Viability of Thermoelectric Cold Preservation for Developing Rural Applications

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Abstract-- **The importance of refrigeration is fundamental in meeting the United Nations Millennium development goals, particularly for the millions of the world's poor living in the tropics. dissigno set out determine the physically viability to produce sufficient refrigeration from manual power generation to preserve food. Thermoelectric cooling has been overlooked as a viable alternative because of its relative inefficiency. However, the efficacy of keeping a cooler in preservation temperatures through human power is a viable alternative. Several other preferred energy sources were evaluated for the viability measured against a set of specifications. Thermoelectric cooling will provide a viable method to preserve all ready cryogenic products.**

I. INTRODUCTION

The power of refrigeration for medicine and food preservation has been widely used in the developed world since the industrial revolution. The dependence on refrigeration is even more vital and elusive in developing communities. An estimated 31% of food in the developing world is perishable with less than 1/5th of that refrigerated. That leads to substantial losses post harvest [7].

Refrigeration in the medical community is used to transport medical supplies and most notably vaccines. Refrigeration can be linked to increased life expectancy through disease eradication. Environmental benefits include a smaller reliance on costly and scarce refrigerants. The economic viability of refrigeration includes the sale of goods, services, and maintenance of equipment [7].

II. EXPERIMENT

This research is focus on identifying established thermoelectric technology to determine the viability for preservation, refrigeration, & cryogenics. The passive heat loss associated with an insulated container will be considered. A thermoelectric device, if available, will be specified to overcome the passive heat loss for preservation. The energy power requirements will then be evaluated against several identified appropriate renewable energy generators. The research will then identify the viability of thermoelectric systems with energy sources for both refrigeration and cryogenic storage.

A. Assumptions

All of the computations and discussions will be based on the following assumptions. Preservation will be the ability to maintain temperatures between 0°C to 8°C. Refrigeration will be defined as lowering an ambient temperature of water to the preservation (8°C) temperature. Cryogenics will be defined less than 0°C. All calculations, except where noted will be at sea level, ambient temperature of 25 C, relative humidity of 80%.

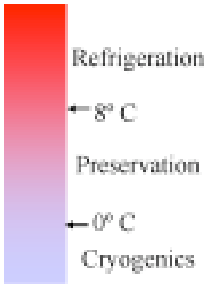

Figure 1- Graphic Illustration of Refrigeration Scale

Preservation viability is defined to meet or exceed the following specifications:

- Affordability: <$350 USD 2006 Retail
- Portability: <25 kg
- Size: >2 liter capacity
- Self-Sufficiency: No consumable fuel source

B. Preservation via Peltier

Preservation is defined as 1 liter of liquid water at 0 C to maintain temperature indefinitely below 8C at the assumptions listed above.

Peltier devices are commonly known as thermoelectric cooling (TEC). The cooling effect was discovered in 1834 by French scientist Jean Peltier. The phenomenon is the result of current flow at the junction of dissimilar conductors. The current flow through appropriately doped semi-conductors will either absorb or reject heat. [3]. This research will focus on giving a practical perspective on the technology and how it relates to developing rural communities. Under a DC power the TEC device will absorb heat on one side and conversely reject it on the other.

Subsequently, solid state refrigeration has become a viable alternative when precise temperature control, size, durability, & reliability are deciding factors. The TEC that are available commercially have several product lines that will be viable for preservation. The lack or refrigerants as compared to TEC's will become a stronger deciding factor as environmental impact is strongly considered in product selection.

TEC devices typically are made of the semi-conductor Bismuth Telluride. It is important to note that the precision of this manufacturing process currently only exists in a few places worldwide. Although the volume of manufacturing appears to be large, there also appears to be few suppliers.

This will create difficulty distributing the technology to remote rural villages. However, the scarcity of this commodity also will create a demand for TEC's driving a lower global cost. In addition, the scarcity provides developed world companies defensibility of the product by holding licensing through low cost availability of the technology.

Preservation by TEC is dependent on several factors most notably a relatively large amperage flow. This paper will begin by sizing a TEC to expel more heat than absorbed in a box defined above. The devices that can meet the heat rejection demand will then be weighed against the predicted energy generation defined above. The commercially available products that meet the heat rejection and power consumption requirements will be compared to the viability standards listed above.

C. Passive Heat Loss

The passive heat loss will be estimated using a cylinder container to minimize surface area for volume. The container will have an estimated thermal conductivity of 0.035 W/m*K. The containers void will be considered to have water at specified temperature. To meet the specification of 2 liters the size of the cylinder was to exceed the 2 liter of water capacity. The geometry chosen for this project was an internal diameter of 115 mm and height of 205mm. An increase in insulation also increases the surface area. Therefore unlimited insulation will actually be theoretically detrimental to the system.

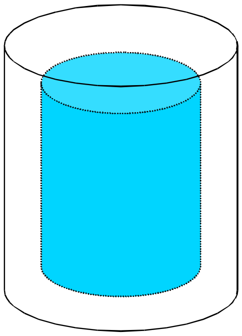

Figure 2- Insulated Container

A cursory study of commercially available coolers suggests an average of insulation of 25 mm. This insulation thickness will give up over 30% more heat assuming a similar thermal conductivity.

Figure 3 shows the passive heat loss as a function of insulation thickness at 25 C. The optimal insulation thickness is independent of ambient temperature. An increase in insulation also increases the surface area. Therefore unlimited insulation will actually be theoretically detrimental to the system. It can be seen in Figure 3 that optimal point on the least passive heat loss occurs at 71 mm. Figure 3 also suggest that the passive heat loss at optimal insulation thickness is approximately 4.7 W.

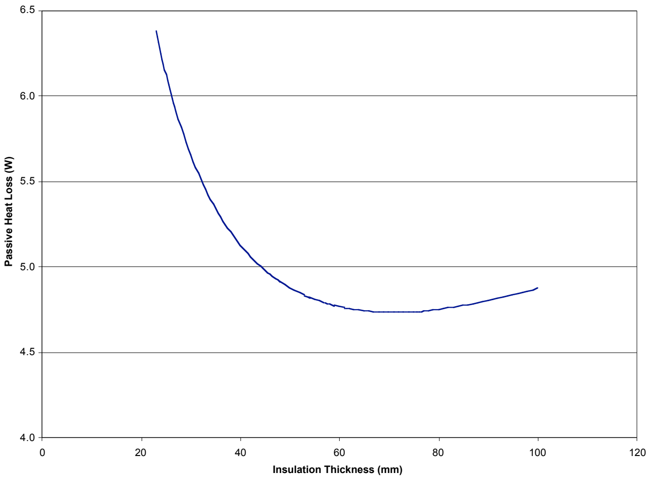

Figure 3- Insulation Point for 2 liter Geometry

The novelty of this design will incorporate the ability to switch between heat pumping and insulation modes. Existing TEC cooling will not function when the power source is removed. The energy creation devices discussed will cycle. Therefore the cooler will use a proprietary design to move from heat pumping to temperature preservation. Existing designs when not heat pumping will reverse and begin to pull heat into the system.

D. Energy Creation

Energy creation will be limited to power generated without access to traditional grid electricity. The power must be reliable and repeatable. The theoretical power generation will be expressed in Volt-Amperes, (VA).

1) Electricity

a) ***Human/Animal Power***

There are commercially available hand and pedal powered generators. The typical average continuous power that can be generated by pedaling the Human Power Generator is estimated at about 125 watts. The maximum power obtainable through hand cranking typically is about 50 watts [6]. Limited documented research is available for torque and revolutions per minute that are capable. The DC motors that are used in these generators typically are limited by nearly 10 Amps at 12 Volts. The relationship between Amperage and RPM for a low RPM low DC permanent magnet motor is linear. At the maximum RPM of the generator maximum amperage is above 10A at 12V power for a theoretical maximum of 120VA.

The power produced is dependent on the physical characteristics of the human/animal. The amount of energy produced without rest is critical to determine the viability of this energy source. Figure 4 demonstrates healthy humans and First Class Athletes ability to produce power (horse-power) until exhaustion.

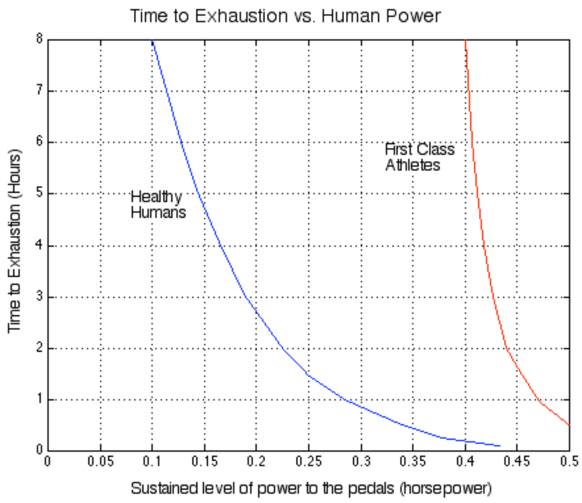

Figure 4- Power until Exhaustion [13]

The AZTEC model was used to determine the maximum TEC heat pumping capability of Human/Animal pedal; power. To meet the affordability target the largest generator available $259 USD will have a maximum of 10 A. Therefore the amount of heat transfer will be limited by 10 amperes at a theoretical power limit of 125 Watts. The Thermoelectric Cooling software [5] was used to identify TEC devices that could meet the required 4.7 W of passive heat loss at less than 10 amperes. The selected TEC was UT-15-7-30-F2 (2 Series). The model predicts power input of 129W at 10A with a COP of 0.389 for a heat pumping capacity of 50.2 W. This is significantly higher than the 4.7 W required overcoming passive heat losses.

Figure 5 depicts the temperature profile for the selected geometry at defined ambient conditions. The control strategy will require the temperature to be below 8C. At the 8 C point, the human/animal power (in not stored) will be requiring 125 W [0.16 hp] of power for 24 minutes. Figure 4 show a healthy human should be able to produce 0.16 hp for more than four hours. The 24 minutes [0.4 hours] required is much less and therefore could be accomplished by a healthy human. The amount of energy required is so significantly less that multiple units or larger systems could be considered.

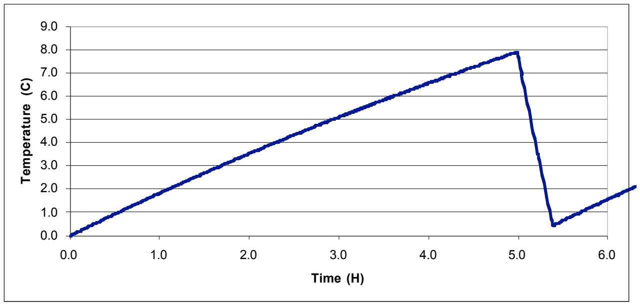

Figure 5- Temperature Profile for Bike Power

A series powered TEC appears to have sufficient power limited by both amperage (human power) and voltage (Bismuth Telluride). A balance of TEC cost and environmental impact of batteries will dictate a final design.

The cost is $250 USD 2006 retails for 10 A 12 V DC motor.

The generator selected for pedal power was used for hand power. The Thermoelectric Cooling software [5] was used to identify TEC devices that could meet the required passive heat loss. The selected TEC was UT8-12-25-F2. The model predicts power input of 48.6W at 5A with a COP of 0.62 for a heat pumping capacity of 30.2 W.

Figure 6 depicts the temperature profile for the selected geometry at defined ambient conditions. The control strategy will require the temperature to be below 8C. At the 8 C point, the hand crank will be requiring 50 W [0.06 hp] of power for 42 minutes. The amount of time until exhaustion for hand cranking is unknown.

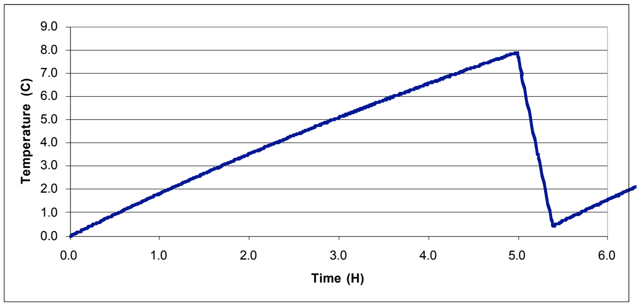

Figure 6- Temperature Profile for Hand Power

b) Photovoltaic Cells

Photovoltaic cells could be used to generate electricity and then drive a TEC device. The purchase costs for small solar applications are approximately $10/W USD. The amount of produced amperage from a photovoltaic cell will limit the heat pumping capability of the TEC. To meet the pricing requirements the panel for purpose of this project will be a 40 Watt panel with a 2005 $250 USD cost.

Electrical Characteristics: Power (max) 40 Watts, Voltage (peak) 17.3 Volts, Current (peak) 2.31 Amps [4]. The AZTEC software identified PT2-12-30 to meet the electrical characteristics. The model predicts power input of 16.7W at 1.6A with a COP of 0.60 for a heat pumping capacity of 10 W. This is substantially less than human powered generators however they will not rely on time to exhaustion for humans. Figure 7 depicts a recovery time of 183 minutes. That is within the average amount of daily sunlight for some communities. Therefore, solar is a viable alternative.

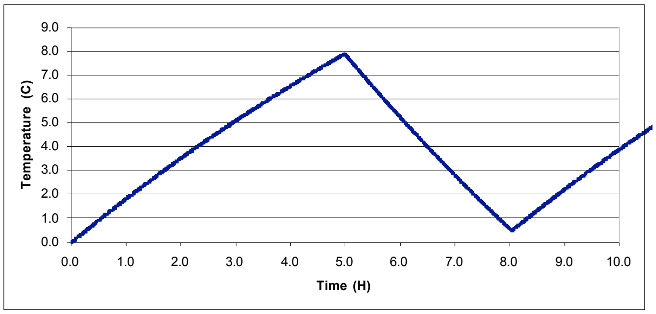

Figure 7- Temperature Profile for Solar

c) Kinetic Flow

Kinetic flow electricity is defined as running a fluid across a collector with kinetic energy source, typically water or wind. The power consumption, less than 5 kW, of the TEC device is defined as pico-power. The power is calculated in equation (1) where theoretical power is given a P, where Q is flow rate, H is head, and g is gravity.

$$P = gQH \tag{1}$$

Energy lost in the efficiency of the system is estimated at 50% [12]. The cost of these systems can be small when in the very small power production needed. The viability of this as power is dependent on a minimum of water/wind flow and head constant defined in conclusions. The AZTEC model identified CP1.4-17-045- L to meet 4.7 W passive heat loss will require 6.5 W Power in, 5.54 A, 1.3 V . Equation 2 shows the head-flow constant needed to meet the minimum heat pumping. The constant using power [P] of 6.5 W and gravity [9.81 m/s^2] gives a constant of 0.7 kg m/s. Assuming an efficiency of 50% [12] the constant will be 1.4 kg m/s.

$$\frac{P}{g} = QH \tag{2}$$

The viability relies directly on geographic and meteorological conditions to meet the constant. Therefore, the kinetic fluid power is viable however; the specifics of performance must be done by individual cases. The supply of kinetic fluid swings by day and by season. The amount needed may not be available in the hot season. In addition, refrigeration must compete for this power over other energy needs.

d) Cathodic Sacrifice Current

Commonly known as a saltwater battery, cathodic sacrifice current can produce a small amount of power for a finite period of time. A commercially available product, Environ-Gen, suggests that the battery is limited to 40 Amp hours of use. This product has a production cost of about $1/Amp Hour. The fuel usage would not make affordability possible for simple refrigeration and it will not work with the viability standard of having a consumable fuel source. Although not practical today, this technology may become viable in regions located near salt water as the production and distribution of Magnesium is more available.

e) Seeback electric generator

The Seeback electric generator is a reverse of the Peltier device. The electric loss to convert heat to electricity and back to heat is significant. The major benefit of the Seeback generator is the solid state design that will be very reliable. The 4.5% power efficiency can produce and open circuit voltage of 2.8 Volts and 8 Amps. The dismal energy efficiency is contrast to the simplicity, reliability, and overall abundance of cooking fuels. However, the limiting factor will be the ability to meet the 9.54 W/sq cm heat flux. An estimated heat flux of the sun at sea level with no cloud cover is 0.035W/sqcm. The Seeback generator will therefore need more than 270 times the heat flux of the sun. This would suggest that a sunlight concentration device would have to have more than 270 times the surface area to concentrate.

Given the relatively, small surface area the Seeback device this may be viable during peak solar radiation. The limitation is the device could only work during part of the day at a minimal power output. There may be applications to match this technology but they will be exceptions. Areas where there is industrial waste heat or residential heat wasted from cooking there could be a captured for a viable electrical alternative.

III. CONCLUSIONS

The many variables associated with renewable power for refrigeration makes a definitive decision difficult. Thermoelectric Cooling (Peltier devices) have been overlooked due to their dismal energy efficiency. However, the solid state design, reliability, and ability to preserve cold temperatures make them effective. The dissigno design of switching between heat pumping and insulation modes makes the TEC device a viable alternative. The economic, cultural, & climactic conditions of the installation environments will dictate the success of TEC as cold preservation.

Cold storage devices in developing especially hot <25 C areas are under insulated. The lack of insulation is using 30% more energy. Optimal insulation thickness is of dimensioning return near the optimization point. Therefore, the increase insulation thickness and subsequent cost may not justify optimal insulation. However, the heat loss is so critical that education of care for coolers may make a substantial difference in passive heat loss.

Human Powered preservation is a viable option. The efficiency is overcome by the ability to substantially pump more heat out than is passive let through the system. The user will have to ride the system for 24 minutes every 5 hours. Additional, riding will then begin to store energy as ice. The specific heat energy was not reviewed in this paper.

Solar refrigeration will also provide a viable alternative for TEC refrigerators. The energy will have to be store as either electricity (batteries) or thermal (ice) for times when the solar power is unavailable. The benefit is that during darkness temperatures tend to fall dramatically and therefore will require less heat pumping capability.

Seeback electricity and cathodic sacrifice current are not viable TEC solutions today. However, these technologies are changing and may be work in specific instances and require additional research.

Additional research should be done to study refrigeration and cryogenic conditions. The viability to indefinitely preserve ice as outlined in this study will have a dramatic effect on the ability to product and store ice. Therefore, further research should be done to combine technologies to produce, use, and store below freezing materials.

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