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An Alternative Option for Milk Cooling-Thermoelectric Cooling-A Review

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ABSTRACT

Typically milk is chilled by using refrigeration systems such as bulk milk cooler, cold storage, cooling rings, surface coolers ice cones, ice bank cooling, direct expansion cooling which is not cost effective and energy effective as it involves bulky piping and mechanical compressors. This refrigeration system produces a cooling effect by using refrigerants like freon, ammonia, etc., which leads to global warming and also these systems are not reliable and economical, where compact design and noiseless operation is required. Existing cooling methods are only suitable for cooling large quantity of milk and it is also uneconomical to use for small holder dairy farms. To overcome these problems (small quantity milk producer, delayed milk cooling and global warming due to refrigerants), there is a need for energy efficient, green and eco-friendly technologies to cool the milk to 4℃ immediately after milking for small scale level. Thermoelectric cooling is one of the convenient options to lower the temperature of the milk to a desirable temperature of 4℃ at farm level as an alternative to a conventional cooling system. Thermoelectric devices are solid state devices, meaning that doesn't have any moving parts and have a lot of applications in different fields like food preservation and processing, storage applications, electronic cooling, military field, automobiles cooling, pharmaceutical products storage, air conditioning and refrigeration field.

Keywords: Thermoelectric cooling; Milk cooling; Cooling methods; Milk cooling; Temperature

INTRODUCTION

Thermoelectric refrigeration works on the principle of Peltier effect. Jean Peltier, a French physicist found the Peltier effect in 1934. It is reverse of Seebeck effect. When a direct current is passed around a circuit of different materials, one junction gets cooled and another junction gets heated. This is known as Peltier effect. Due to Peltier effect phenomenon, thermoelectric coolers are more advantageous than heat pumps and refrigerators. A Thermoelectric (TE) cooler is a semiconductor based electronic component. On application of DC power with less voltage, heat is transferred through the TEM. Hence, a thermoelectric module is used for heating and cooling. Therefore, it makes it applicable for applications of accurate temperature control. When compared with a mechanical refrigeration unit, a doped semiconductor material is used instead of a liquid refrigerant in a TEC. Further, a finned heat sink is used instead of a condenser and a power source (DC) is used instead of the compressor.

A TEC comprises a p-type and n-type semiconductor and copper wires that are used to connect the semiconductors. The number of thermoelectric pairs in the module is based on

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the application. Bismuth telluride is commonly used semiconductor. Materials such as Skutterudite were proved to provide improved results in certain conditions. A Peltier module has two external ceramic plates that are separated by semiconductor pellets. When a current is passed through these micro conductor pellets, one of the plates absorbs heat and dissipated by the other plate.

When compared with a mechanical refrigeration unit, the doped semiconductor material is used instead of a liquid refrigerant in a Thermoelectric Cooler (TEC). Further, a finned heat sink is used instead of a condenser, and a DC power source is used instead of a compressor.

The present research work aims to provide an eco-friendly, affordable milk cooling using Peltier effect to avoid delay in chilling of raw milk for small farm (domestic) levels to increase shelf life and maintain quality of milk with the following objectives.

LITERATURE REVIEW

Milk Production

India is the world's largest milk producer with 198.4 million tons during 2019-20, accounting for 17% of the global milk production. The annual growth rate of milk production is 6.3% per year in the last 6 years, whereas the world growth rate is 1.5% per year. The per capita availability is increased to 406 grams from 281 grams.

With a daily production of 206 lakh liters, Tamil Nadu ranks among the top 10 milk producing states in the country. The state has a thriving milk cooperative sector, with milk producers cooperative societies located throughout the state. There are 12,585 milk producers' cooperative societies with a total membership of 20.30 lakh milk farmers. During the 2018-19 financial years, the average milk procurement through the 19 district cooperative milk producers unions was 33.23 (in lakh liters).

The Indian dairy industry engages in the production and processing of milk and cream. This industry is involved in the manufacture of various dairy products like cheese, curd, yoghurt. The Indian dairy industry specializes in the procurement, production, processing, storage and distribution of dairy products. India as nation stands first in its share of dairy production the international scenario. The industry contributes about Rs. 1,15,970 crores to the national economy. In India, milk is procured through village level societies under the co-operative dairying system the majority of these cooperative societies are located far from the milk processing unit and lack proper milk cooling facilities. This is a limiting factor that causes milk to deteriorate in quality and has a shorter shelf life. To stop bacterial growth and improve milk quality, raw milk should be cooled immediately after milking.

Importance of Milk Cooling

Milk leaves the udder at body temperature containing only a few microorganisms. The number increases rapidly at this temperature, if growth is not controlled immediately by chilling the milk. Chilling is necessary after receiving milk at collection/chilling center. Chilled milk can easily and safely be transported without having appreciable deteriorative changes due to microbial growth. Thus, raw milk is chilled to;

- Limit the growth of bacteria.
- Minimize micro induced changes.
- Maximize its shelf life.

However, chilling of milk involves additional expense which increases the cost of processing. Importantly, chilling process does not kill microorganisms nor it renders milk safe for human consumption. It is only a means of checking the growth of microorganisms for a certain period.

Milk Cooling Facilities for Milk Cooling

To prevent deterioration, milk and milk products must be refrigerated at all stages. As a result, refrigeration has a critical application in the dairy industry. Shelf life and quality of milk can be extended by cooling it immediately after milking and maintaining a cold chain until it reaches the user. Raw milk stored at tropical atmospheric temperatures will deteriorate in quality, resulting in milk spoilage within 4 to 6 hours of milking due to the rapid growth of bacteria.

Kumar, et al., discussed the different options available for milk chilling systems at the village level such as refrigerated transport of milk and milk [2]. They reported on the current state and future prospects of the refrigeration system in the Indian dairy industry. Among the other options the suggested that the vapour absorption refrigeration technology is best for the dairy industry.

Different Methods and Systems Followed for Milk Cooling

Wilster, et al., reported different farm level cooling systems (hydro-vac cooler, surface cooler, sprinkler cooler, and tub cooler) [3]. It was discovered that quick cooling of raw milk from 32.7℃ to 14.4℃ was recorded in the hydro-vac cooler within 15 minutes, but the sprinkler cooler and tub cooler reached the same degree of cooling after 80 and 90 minutes, respectively. It was also discovered that cooling with a hydro-vac cooler resulted in the highest sensory scores of 126 points. The surface cooler had the lowest bacterial count, whereas the tub cooling system had the highest cream volume.

Awasthi, et al., reported that typically milk is chilled by using refrigeration systems such as bulk milk cooler, cold storage, cooling rings, surface coolers ice cones, ice bank cooling and direct expansion cooling.

Issue in Conventional Refrigeration System

The present refrigerator system produces cooling effect by using refrigerants like freon, ammonia, etc. Using these refrigerants can get maximum output but one of the major disadvantage is harmful gas emission like, chlorofluoro carbons and Hydro Chlorofluoro Carbons (HCFCs) which leads to global warming and also these systems are not reliable and economical where compact design and noiseless operation is required [4].

Azridjal, et al., reported that the CFC (Chlorofluorocarbon) refrigerant was utilized as a working fluid in vapor compression refrigeration [5]. It has various environmental pollution drawbacks, including Ozone Depletion Potential (ODP) and Global Warming Potential (GWP). Many studies have shown that the refrigerant contributes between 15% and 12% of global warming, causing the earth's temperature to rise. As a result, ozone depletion and rising global temperatures will degrade the global biosphere.

Thermoelectric System

Thermoelectric cooling technology has shown to be a viable alternative to traditional Refrigeration and Air Conditioning (R and AC). This method eliminate the usage of refrigerants, solving the fundamental drawback of traditional systems, namely ozone depletion and global warming. The Peltier effect is the fundamental principle of thermoelectric cooling. Heat is transferred by causing electrons to travel through conductors with varying electron concentrations. Cooling is caused by the energy absorbed by electrons as they transit from a low to a high energy level. The direction of heat transfer is in the direction of charge carriers. Thermoelectric cooling system works similar to traditional cooling. Cold surface replaces the evaporator surface, the hot junction replaces the condenser and the two dissimilar conductors replace refrigerant in both liquid and vapour form. Compared to classic R and AC, this solid state technology offers numerous advantages.

Thermoelectric systems are solid state devices that use the Seebeck effect to operate. They are made up of a hot junction and a cold junction and when a temperature gradient exists between the hot and cold junctions, they convert heat energy into electrical energy. The Peltier effect allows solid state thermoelectric devices to transform electrical energy into thermal energy for cooling or heating, depending on the direction of current flow. Thermoelectric devices do not need refrigerants or operating fluids and their life cycle produces very few greenhouse gas emissions Chen, et al. This is a significant benefit for firms seeking to reduce their carbon footprint [7].

Namdev, et al., revealed that the thermoelectric refrigeration system is a new alternative for commercial refrigeration systems that has the advantages of being light, reliable, noiseless, rugged and low cost in mass production, uses electrons rather than refrigerant as a heat carrier and is feasible for outdoor use in conjunction with solar Photovoltaic (PV) cells, despite the fact that its coefficient of performance is not as high as for a vapor compression cycle [8]. Thermoelectric cold storage is helpful for small and marginal farmers since it allows them to preserve items for a shorter amount of time and sell them without the product deteriorating.

Thermoelectric Modules (TEM) and Materials

Bismuth Telluride (BiTe), Skutterudite (CeFeSb), Zinc-Beryllium (ZnBe), Silicon-Germanium (SiGE) and nanocrystalline materials are examples of thermoelectric materials. The minimum heat to electricity conversion efficiency is a fundamental barrier to the development of large scale thermoelectric power generation and various efforts are underway to improve thermoelectric materials natural conversion efficiency. For waste heat recovery, a bulk thermoelectric material based on BiTe is used. It is widely available and reasonably priced. HZ-14 modules based on Bi_2Te_3 have been developed by Hi-Z technology.

Thermoelectric modules comprise of thermoelectric elements that are made up of semiconductors. A thermocouple is a pair of thermal elements that is commonly recognized. A thermocouple is made up of multiple n-type and p-type semiconductor pairs that are electrically connected in series between two ceramic plates to form a module, within a single thermoelectric module, 3 to 127 thermocouples may present as shown in **Figure 1** [9]. During operation, the thermoelectric module's cold side ceramic plate compresses, while the hot side ceramic plate expands.

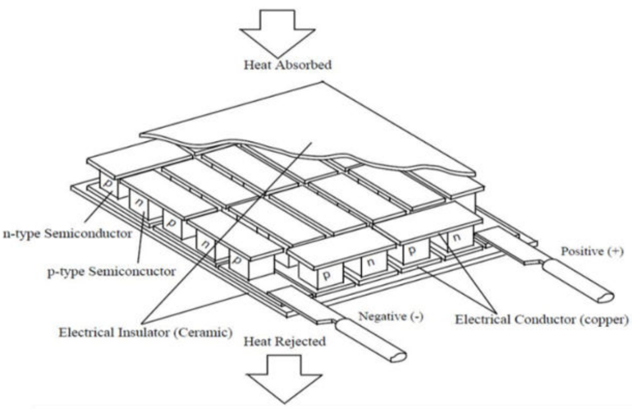

Figure 1: Construction of a typical thermoelectric module.

A commercially produced bismuth telluride module can operate at temperatures ranging from ambient to 250℃. These modules are designed for low temperature waste heat recovery applications. The companies that make these thermoelectric devices and modules, also known as thermoelectric generator TEGs, publish data on the individual modules performance [10]. The datasheets give critical information to the user, such as performance curves, maximum output Voltage (V_{max}), maximum output current (I_{max}), maximum absorbed heat energy (Q_{max}) and maximum output power (P_{max}) for a variety of test settings.

Dongliang, et al., studied thermoelectric materials and their applications, focuses on the development of thermoelectric cooling during the last decade [11]. A good thermoelectric material should have a high see beck coefficient, high electric conductivity, and low thermal conductivity, according to the primary requirements of figure of merit (ZT=2T/k). Bulk alloy materials such as Bi_2Te_3, PbTe, SiGe and C_0Sb_3 are common thermoelectric materials, with Bi_2Te_3 being the most frequent. ZT values of roughly 1.0 are currently seen in the best commercial thermoelectric materials. Thermoelectric coolers with a ZT value of 1.0 are estimated to have a carnot efficiency of just 10%. Bell also suggested that if the average ZT approaches 2.0, thermoelectric material might be used in home and commercial solid state heating, ventilating, and air conditioning systems.

Fabrication of Thermoelectric Cooling System

Dai, et al., experimentally investigated and analyzed a thermoelectric refrigerator driven by solar cells [12]. The performance of a portable solar thermoelectric refrigerator for small scale remote applications or in places where electricity is unavailable. During the day, solar cells are utilized to deliver electric power to the thermoelectric module, and at night, a storage battery and an AC rectifier are used. From the results it was observed that the system performance is greatly influenced by the intensity of solar insolation and the temperature difference between the hot and cold sides of the thermoelectric modules. The refrigerator has a COP of roughly 0.3 and can keep the temperature in the chilled chamber at 5℃ to 10°C.

Experimental evaluation of prototype thermoelectric household refrigerators was carried out by Gao, et al. Cooling performance is measured in terms of coefficient of performance, heat pumping capacity, and lowering the temperature. For a normal cooling temperature of 5℃ and an ambient temperature of 25℃, the refrigerator's COP is found to be around 0.3-0.5. The results of this study's experiments revealed that by improving module contact resistances, thermal interfaces, and heat exchanger efficacy, the COP can be increased.

A thermoelectric air cooling and air heating system was studied experimentally and numerically [13]. By supplying an electrical intensity of 4A and maintaining a 5℃ temperature difference between the hot and cold sides, they were able to achieve a cooling power of 50 W per module with a COP of between 1.5 and 2.

Rawat, et al., developed a solar powered thermoelectric refrigeration system. The thermoelectric cooling system prototype that uses solar photovoltaic cells to create DC electricity [14]. A 1 liter size refrigeration compartment is refrigerated using four Peltier modules and a heat sink. With a COP of 0.1, the testing findings demonstrate a reduction of 11℃ without any heat load and 9℃ with 100 ml water held inside the refrigeration compartment in 30 minutes when compared to 23℃ ambient temperature. In addition, the scientists discovered that when a battery is fully charged with a solar panel, it performs best at 2.5 A, 8 V. As a result, the proposed thermoelectric refrigeration system has the potential to be used for the storage and transportation of life saving pharmaceuticals and biological materials in distant places without access to electricity.

Onoroh, et al., examined the performance of a thermoelectric refrigerator [15]. In the performance evaluation, they concentrated on the modeling of a thermoelectric refrigerator was simulated at 40℃ using Matlab under various settings. The thermoelectric refrigerator is made up of a refrigeration chamber, thermoelectric modules, a heat source, and a heat sink. The coefficient of the fundamental criterion of performance for such a device is the temperature difference between the source and sink. The results indicated that, in order to maximize efficiency, temperature differences should be kept to a minimum in the hot side and cold side of the module.

The development of renewable energy based Thermoelectric Refrigeration (TER) and air conditioning systems was examined by Rawat, et al., with a refrigeration space of 1 liter [14]. It was cooled by four thermoelectric cooling modules (Q_{max}=19 W) and a heat sink fan assembly for each thermoelectric module used to increase heat dissipation rate. In the first 30 minutes under ideal operating settings, a temperature drop of 11℃ without any heat load and 9℃ with 100 mL of water in refrigeration space was found in comparison to 23℃ ambient temperature. The C.O.P of thermoelectric refrigeration cabinet was 0.1.

Venugopal, et al., developed a cost effective refrigerator using thermoelectric effect and phase materials [16]. Thermoelectric cooling is a very efficient way of cooling tiny spaces that has various advantages over compressor based cooling systems, including ease of miniaturization, noise reduction, and mobility. From this study it was concluded that the coefficient of performance is affected by factors such as heat load, power applied, and temperature difference.

Patil and Devade designed a hybrid refrigerator by incorporating two Peltier modules into a residential refrigerator and to study compressor cycles of a traditional refrigerator with Peltier module in order to improve the energy efficiency of the vapor compression cycle [17]. The effect on energy efficiency in terms of compressor trip time was measured after a Peltier module of size 4 cm × 4 cm × 0.4 cm was installed in the refrigerator cabinet. In addition, the effect of an air cooled and a water cooled condenser with Peltier module in various structures was examined and discovered that applying the thermoelectric effect lowered VCR (Vapor Compression Refrigerator) energy usage by over 10.92 percent annually or 80 units per year.

Thermoelectric cooling system experiment and assessed design parameters such as heat load, heat sink design, TE module selection and material selection. They created a 1.5 liter container prototype that can be operated at temperatures ranging from 8℃ to 35℃. An experiment is carried out to achieve a temperature of up to 5℃. It was concluded that different thermoelectric materials can improve performance [18].

Dhokane, et al., developed a thermoelectric refrigerator for greater efficiency [19]. The developed experimental thermoelectric refrigeration cabinet had a calculated COP of 0.12. When the system was run for 6000 seconds, the temperature differential between the heat source and the heat sink was found to be 20.8℃. The model's COP can be enhanced by incorporating a cascade system and employing numerous high efficiency fans. Bulk production also improves the system's cost effectiveness. According to the available literature, thermoelectric cooling systems are typically 5% to 15% more efficient than conventional compression cooling systems, which attain 40% to 60% efficiency.

Pathak and Malusare worked on thermoelectric refrigerator and power generator design, development and testing [20]. Using four thermoelectric cooling modules at low load, the authors were able to obtain a temperature of 5℃ in the lab. Using modules with a higher figure of merit (ZT) max, increasing the number of modules, and providing a more efficient heat dissipation system can improve efficiency even more. Because of no moving parts, such as a compressor, the system requires relatively little maintenance. It was also transportable. It generated a power of roughly 7 W in the laboratory using four cooling modules for a temperature difference of 100℃
(working range T_{min}=33℃, T_{max}=133℃). The efficiency of the thermoelectric power generators under construction was 17%. The efficiency of the expected thermoelectric module is estimated to be around 25%, with a range of 35% to 40%.

Suryawanshi, et al., developed a thermoelectric refrigerator for liquid cooling to keep liquids milk and milk products, drinks, water at a lower temperature than the ambient temperature [21]. Due to the poor COP of the developed cooling module, the system is limited to a small capacity. The system took 4 minutes to drop the temperature by 11℃ at no load condition. It took 21 minutes to lower the temperature by 8℃ in load condition. The results shows that the heat rejection rate due to the temperature difference between the hot and cold sides of the Peltier module increase with respect to time.

Hammad, et al., investigated water cooling by utilizing Peltier effect [22]. The research work purpose was to give power to the five number of thermoelectric modules from an alternating current source by converting it to direct current power. To convert the available AC power to DC, a circuit of five transformers was designed. There were five output terminals, each with a maximum current capacity of 10 A at 12 V DC. The results indicated that increasing the number of thermoelectric module the performance of the system also increased.

Surendarkumar developed a model cooling chamber with the combined thermoelectric module [23]. Solar panel was used to provide the electricity for thermoelectric cooler which was employed to absorb heat from the indoor space of the green building and then dissipated heat to the cooling water flowing in the regeneration channel. Experimental results showed that the heat dissipated from the hot side of the thermoelectric cooler can also be efficiently removed by the cooling water to elevate the performance of the thermoelectric cooler. It was also found that without cooling water temperature of hot and cold side in TEC may be higher than 44℃ and 34℃ respectively. When cooling water allowed to flow through the heat regeneration water channel temperature of hot and cold side in TEC were reduced to 25℃ and 16℃ respectively.

Patil, et al., developed a Peltier based ice maker [24]. The Peltier module and its impact are at the basis of the portable ice maker system. The Peltier or Thermoelectric Cooler (TEC) can be used for either heating or cooling. Because it operates on the thermodynamic principle, the module can be employed as a generator or as a source of thermal dissipation of heat and cold. The Peltier effect causes temperature differences at two separate junctions; the hot junction temperature is reduced by water cooling; as a result, the temperature at the opposite cold junction lowers dramatically to create ice cubes at lower degrees. To achieve the best results, the container holding the water to create ice at the cold junction is made of pure aluminum. To maximize efficiency, the portable ice maker is housed in an enclosed insulated cabinet.

Utkarsh, et al., fabricated and analyzed the thermoelectric cooling system. Experiments were carried out to determine the performance of two Peltier modules are TEC1-12706 and TEC1-12715 [25]. The results show that TEC1-12715 is more than the temperature reduced by the Peltier module TEC1-12706. It was concluded that TEC1-12715 is more effective than TEC1-12706.

Performance of TEC at Various Flow Rate

Gokcek and Sahin conducted an experimental performance analysis on mini channel water cooled-thermoelectric refrigerator [26]. The experiments carried out for different system voltages and different flow rates of cooling water in the mini channel. The results showed that the inner temperature of water cooled thermoelectric refrigerator was about 2℃ for 0.8 L/min flow rate while it was about -0.1℃for 1.5 L/min flowrate at the end of 2 h experiment. COP value of thermoelectric refrigerator was found to be 0.23 in the flow rate of 1.5 L/min while COP of 0.19 in the flow rate of 0.8 L/min at the end of 25 min cooling times. When it comes to 8 V system voltages, COP of the thermoelectric refrigerator found to be 0.41 at the end of 25 min operating period for the flow rate of 1.5 L/min.

The performance of a thermoelectric cooler on water in a tank used to chill a refrigerated system was investigated both experimentally and theoretically by Chein and Chen. Micro channel heat sinks have been employed with etched silicon wafers to maximize the heat rejected from the hot side. The finding demonstrates that when the flow rate increases, the temperature decreases, and this decrease continues over time.

Cooling Performance of TEC at Different Load Conditions

Bondre and Deshpande revealed different methods used to improve COP of thermoelectric refrigeration system [27]. The cooling load and Coefficient of Performance (COP) of TE system was greatly influenced by total heat transfer surface area and working electrical current. It was concluded that effectively dissipating heat at the sink was the most effective way to improve the Coefficient of Performance (COP). It was convenient to use a single stage thermoelectric refrigerator when the temperature ratio was small and a multi stage thermoelectric refrigerator when the temperature ratio was large. The author reported that the dissipation of heat at sink can be improved with the help of PCM (Phase Change Material). Using multi stages instead of a single stage of TE cooler was also an effective way to improve performance.

Jaspalsinh, et al., conducted a thermoelectric refrigeration system analysis and discovered the effect of various input parameters on the thermoelectric refrigeration system's coefficient of performance [28]. They discovered that the COP of a TE system increases with increasing current up to a certain point, then declines, and that COP decreases with increasing input power and temperature difference.

The thermal performance of a thermoelectric cooler is investigated experimentally with input power and cooling load variations. Three different input power variations (50.5 W, 72.72 W and 113.64 W) and two different cooling load utilizing mineral water (1440 ml and 2880 ml) were used in the study. At input power of 50.5 W, 72.72 W, and 113.64 W, the box temperature is 19.98℃, 19.77℃, and 18.52℃, respectively. The temperatures attained in the box at 1440 mL and 2880 mL cooling loads are 22.45℃ and 23.32℃, respectively. The test results revealed that as the input power is increased from low to high, the temperature in the box decreases, resulting in a lower coefficient of performance. This is due to the fact that when the input power is large, more energy can be absorbed [29]. Because more energy is required to lower the temperature of the cooling box, the greater the cooling load delivered in the cooling box, the longer the box temperature stability attained.

Al-Rubaye, et al., conducted on experimental work on performance of a portable thermoelectric water cooling system [30]. Power applied on thermoelectric module was changed to determine its effect on thermal performance. DC power supply was used to supply power to the thermoelectric modules. The modules will cool a container which was cylindrical in shape with 100 mm diameter and 120 mm height wherein water will be filled for testing. The container was cylindrical shape in with diameter (100 mm) and height of (120 mm). The base of the container was attached directly to the cold side of TE with thermal grease. The water containers were insulated to diminish heat loss. Heat sink with 35 fins were used with 1.2 mm distance between, a 12 V fan were set below the heat sink and connected with another power supply. The coefficient of performance was found to be 0.14 when using initial water temperature of 15℃, while, it increased to be 0.5 when the initial water temperature increased to 30℃.

Development of Thermoelectric Refrigerator for Food

Experimental and theoretical analysis of a quick beverage chiller based on the thermoelectric refrigeration principle was conducted by Adeyanju, et al. Experiments with various volume of beverage at various temperatures were undertaken and heat sinks were used to improve cooling efficiency [31]. The chilling time of the beverage chiller was compared to the cooling time acquired from the freezer and cold space of a domestic refrigerator. All comparative tests were conducted in a glass jar with 325 mL of water and beverage. Theoretically, increasing the number of thermoelectric modules and heat sinks boosts the beverage cooling rate. With the passage of time, the temperature of the beverage fell exponentially. The temperature of the water declined linearly with increasing time in the refrigerator freezer compartment respectively.

Kaushik, et al., analyzed and experimentally investigated the performance of solar photovoltaic driven thermoelectric cooler system for cold storage of cold storage of food, vaccine and milk products in remote areas where electric power supply is not available [32]. A small cold storage box of 3 liter capacity has been made and analyzed for its performance in the composite climate of Delhi, India. Experimental results demonstrated that this unit could maintain the temperature of 10℃ to 15℃. Inside the cold box. Moreover, energy and energy analysis of the photovoltaic thermoelectric system has been performed to identify and quantify the irreversibility's occurring in the system. The performance of the system depends on incoming solar insolation and the temperature difference between the hot and cold sides for thermoelectric cooler module. It is expected that the cooler have potential for Shetty, et al., designed thermoelectric cooling system using both solar power and electrical power supply which is applicable for food preservation, military, aerospace and medical cooling using Peltier effect to refrigerate and maintain a selected temperature up to 10℃ [33]. The designed thermoelectric system was able to cool 250 ml volume to require 10℃ temperature within a time period of 2 hours and can retain the cooling for the next half an hour.

Akinyemi and Simolowo designed a cooling system using Thermoelectric or Peltier Module (TEM) and heatsinks with considerations for temperate climatic conditions in Nigeria [34]. Nigeria as a tropical region experiences high temperature difference between the year (18℃ to 40℃) with sun hours ranging between (100 hrs-210 hrs) monthly, such that the desire for chilled beverages almost throughout the day becomes paramount necessitating the need for a Peltier mobile cooler in tropical regions especially with inadequate electricity supply. A 9 liters rectangular shaped cooler was chosen with an area of 1.155 m^2, a dimension of 0.65 m × 0.35 m, estimated to contain 120 beverages with an estimated heat load of 483 W. It is estimated to use five thermoelectric modules, a temperature sensor, DC powered battery and ten heats sinks for design of cooling system. Comparatively, the design criteria of this Peltier cooler were compared with the performance evaluation of existing similar designs and found to be within optimum performance levels. At 10℃, the thermoelectric modules are powered to start cooling until the beverages are at 0℃ (estimated to be a period of fifteen minutes), after which the tec controller turns off the power and the system is temporarily off until a temperature of 10℃

is detected by the temperature sensor and a re-cooling is initiated. With these, the frozen beverage products received in the morning can be re-cooled as many times as possible.

Prototypes with various sizes (18 cm width, 12 cm length and 14 cm height) and body materials, such as polystyrene, polypropylene, and aluminum, were successfully fabricated and tested utilizing a 5 V power source to obtain the minimal temperature. The experimental results showed that the temperature for each body material is lowest at the smallest size of the cooled compartment (18 cm width, 12 cm length, and 14 cm height) than other sizes. Among all body materials aluminum has the lower temperature of 11.2℃ after 100 minutes, which is lower than the other prototypes.

Escolar, et al., fabricated a thermoelectric cooler with SS 04 for cooling of carabao milk [36]. A thermal paste was employed to integrate the thermoelectric cooler into the heatsink and fan assembly in order to improve heat transfer between the cold side and the container, as well as the hot side and the heatsink. Two lead acid batteries powered the cooling system, which were charged using a solar panel. From the results of physico chemical analysis of carabao milk, it was observed that the quality of milk was preserved. But, the milk does not reach the desired temperature of 4℃ due to several factors including fabrication of the flat side, battery power rating, and an insufficient number of thermoelectric modules used, and heat loss in the system.

DISCUSSION

A Solar Thermoelectric Cooler (STEC) was fabricated by exploiting the solar energy and evaluated its cooling performance with and without product load by Biswas, et al. The STEC is comprised of a Thermoelectric Module (TEM), inner and outer heat sink fan fixed in the cooler box wall, and Photovoltaic (PV) panel connected with the device through battery and PV charge controller. The PV power was utilized to drive the device, charge the battery in the daytime, and the store electricity exploited during nighttime. The effect of varying input electric current on the cold side temperature of TEM, cooling capacity, power consumption and Coefficient-Of-Performance (COP) were investigated. The results showed that the cold side temperature decreased to 5℃ ± 0.2℃ in 120 min and 180 min for without and with product load of 0.5 kg fish fillets respectively. The cooling capacity, power consumption and COP of the STEC were 23.8 W, 53.5 W and 0.44 W, respectively, at the input electric current of 3.5 A. The battery power was utilized to drive STEC for 5 h-6 h after sunset. The STEC could be considered as an alternate "green option" to the domestic refrigerator where electricity is not accessible.

Constraints in Thermoelectric Module

Peltier module capable of lowering the temperature of the cooling heatsink to the point where moisture in the air condenses, causing a hazard to electronic circuits. Electronic circuits of any device can be short circuited if water is constantly generated by condensation. To avoid short circuits, Hajovsky, et al., recommend to maintain the spacing between the wires and the surfaces of the solid state modules [37].

Due to the space between two surfaces, heat/cold rejection is a difficult task while modules are running. One energy should be rejected for efficient cold/heat and sometimes using both energies at the same time would improve the performance of solid state modules, such as heat pumps. The life of the module will be shortened if the polarity of the module is quickly changed and both energy (cooling and heating) is obtained from the same module and from the same surface of the module Al-Madhhachi, et al. The heat sinks must be attached to both sides of the module, which is a tough process due to the module's thickness [38-41].

CONCLUSION

The thermoelectric milk cooling system is having many advantages over vapour compression refrigeration system. The thermoelectric milk cooling system produces cooling effect by Peltier affect due to power input and no refrigerant is present to produce the cooling effect whereas Vapor Compression Refrigeration System (VCRS) uses refrigerants to produce cooling effect. Even though the VCRS have higher C.O.P, the presence of chlorofluorocarbons and Hydrochlorofluoro Carbons (HCFCs) leads to global warming. The Peltier based cooling system is eco-friendly and doesn’t produce any environmental pollution. It is an alternative option to vapour compression refrigeration system. The Peltier cooling system also known as solid state cooling system does not contain any moving parts. The Peltier based cooling system are portable. The vapour compression system occupies space. Hence, the thermoelectric milk cooling system is considered to be a best option to chill milk on small capacity. This system would be helpful for small and marginal famers. A decreasing cooling rate with respect to time is considered to be a problem in Peltier cooling system and it is required optimum power supply to achieve desired temperature and C.O.P of the cooling system.

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