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Review on Vapour Compression-Thermoelectric Hybrid Refrigeration system

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***Abstract*—Refrigeration means removal of heat from a body in order to bring it to a temperature lower than those of the atmospheric temperature. There are various methods of refrigeration. All having their own advantages and disadvantages, in order to utilize their advantages some researchers tried to combine these methods with each other and performed experimentation on it to get some worthy results. This paper provides an overview on one of the refrigeration method that is thermoelectric refrigeration system utilized to produce the cooling effect. This technology of producing cooling effect has handful of advantages, as given in the paper by the various researchers, whose studies have shown the usage of the thermoelectric system having possibility of innovation and modification to provide future refrigeration thermoelectric system, which is environmental and consumer friendly. In this sequence some, researchers tried to develop the hybrid system by combining VCRS and Thermoelectric system that gives the different way of thinking about existing technology for the enhancement.**

Keywords-*VCRS, thermoelectric refrigeration, peltier unit, COP, hybrid refrigeration system .*

I. INTRODUCTION

There are four well known cooling systems, Vapour Compression, absorption, thermoelectric and newly known Thermo-acoustic refrigeration system. The cooling effect produced by refrigeration system is based on simple principle of operation, that a heat flux is absorbed from a room, and evacuated to exterior. In domestic refrigerators, the most used cooling system is vapour compression, as it has a good value of COP.

Refrigeration systems extract heat from a closed cabinet and leaves into environment. Main components of a refrigeration system are condenser, an evaporator, a compressor, and an expansion valve. In a cyclic phenomenon of a refrigeration system, the refrigerant vapour leaves the evaporator and enters the compressor as a saturated vapour at the vaporizing temperature and pressure and the liquid leaves the condenser and enters the expansion valve as a saturated liquid at the condensing temperature and pressure [16]. The improvement in the technology is the continuous process to fulfil the requirement of the rapidly changing world.

II. THERMOELECTRIC REFRIGERATION

Thermoelectric refrigeration is one of the methods of producing low temperature and it is based on the reverse Seebeck effect [12]. The theories behind the operation of thermoelectric refrigeration can be traced back to the early 1800s.Jean Peltier discovered there is a heating or cooling effect when electric current passes through two conductors of dissimilar metals. Thomas Seebeck found that, when two dissimilar conductors at different temperatures would create an electromotive force or voltage [13].

William Thomson (Lord Kelvin) showed that, over a temperature gradient a single conductor with current flow will have reversible heating and cooling effect. With these principles in mind and the introduction of semiconductor materials in the late 1950s [13], many researchers studied and tried to develop a better thermoelectric refrigeration system to utilize this technique in industry and domestic appliances [2-3].

A Thermoelectric Refrigeration module is a small heat pump, which has the advantage of no moving parts. The Thermoelectric module operates on direct current and used for heating or cooling by reversing the direction of current flow. This is achieved by moving heat from one side of the module to the other with current flow. The elements of semiconductor material are connected electrically in series and thermally in parallel [13].

When a positive DC current is applied to the n-type thermo-element, electrons pass from the p- to the n-type thermo-element and the cold side temperature decreases as heat is absorbed. This heat is transferred to the hot side, where it is dissipated into the heat sink and surrounding environment [13]. The heat absorption (cooling) is proportional to the current and the number of thermoelectric couples [13]. Thermoelectric cooling has become a viable technology for small cooling applications. The performances of Thermo-electric cooler [12] are expressed as follows:

$$Q_C = \propto_{pn} T_c I - \frac{1}{2}(I^2 R) - K(T_h - T_c) \quad [12]$$

The overall rate of expenditure electric energy is given by

$$W = \propto_{pn} I(T_h - T_c) + I^2R \qquad [12]$$

The Coefficient of Performance is define as

$$COP = \frac{Q_c}{w} \qquad [12]$$

The refrigeration capacity of a semiconductor material is depend on a combined effect of the material's Seebeck coefficient, thermal conductivity and electrical resistivity over the operational temperature range of hot and cold side named as figure of merit and expressed as

$$Z = \frac{\propto^2}{\rho\lambda} \qquad [12]$$

Although, FIGURE OF MERIT (ZT) of thermoelectric modules has increased significantly in recent years, still their practical applications are limited. To date, reported thermoelectric system efficiency could not compete with conventional vapor compression technology. The common material employed for commercially available thermoelectric cooler is based on Bismuth Telluride mixed crystal and modification of Bi_2Te_3 have the highest figure of merit and most suitable in refrigeration.

III. LITERATURE REVIEWED

Pradeep Bansal et al. [1] thoroughly investigated about the current status of the major household appliances, around them we are interested in refrigerator-freezers, and they found that by taking little bit care during insulation of refrigerator cabinet not only reduces the heat gain and air leakages but also reduces the electrical consumption of compressor.

The proper selection of compressor, such like variable speed linear compressor and variable capacity compressor will leads to 25%efficiency improvement over conventional reciprocating compressor, also improved heat exchangers and defrost mechanism with all above mentioned improvement leads to 10% reduction in energy consumption of refrigerator [1].

Apart from the conventional cooling producing methods some non-traditional method also studied and investigated by author, such as thermoelectric refrigeration, world know about this phenomenon of the thermoelectricity since from the 18th century but not much progress has been done in this technique because of the material limitation on which it fully dependant, In current status COP of the thermoelectric refrigerator is not compatible with Vapour Compression refrigerator.

Gao Min et al.[2] studied and investigated number of prototype of thermoelectric refrigerator and evaluate them on the basis of the COP, Heat –pumping capacity and cooling down rate .Starting with basic configuration of thermoelectric refrigerator as shown below in fig.1,it consist of thermoelectric unit, sandwiched between two electrically insulating but thermally conducting ceramic plates. The energy efficiency of thermoelectric refrigerator is mainly dependant on the COP of the peltier module and the heat – transfer effectiveness of the heat exchangers.

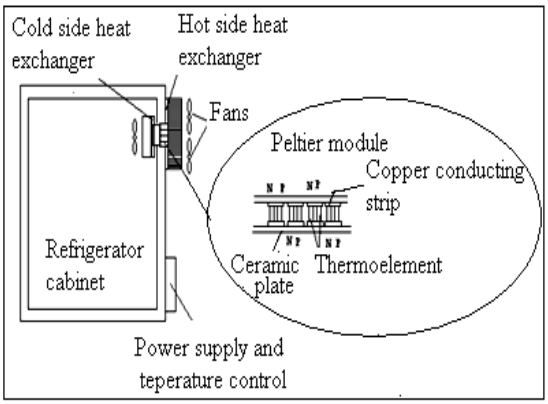

Fig.1. Schematic of thermoelectric refrigerator and peltier module [2].

They compared the heat dissipation method using exchangers like,

1. Heat exchangers with forced convection
2. Liquid circulation heat exchangers

And found that, the exchangers are help in improving the COP of thermoelectric refrigerators.

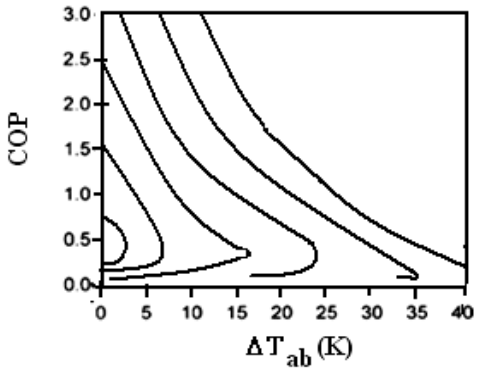

Fig.2. Coefficient of performance as a function of temperature difference for different heat pumping capacities [2]

In this paper, they also compared the three thermoelectric refrigerators with conventional compressor type refrigerator. TER- 1, TER-2 and TER-3, first one unlike conventional compressor type refrigerators, the temperature of thermoelectric prototype is controlled by adjusting the level of the input power. Result obtained during the test are shown in graph

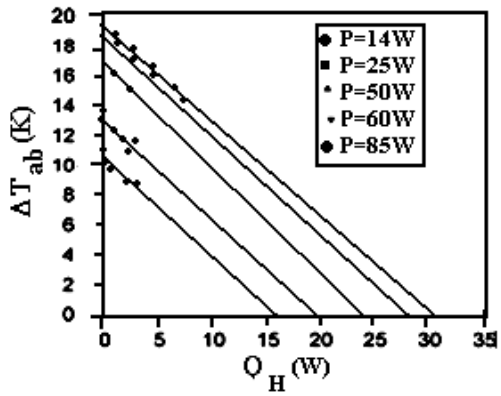

Fig.3. Tab–QH plot to obtain the coefficient-of-performance of TER-1 for different input-powers [2]

An experiment has been carried out on these entire three prototype refrigerator, TER-1, TER-2 and TER-3, between these, TER-3 designed to maintain temperature at 5^0c by using PID temperature controller. The result of the TER-3 prototype compared with CCR and found that the temperature stability of TER is better than the CCR which clearly have been shown on the graph that plotted between TER and CCR.

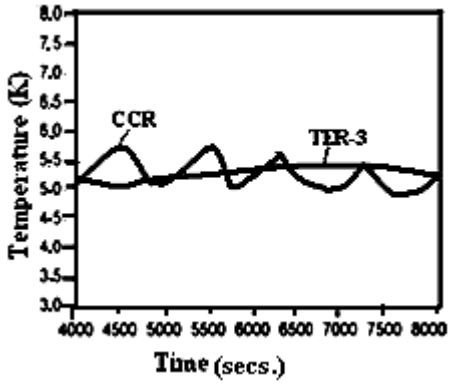

Fig.4. Comparisons of temperature stabilities of CCR and TER-3 [2]

Thermoelectric refrigerator are environmental friendly but for this consumer will ready to spend a little bit more money [2]. In thermoelectric refrigerator the energy consumption is more and because of this, the COP is less, apart from peltier unit fans and exchanger component fitted on thermoelectric module are affect the energy consumption of the refrigerator.

THERMOSYPHON WITH PHASE CHANGE ‘‘TSF’’

Thermo-syphon is heat dissipating, a self feed closed cycle. It consists of the hermitically closed chamber, with fluid inside. It uses the latent heat of phase change to dissipate the heat continuously [3]. The hot side of the peltier pellet is in contact with chamber surface, filled with liquid, where it gives heating power, and so it is transmitted to fluid which converts into vapour.

The vapour rises up by natural convection in thermo-syphon, where the vertical fins have been placed, as vapour comes in contact with upper surface of thermo-syphon it get condensed and came back to bottom surface in liquid phase and heat has given out with the help of fins. In compare with classical dissipater, it spreads heat over the large surface because of this, it’s become more efficient.

Vain & Astrain [3] has been studied, the various thermoelectric refrigerator with a two-phase thermosyphon system (TSF), with incorporated fan, for the hot side of the peltier module as shown in reference [4].It improved the thermal resistance by 36% in comparison with finned heat sink Also improving the thermal resistance by using thermosyphon with two-phase and capillary lift (TPM) up to 37% for the cold side of peltier module.

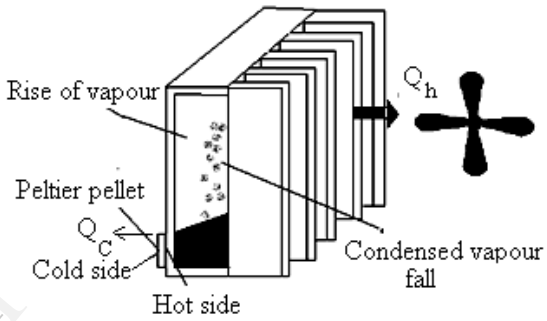

Fig.5.Thermal diagram for the TSF [4]

A thermoelectric refrigerator has been developed, with single compartment of capacity $0.225m^3$ to maintain the inside temperature of 5^OC. the result which were obtained demonstrate that, it is able to maintain a thermal drop of 19^0C [3]. The heat dissipation method applied in this refrigerator consist of thermoelectric devices, each composed of a peltier module 50w, with a two phase and natural convection thermosyphon and a two phase capillary lift thermosyphon, in contact with the cold side [3]. It had been found that, by including the developed thermosyphons, there were increased of 66% in the COP of the thermoelectric refrigerator with respect to the fan cooled thermoelectric refrigerator.

Thermoelectric cooling system is used to cool the inner part of in the electronic system, this is because of the useful studies and thinking of some researchers in past. Miniature refrigeration systems had received much attention since the pioneer work by W.A.Little [8].

The review paper by Pelan et al. [10] summarized several current and future miniature refrigeration cooling technologies for high power electronic system. According to him a miniature vapour compression refrigerator could be a future solution for electronic heat management. In such a refrigeration system, the maximum power dissipation rate and lowest temperature that could be attained are 350 W and 12^0C, respectively.

The miniature vapour compression refrigerator principle is the same, as that for a conventional sized refrigerator except that the size is reduced to the centi-or millimeter order [10]. The main difficulty is the micro scale compressor design and fabrication. The micro compressor is the essential component in the vapour compression refrigerator. Another possible candidate that might also fit the requirement is a mini-scale capillary pump loop (CPL). Operating such a system is similar to the meso-scale vapour compression refrigerator except that the working fluid is driven by capillary pressure.

Thermoelectric cooling is also the one of optional method and now a days mostly used in electronic system [10]. However, it does have advantages such as high reliability, flexibility in packaging and integration, low weight and more importantly maintaining the junction temperature as low as required. These characteristics make the TEC a candidate for electronic cooling applications.

Selecting the proper thermoelectric module for the cooling purpose in domestic refrigerator or for the electronic system is tedious work. Manufacturers are having various products related to TEC. With that, they provide properties manuals or electronic search facilities for their products; the process is still difficult to choose the comfortable TEC, as these facilities are incompatible.

Tan & Fok [7] have been given some steps to select the thermoelectric module.
The following is the step by step procedure suggested by authors for selection of the TEC in cooling system designs:
Step 1: Determine the amount of heat to be pumped (Qc).
Step 2: Determine the lowest needed heat load temperature (minimum Temp.load).
Step 3: Determine the worst case ambient temperature (Tamb).
Step 4: Determine the TECs hot and cold side temperatures and the temperature difference across it.

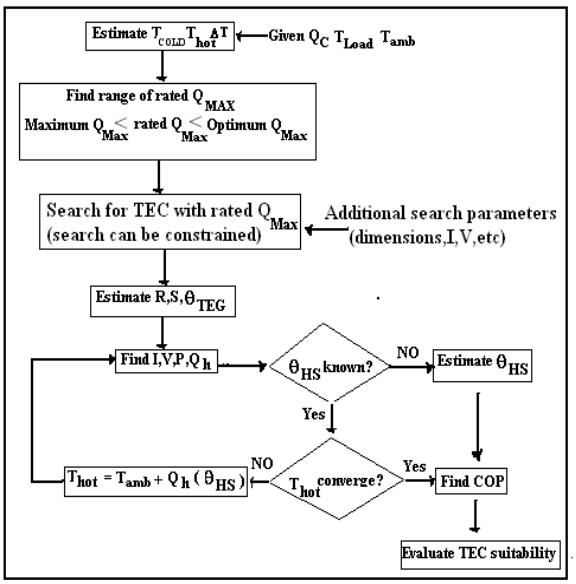

Fig.6.TEC search and analysis flow chart [11].

HYBRID TECHNOLOGIES FOR THE VALUE ENHANCEMENT

No moving part, no noise, and low maintenance are the advantages of thermoelectric system, whereas system has COP less as compare to the conventional refrigeration system [15].

In current vapour compression refrigeration system (VCRS), one of the main disadvantages lies on oscillatory pattern of the inner temperature, caused because of the stop and start of cycles of the compressor [11]. This effect leads to considerable oscillation in the temperature of the air enclosed in the refrigeration compartment, which affect to great extent the conservation of food [11].

To overcome this problem in vapour compression refrigeration system (VCRS), some researchers given the idea to used variable speed compressor, fixed speed compressor with improved temperature control systems, these systems turn out to be very complex and expensive to install into domestic refrigerators, which increases the cost of the system [1]. Capillary tubes are cheaper and simple devices used in system but it entails a decrease in the quality of the temperature control.

The thermoelectric devices may be the appropriate alternative to attain the accurate constant temperature without much more complication in the domestic vapour compression refrigerators and also, the reduction in energy consumption by system. In this way Vian et al. [11] tried to developed, the domestic refrigerator, which combines technologies, thermoelectricity and vapour compression. They were developed the two prototype model in which the thermoelectric cabinet had installed.

In first configuration the peltier modules were placed in the back wall of the super preservation room. Thus, when an electric power is supplied to the peltier modules, these absorbed heat flux from interior of the compartment and throws to the exterior. In second configuration in order to decrease the temperature gap between the faces of the peltier module ,heat flux from the hot side of the peltier modules had introduced in the refrigerator room from where the evaporator was charged to absorb and throw it to the exterior by vapour compression cooling system, with a good COP value[11].

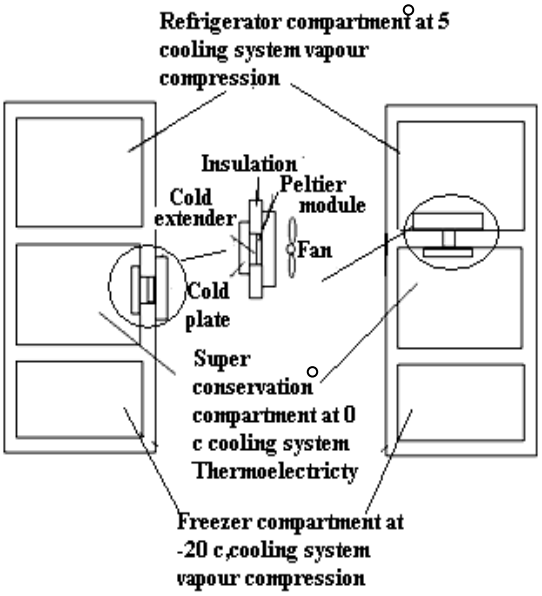

Fig.7. Sketches of the hybrid domestic refrigerator. Configuration I and II [11]

From experimentation done on the prototypes these models have been validated experimentally, with very good predictive values and maximum error in the temperature of the thermoelectric compartment were 1.2^0C and 8% for the power consumption [11].

CONCLUSION

From this review, it is clear that thermoelectric refrigeration system utilized to produce the cooling effect is emerging field. The energy efficiency of thermoelectric refrigerator is still lower than vapour compression refrigeration system (VCRS). More over, further improvement is possible in COP of thermoelectric refrigerator by the use of semiconductor material with good figure of merit (FOM) and also increase in heat exchange capability of heat exchanger to bring down the temperature difference between two faces of peltier plate. However, continuous research is required on the thermoelectric refrigeration method to make it compatible with conventional refrigeration techniques.

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