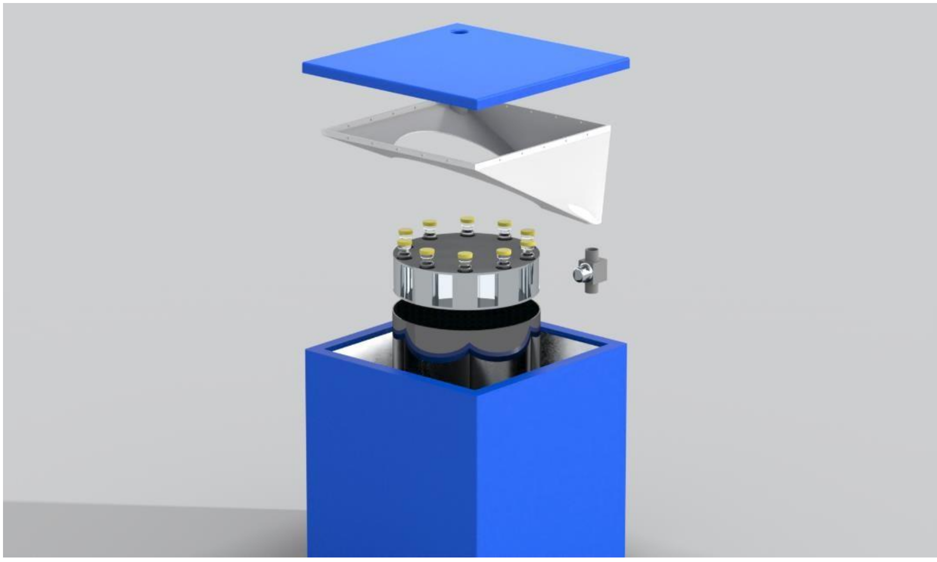
A multiplexer (MUX) is a network device that allows one or more analog or digital input signals to travel together over the same communications transmission link. The purpose of multiplexing is to combine and transmit signals over a single shared medium in order to optimize efficiency and decrease the total cost of communication.

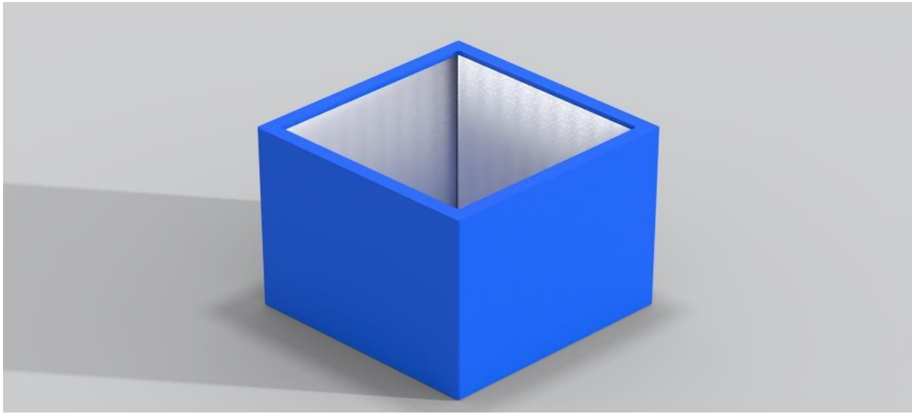
We have selected the 16:1 MUX based on cost.

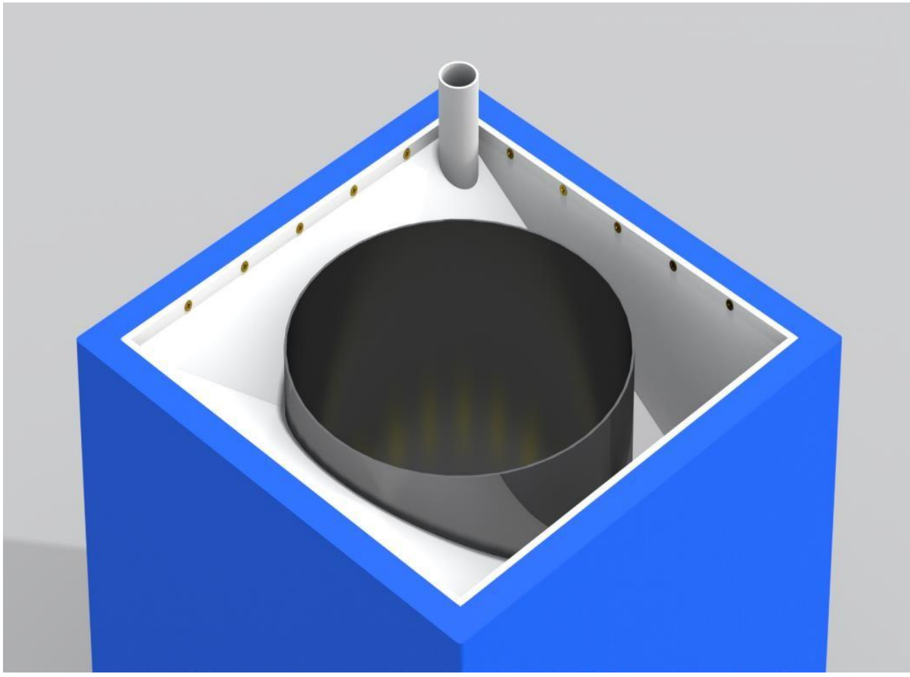


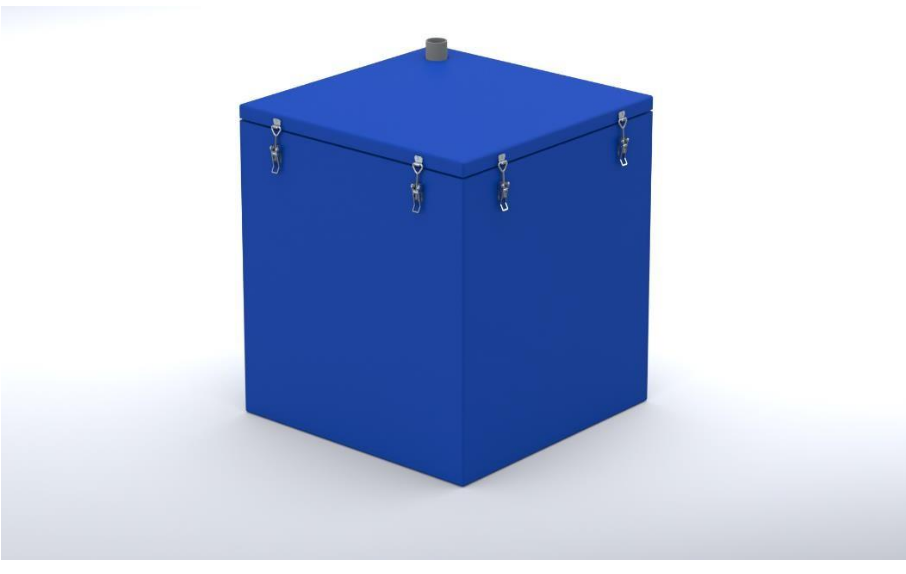
Various Cross Section of Our Product











Firmware

```
#include <math.h>
#include <SoftwareSerial.h>

#define rxPin 2 //PD2
#define txPin 3  //PD3
#define interruptPin0 8 //PB0 --> PCINT0

#define g 980  //cm/s^2
#define SOLENOID 13 //PB5
#define S0 15 //PC1
#define S1 16 //PC2
#define S2 17 //PC3
#define S3 18 //PC4
#define T_PIN 14  //PC0
#define STATE_NORMAL 0
#define STATE_OVERTEMP 1

SoftwareSerial hc05BLE = SoftwareSerial(rxPin, txPin);

float amounts[8]= {83.59, 89.18, 95.15, 101.52, 108.32, 115.57, 123.31, 131.57};  //in grams
float temp[10];
float Ao=3.14*pow(4/2,2);       //area of orifice (cm^2)
float Ac=3.14*(pow(16.6,2)-pow(14.2,2));       //area of container (cm^2)
float h=5;      //cm
float rho = 1.74; //density (g/cc)
int ovt, unt; //overtemperature and undertemperature flags (0 --> normal, 1 --> fault)
int ncycle=0;
int state;

float thermistorCallib(int adcRead);
int calcOpenTime(int saltWeight);//calculates the time in miliseconds
void updateHeight(int timeSeconds);
void readTemp();
void checkTemp(); //sets ovt and unt flags
void openValve();
void sendOvtEvent();
void sendTemp();
void sendToSleep();

void setup() {
  pinMode(SOLENOID, OUTPUT);
```

```
  pinMode(S0, OUTPUT);
  pinMode(S1, OUTPUT);
  pinMode(S2, OUTPUT);
// pinMode(BUZZER, OUTPUT);
  pinMode(rxPin, INPUT);
  pinMode(txPin, OUTPUT);

  state=STATE_NORMAL;
}

void loop() {
  switch(state)
  {
    case STATE_NORMAL:
      readTemp();
      sendTemp();
      checkTemp();
      if(ovt==1)
        state = STATE_OVERTEMP;
      else
        sendToSleep();
      break;

    case STATE_OVERTEMP:
      openValve();
      ovt=0;
      state=STATE_NORMAL;
      break;
  }
}

float thermistorCallib(int adcRead)
{
  return (float)adcRead;
}

int calcOpenTime(int W) {
  int timeSeconds = W/(rho*Ac*sqrt(2*g*h));
  return (int)(timeSeconds*1000);
}

void updateHeight(int timeSeconds){
  h = pow((sqrt(h) - (Ao/Ac)*sqrt(g/2)*timeSeconds),2);
}
```

```
void readTemp() {
  for(int i=0;i<10;i++)
  {
    digitalWrite(S0, (i & ( 1 << 0 )) >> 0);
    digitalWrite(S1, (i & ( 1 << 1 )) >> 1);
    digitalWrite(S2, (i & ( 1 << 2 )) >> 2);
    temp[i] = thermistorCallib(analogRead(T_PIN));
  }
}

void checkTemp(){
  for(int i=0;i<8;i++)
  {
    if(temp[i] > 8){
      ovt=1;
      return;
    }
    if(temp[i] < 2){
      unt=1;
      return;
    }
  }
}

void openValve(){
  int saltWeight = amounts[ncycle];
  int timeMiliseconds = calcOpenTime(saltWeight);
  digitalWrite(SOLENOID,1);
  delay(timeMiliseconds);
  digitalWrite(SOLENOID, 0);
  updateHeight(timeMiliseconds/pow(10,3));
  ncycle++;
  sendOvtEvent(timeMiliseconds/pow(10,3));
}

void sendTemp(){
  hc05BLE.println("Current temperatures (in deg C)...");
  for(int i=0;i<10;i++){
    hc05BLE.println(temp[i]);
  }
}

void sendOvtEvent(float tempSeconds){
```

```
  hc05BLE.println("Overtemperature event occured");
  hc05BLE.print("Valve opened for ");
  hc05BLE.print(tempSeconds);
  hc05BLE.print(" seconds");
}

void blink() {
  sleep_disable();//Disable sleep mode
  detachInterrupt(interruptPin0);
}

void sendToSleep(){
  sleep_enable();//Enabling sleep mode
  attachInterrupt(digitalPinToInterrupt(interruptPin0), blink, FALLING);
  // * The 5 different modes are:
  // * SLEEP_MODE_IDLE -the least power savings
  // * SLEEP_MODE_ADC
  // * SLEEP_MODE_PWR_SAVE
  // * SLEEP_MODE_STANDBY
  // * SLEEP_MODE_PWR_DOWN -the most power savings
  set_sleep_mode(SLEEP_MODE_IDLE);
  sleep_cpu();//activating sleep mode
  // Serial.println("just woke up!");//next line of code executed after the interrupt
}
```

Impact Guesstimates –

Vaccine wastage estimated by WHO is around 50%. According to the WHO report, a large part of this wastage occurs due to a lack of temperature control. Hence, we have assumed 60-80% of the wastage is due to this factor alone. Our product primarily serves the population living in Tier-3 areas (remote rural India), and makes up about 30% of the total vaccine consumption in India. Therefore, this device would potentially reduce vaccine wastage for this geographical segment.

50% x (60 to 80) % x 30% = 9 to 12% Extra vaccines added to inventory

As we are adding 9 to 12 % extra vaccines and earlier 50 % was getting wasted, we are essentially obtaining a (9 to 12%)/50% = 18-24% of reduction in vaccine wastage numbers.

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