

# Design and Development of Thermoelectric Refrigerator

Gadhe Manoj<sup>1</sup> Jadhav Mahesh<sup>2</sup> Patil Shekhar<sup>3</sup> Shinde Ravindra<sup>4</sup> Sawant S. G.<sup>5</sup>

<sup>1,2,3,4</sup>B.E. Student <sup>5</sup>Assistant Professor

<sup>1,2,3,4,5</sup>Department of Mechanical Engineering

<sup>1,2,3,4,5</sup>S.N.D. COE & RC, YEOLA, Pune University, India

**Abstract**— The development of renewable energy is on the rise worldwide because of the growing demand on energy, high oil prices, and concerns of environmental impacts. In recent years, progress on solar-powered air conditioning has increased as nowadays, air conditioning system is almost a must in every building if we want to have a good indoor comfort inside the building. Therefore, this paper focuses in the design and construction of a direct current (DC) air conditioning system integrated with photovoltaic (PV) system which consists of PV panels, solar charger, inverter and batteries. The air conditioning system can be operated on solar and can be used in non-electrified areas. As we all known, solar energy is cost effective, renewable and environmentally friendly.

**Key words:** Thermoelectric Refrigerator

## I. INTRODUCTION

Refrigeration is defined as the process of removing heat from an enclosed space or from a substance for the purpose of lowering the temperature. Refrigeration is closely related to the demand for cooling foodstuffs and many other commodities as a normal part of commercial domestic life. Solar refrigeration is thought of as one of the best alternatives to address this issue and it may be accomplished by using one of the refrigeration systems: vapor compression, absorption or thermoelectric refrigeration system. Before mechanical refrigeration systems were introduced, ancient peoples, including the Greeks and Romans, cooled their food with ice transported from the mountains. Wealthy families made use of snow cellars, pits that were dug into the ground and insulated with wood and straw, to store the ice. In this manner, packed snow and ice could be preserved for months. Stored ice was the principal means of refrigeration until the beginning of the 20th century, and it is still used in some areas. Conventional refrigeration systems use ChloroFluoro Carbons (CFCs) and Hydro Chlorofluorocarbons (HCFCs) as heat carrier fluids. Use of such fluids in conventional refrigeration systems has a great concern of environmental degradation and resulted in extensive research into development of novel refrigeration technologies. The current tendency of the world is to look at renewable energy resources as a source of energy. This is done for the following two reasons; firstly, the lower quality of life due to air pollution and secondly, due to the pressure of the ever increasing world population puts on our natural energy resources. From these two facts comes the realization that the natural energy resources available will not last indefinitely. Therefore, the ideal solution would be to use some type of renewable energy resource.

Thermoelectric refrigeration system powered by solar photo voltaic (PV) cell generated DC voltage is suitable for Indian climate conditions and applicable for rural health centers. For utilizing solar energy efficiently and cost effectively, proper design of reliable solar devices and system

have to be attempted to suit the radiation climate and socioeconomic conditions. From this perspective, sizing of PV system involves finding the cheapest combination of array size and storage capacity that will meet the anticipated load requirement with the minimum acceptable level of security. The information required is including the daily or hourly load requirement, peak current and voltage characteristics of the solar module, the number of autonomous days, the estimated percentage of energy losses in the battery and power conditioning equipment, and the estimated losses in the array due to module mismatch, cable, dust and shading. The thermoelectric refrigerator is a unique cooling device, in which the electron gas serves as the working fluid. In recent years, concerns of environmental pollution due to the use of CFCs in conventional domestic refrigerators have encouraged increasing activities in research and development of domestic refrigerators using Peltier modules. Moreover, recent progress in thermoelectric and related fields have led to significant reductions in fabrication costs of Peltier modules and heat exchangers together with moderate improvements in the module performance. It is now possible to develop an economically-viable thermoelectric refrigerator which has improved performances and the inherent advantages of environmentally-friendly silent operation, high reliability, and ability to operate in any orientation. Although the COP of a peltier module is lower than that of conventional compressor unit, efforts have been made to develop thermoelectric domestic refrigerators to exploit the advantages associated with this solid-state energy-conversion technology.

## II. METHOD OF REFRIGERATION

### A. Non-cyclic refrigeration

In non-cyclic refrigeration, cooling is accomplished by melting ice or by subliming dry ice (frozen carbon dioxide). These methods are used for small-scale refrigeration such as in laboratories and workshops, or in portable coolers. Ice owes its effectiveness as a cooling agent to its melting point of 0 °C (32 °F) at sea level. To melt, ice must absorb 333.55 kJ/kg (about 144 Btu/lb.) of heat. Foodstuffs maintained near this temperature have an increased storage life. Solid carbon dioxide has no liquid phase at normal atmospheric pressure, and sublimates directly from the solid to vapor phase at a temperature of -78.5 °C (-109.3 °F), and is effective for maintaining products at low temperatures during sublimation. Systems such as this where the refrigerant evaporates and is vented to the atmosphere are known as "total loss refrigeration"

### B. Cyclic refrigeration

This consists of a refrigeration cycle, where heat is removed from a low temperature space or source and rejected to a high-temperature sink with the help of external work, and its

inverse, the thermodynamic power cycle. In the power cycle, heat is supplied from a high-temperature source to the engine, part of the heat being used to produce work and the rest being rejected to a low-temperature sink. This satisfies the second law of thermodynamics.

A refrigeration cycle describes the changes that take place in the refrigerant as it alternately absorbs and rejects heat as it circulates through a refrigerator. Heat naturally flows from hot to cold. Work is applied to cool a living space or storage volume by pumping heat from a lower temperature heat source into a higher temperature heat sink. Insulation is used to reduce the work and energy needed to achieve and maintain a lower temperature in the cooled space.

The most common types of refrigeration systems use the reverse-Rankin vapor-compression refrigeration cycle, although absorption heat pumps are used in a minority of applications.

1) *Cyclic refrigeration can be classified as*

a) Vapor compression system:

In vapor compression systems, compressors activate the refrigerant by compressing it to a higher pressure and higher temperature level after it has produced its refrigeration effect. The compressed refrigerant transfers its heat to the sink and is condensed to liquid form. This liquid refrigerant is then throttled to a low-pressure, low temperature vapour to produce refrigerating effect during evaporation. Vapor compression systems are the most widely adopted refrigeration systems in both comfort and process air conditioning.

b) Absorption system:

In an absorption system, the refrigeration effect is produced by thermal energy input. After absorbing heat from the cooling medium during evaporation, the vapor refrigerant is absorbed by an absorbent medium. This solution is then heated by direct-fired furnace, waste heat, hot water, or steam. The refrigerant is again vaporized and then condensed to liquid to begin the refrigeration cycle again. Absorption and adsorption refrigeration are thermally driven technologies that respectively use liquid and solid sorbents. These systems are popular in applications where demand side management is important and/or waste heat is readily available. An absorption cycle, shown in utilizes a binary mixture of refrigerants such as ammonia–water or water–LiBr.

The single effect cycle consists of an absorber, a generator or, a condenser, an evaporator, and an electric solution pump, with the possibility of additional components, such as internal heat exchangers, to enhance efficiency. An external heat source, such as a gas burner in a direct fired system, steam or hot water in an indirect fired system, or waste heat, is used in the generator. Heat absorbed in the generator allows the refrigerant to desorb from the absorbent, creating a high pressure vapor. In cases where a volatile absorbent is used (e.g. ammonia–water), a rectifier is needed to reduce the concentration of the volatile absorbent (e.g. water) in the vapor to the condenser.

c) Air or gas expansion system:

In an air or gas expansion system, air or gas is compressed to a high pressure by mechanical energy. It is then cooled and expanded to a low pressure. Because the temperature of air or gas drops during expansion, a refrigeration effect is produced.

d) Adsorption refrigeration:

An adsorption system uses multiple beds of adsorbents such as silica-gel in a silica-gel water system, to provide continuous capacity, and does not use any mechanical energy but only thermal energy. An adsorption refrigeration system usually consists of four main components: a solid adsorbent bed, a condenser, an expansion valve and an evaporator. The solid adsorbent bed is linked to the evaporator. It desorbs refrigerant when heated and adsorbs refrigerant vapor when cooled such that the bed works like a thermal compressor to drive the refrigerant around the system to heat or cool a heat transfer fluid or to provide space heating or cooling. When the bed becomes saturated with refrigerant, it is isolated from the evaporator and connected to the condenser. The refrigerant vapor is condensed to a liquid, followed by expansion to a lower pressure in the evaporator where the low pressure refrigerant is vaporized producing the refrigeration effect (i.e. cooling the refrigerator air). When further heating no longer produces desorbed refrigerant from the adsorbent bed, the refrigerant vapor from the evaporator is reintroduced to the bed to complete the cycle. To obtain a continuous and stable cooling effect, generally two (or multiple) adsorbent beds are used, where one bed is heated during desorption while the other bed is cooled during adsorption. In order to achieve high efficiency, heat of adsorption needs to be recovered to provide part of the heat needed to regenerate the adsorbent.

### III. SINGLE-STAGE IDEAL VAPOR COMPRESSION CYCLE

The Carnot cycle cannot be achieved for the vapor cycle in actual practice because liquid slugging would occur during compression of the two-phase refrigerant. In addition, the mixture, mostly liquid, does very little work when it expands after condensation in the heat engine. Therefore, a single-stage ideal vapor compression cycle is used instead of the Carnot cycle. Figure 1.2.1 shows an ideal single-stage vapor compression cycle in which compression occurs in the superheated region. A throttling device, such as an expansion valve, is used instead of the heat engine.

Single-stage means that there is only one stage of compression. An ideal cycle is one in which the compression process is isentropic and the pressure losses in the pipeline, valves, and other components are negligible. All the refrigeration cycles covered in this chapter are ideal cycles except the air expansion refrigeration cycle. Vapor compression means that the vapor refrigerant is compressed to a higher pressure, and then the condensed liquid is throttled to a lower pressure to produce the refrigerating effect by evaporation. It is different from the absorption or air expansion refrigeration cycle.

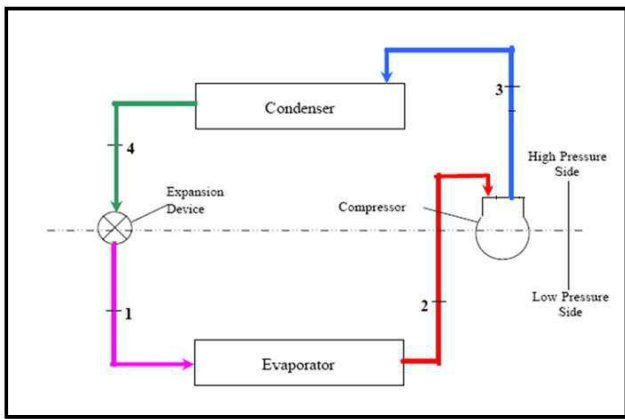


Fig. 1: Vapour Compression Cycle

#### A. Thermoelectric refrigeration

Thermoelectric cooling uses the Peltier effect to create a heat flux between the junctions of two different types of materials. This effect is commonly used in camping and portable coolers and for cooling electronic components and small instruments. The absolute Seebeck coefficient,  $a$ , for metals does not exceed 50  $\mu\text{V}$  per K (ASHRAE, 1981). However,  $a$  can be much higher for semiconductor materials. The highest (250  $\mu\text{V}$  per K) is achieved from alloys of Tellurium (Te) doped with antimony tri-iodide ( $\text{SbI}_3$ ) to produce an "n type" semiconductor and with excess Te to make a "p-type" semiconductor. In the cooling mode, direct current passes from the n- to p-type semiconductor materials. The temperature TC of the conductor decreases and the heat is absorbed from the space to be cooled. This occurs when electrons pass thermoelectric modules increases rapidly with decreasing temperature lift, where it may have some advantage over traditional vapor compression systems.

#### B. Magnetic refrigeration

As shown in Fig.2 magnetic refrigeration or adiabatic demagnetization, is a cooling technology based on the magneto caloric effect, an intrinsic property of magnetic solids. The refrigerant is often a paramagnetic salt, such as cerium magnesium nitrate. The active magnetic dipoles in this case are those of the electron shells of the paramagnetic atoms.

A strong magnetic field is applied to the refrigerant, forcing its various magnetic dipoles to align and putting these degrees of freedom of the refrigerant into a state of lower entropy. A heat sink then absorbs the heat released by the refrigerant due to its loss of entropy. Thermal contact with the heat sink is then broken so that the system is insulated, and the magnetic field is switched off. This increases the heat capacity of the refrigerant, thus decreasing its temperature below the temperature of the heat sink. Because few materials exhibit the needed properties at room temperature, applications have so far been limited to cryogenics and research.

### IV. EXPERIMENTAL SETUP AND INSTRUMENTATION

#### A. Experimental Setup

A solar powered thermoelectric refrigeration system consists of many components, such as

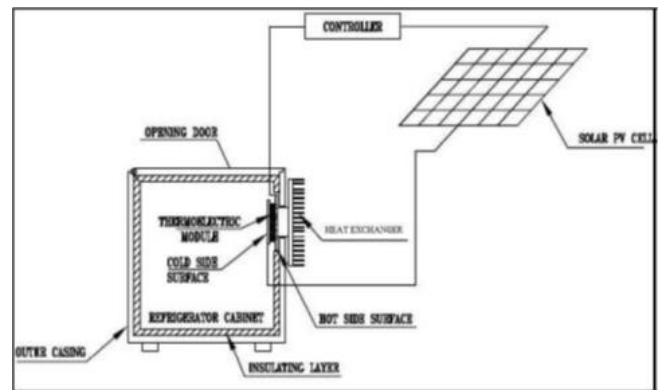


Fig. 2: Experimental Setup

The construction set up (Fig 4.1.1) for this system require following parts:

- 1) Solar panel
- 2) Charge controller
- 3) Thermoelectric module
- 4) Exhaust fan
- 5) Cabinet
- 6) Battery bank
- 7) Relay switch

### V. EXPERIMENTAL WORKING

Thermoelectric refrigeration uses the Peltier effect to create a heat flux between the junction of two different types of materials. A Peltier cooler, heater, or thermoelectric heat pump is a solid-state active heat pump which transfers heat from one side of the device to the other, with consumption of electrical energy, depending on the direction of the current. Such an instrument is also called a Peltier device, Peltier heat pump, solid state refrigerator, or thermoelectric cooler (TEC). They can be used either for heating or for cooling (refrigeration), although in practice the main application is cooling. It can also be used as a temperature controller that either heats or cools. This technology is far less commonly applied to refrigeration than vapor compression refrigeration. The main advantages of a Peltier cooler are its lack of moving parts or circulating liquid, near-infinite life and invulnerability to potential leaks, and its small size and flexible shape. Its main disadvantage is high cost and poor power efficiency. Many researchers and companies are trying to develop Peltier coolers that are both cheap and efficient.

### VI. CONCLUSION

Thermoelectric and thermoelectric cooling are being studied exhaustively for the past several years and various conclusions have been conceived regarding the efficient functioning of thermoelectric refrigerators. Thermoelectric refrigerators are greatly needed, particularly for developing countries, where long life, low maintenance and clean environment are needed. In this aspect thermoelectric cannot be challenged in spite of the fact that it has some disadvantages like low coefficient of performance and high cost. These contentious issues are the frontal factors hampering the large scale commercialization of thermoelectric cooling devices. An overall system coefficient of performance (COP sys) can be defined as the ratio of refrigeration capacity to input solar energy. The COP sys is

low for all three types of solar refrigeration systems. However, this definition of efficiency may not be the most relevant metric for a solar refrigeration system because the fuel that drives the system during operation, solar energy, is free. Other system metrics that are more important are the specific size, weight, and, of course, the cost.

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