THERMOELECTRIC REFRIGERATOR WITH PATTERNED AIR FLOW ARRANGEMENT

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Abstract

In the present world, refrigeration systems produce cooling effect using refrigerants and release harmful hydro fluorocarbons into environment. Using such refrigerants higher output can be achieved but one of the major disadvantages is harmful gas emission and global warming. Such problems are not present in thermoelectric modules and do not pollute the environment. This work deals with the design of a thermoelectric refrigerator with an effort to improve performance by designing patterned air flow management system. A thermoelectric refrigerator prototype has been built and performance analysis has been carried out in controlled ambient condition (25^{o}C). A sheet metal enclosure with vents for creating patterned air flow is designed in solid works and fabricated. The proposed refrigerator with patterned air flow arrangement could achieve up to 5^{o}C refrigeration temperature inside the cabinet. The comparative study revealed reduction of power consumption by 6.31% due to the changes made in the air flow pattern. CFD Analysis has been performed to validate the experimental results.

Keywords: *Thermoelectric Cooling, Peltier Refrigerator, Cooling System, Patterned Air Flow*

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1. INTRODUCTION

Conventional refrigerators used in homes and industries depend on refrigerants such as R140, R434 consists of hydro fluorocarbons which are a threat to the ozone layer. Hence thermoelectric or Peltier refrigerator is best suitable for above requirements. Thermoelectric refrigerators are environment friendly, compact and affordable. Thermoelectric refrigerators are semiconductor based devices. They have got several advantages like solid construction, quiet & reliable operation, no CFC's, precise temperature control. Since the air flow on both sides of electrical module affects the performance and inside temperature of unit, a great care must be taken during the design of sheet metal enclosures for effective air flow in both inside and outside of unit.

Scope of the project is to design a Peltier refrigeration system with sheet metal enclosure for patterned air flow both inside and outside of unit. Sheet metal enclosures are designed considering the general design considerations. Two sheet-metal enclosures both outside and inside of unit to produce patterned air flow on to the Peltier module have been designed. Two fans are arranged on both hot and cold side of Peltier module to extract the heat and cold from module respectively. The refrigerator performance has been analyzed with patterned air flow and without patterned air flow arrangements.

An experimental model was developed concentrating on heat sink design criteria and the model achieved cooling power of 50W [1]. A refrigerator using different TEC modules were built that achieved COP of 0.65[2]. Thermoelectric effect driven by solar power has been conducted [3].Comparison studies of thermoelectric and VCRC units were performed [4].Comparison study of COP for the rmoelectric and VCRC were performed [5].Study on effect of thermo syphon on heat dissipation was performed [6].A thermoelectric module with heating as well as cooling application was designed [7]. The Study of thermoelectric materials was conducted [8].Compact cooling air conditioners were designed with thermoelectric principle [9]. Thermoelectric cooling for cars was presented [10]. Study of performance of multiple thermoelectric materials was conducted [11]. Study on green refrigeration concepts were performed [12]. Experiment for cheapest heat sink design was conducted [13].

The literature survey reveals that most of the works have been carried out on heat sink designs and different thermoelectric materials. Since the analysis of the Peltier refrigeration system with patterned air flow arrangement is not present in the above literature, this work focuses on the air flow management of the system. Three different air flow patterns have been designed and analyzed. The arrangement which achieved least refrigeration temperature has been considered for further analysis. The patterned air flow has been arranged with the help of sheet-metal enclosure.

2. DESIGN AND EXPERIMENTAL SETUP

The outer and inner sheet-metal enclosures for creating patterned air flow in the exhaust system have been designed. Sheet-metal enclosures are developed in Solid Works software and then fabricated. Figure 1 shows the image of enclosure that has been assembled to the setup. The experimental setup has been arranged using polystyrene cabinet of 3.6 cubic feet size with the Peltier module and exhaust system assembled on the top. The refrigerator is placed inside an air condition controlled roomat 25^{o}C. A

hole has been made to the cabinet to accommodate the heat sink and Peltier module. 4 fans (CFM 75) are used in the exhaust system. One fan is used for internal air circulation and the other three for external air circulation. A power supply of 120V is used as the source and harness is used for connections.

Fig.1 Sheet metal enclosure for creating patterned air flow

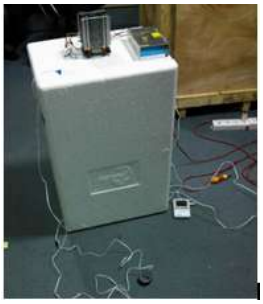

Fig.2 Refrigerator cabinet

3. PERFORMANCE ANALYSIS

The refrigerator is set in a controlled ambient condition and power supply has been given. The unit ran with patterned air flow and without patterned air flow till it achieved lower temperatures up to 5°C. 2 Fans were used in the exhaust system to circulate the hot and cold air in the cabinet. The power consumption and time taken to reach temperatures are documented and the CFD analysis has been performed using ANSYS Work bench to check the maximum and minimum temperatures of the unit numerically. The boundary conditions wereset. Numerical simulations were conducted using ANSYS Workbench 17.2. A second order upwind scheme was used to convert governing equations of momentum and energy to algebraic ones by integration of the governing equations and using the applicable numerical schemes on the control volumes. The coefficient of performance of the thermoelectric refrigerator is determined by following equations:

$$Qc = I\,\alpha\,Tc - 0.5\,I2R - Kt\,(Th - Tc)$$

$$Q_h = I\,\alpha\,Tc + 0.5\,I2R - Kt\,(Th - Tc)$$

Where,
Q_h = Heat rejection from Peltier Hot side
Qc = Heat absorption into Peltier Cold side
α = See beck coefficient (VK^{-1})
I = Current (A)
R = Electrical Resistance of TEC (Ohms)
K = Thermal conductivity

The values of TEC 12715 have been considered

$$COP = \frac{Q_C}{Q_h - Q_C}$$

$$= \frac{[I\,\alpha T_c - 0.5I^2R - K_t(T_h - T_c)]}{\alpha I(T_h - T_c) + I^2R}$$

Table -1: Peltier module data and temperature readings

Parameter	General Air flow	Patterned air flow
I	12	11
α	0.0532	0.0532
T_{hot}	320	310
T_{cold}	270	267
R	0.866	0.866
K_t	1.233	1.233
T_h-T_c	50	36

4. RESULTS AND DISCUSSION

The experimental observations are tabulated and the results are calculated. The current and voltage values are noted and power consumed by the refrigerator to reach to the refrigeration temperature up to -5°C has beencalculated. Table 2 and 3 shows the results of experimental analysis.

Table -2: Power consumption – without patterned air flow

Current (A)	Voltage (V)	Power (W)
0.46	1.43	0.65
0.76	2.54	1.93
1	3.1	3.1
1.24	4.47	5.54
1.32	5	6.6
1.56	7.3	11.38
1.59	7.5	11.92
1.63	8.2	13.36
1.69	11.8	19.94

Table -3: Power consumption – with patterned air flow

Current (A)	Voltage (V)	Power (W)
0.41	1.42	0.58
0.72	2.52	1.81
0.99	3	2.97
1.22	4.46	5.44
1.29	5	6.45
1.50	7.2	10.80
1.54	7.4	11.39
1.60	8.1	12.96
1.61	11.6	18.676

Considering the values from the experimental data,
COP – for normal air flow = 0.308
COP – for Patterned air flow = 0.391

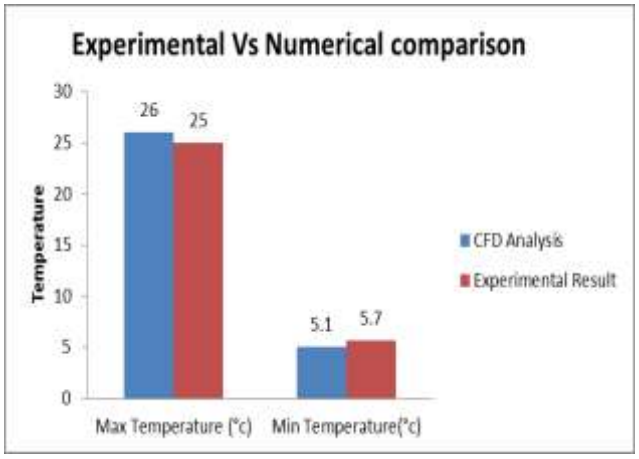

Fig.3: Experimental Vs Numerical data

The above graphs show that there is a deviation in experimental values when compared with the numerical analysis. This deviation might be because of the assumptions made in software and losses in practical environment.

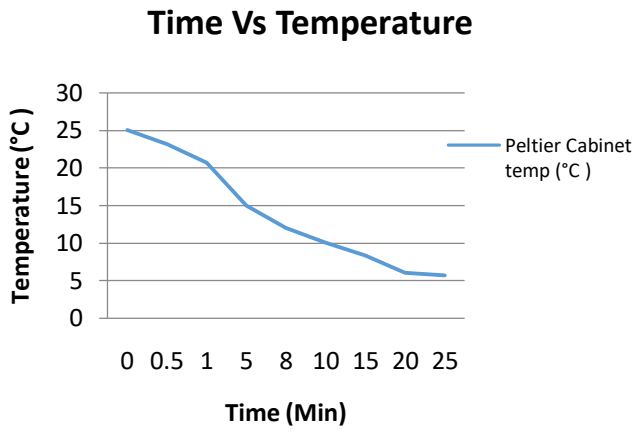

Fig.4: Variation of Temperature with Time inside cabinet

Figure 4 shows the temperature variation with time inside the Peltier cabinet. From ambient condition of 25 °C, the system takes 25 min to reach 5°C temperature. The ambient condition is maintained by using an air conditioner

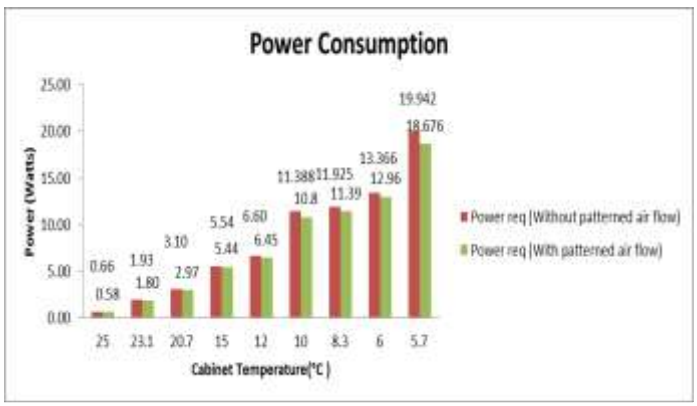

Fig. 5: Power consumption comparison – with and without patterned air flow

Figure 5 shows the difference in the power consumption of the Peltier refrigerator with metal enclosure and without the metal enclosure. The observations clearly state that the refrigerator with enclosure needs 1.26 W less to obtain 5°C temperature in the cabinet. Statistically, we can state that 6.3% of energy consumption is reduced by the modification

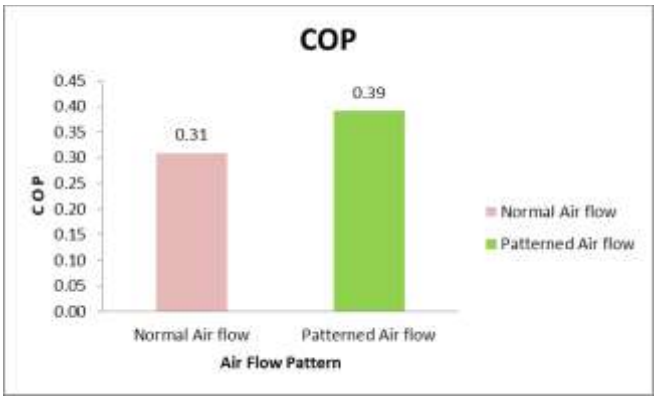

Fig.6: COP variation with air flow

There is a slight increase in COP of the thermoelectric refrigerator with the patterned air flow system which is depicted in Figure 6.

5. CONCLUSION

The following are the conclusions derived from the analysis:

- Patterned air flow arrangement (Exhaust and intake) improves performance of the thermoelectric refrigerator.
- Up to 6.31% of energy consumption can be reduced for the same refrigerator by regulatingthe air flow.
- COP of 0.39 is achievable withthermoelectric refrigerator with patterned airflow arrangement.
- Refrigeration temperatures as low as 5°C can be achieved using the thermoelectric modules.
- Air flow system is crucial in a thermoelectric refrigerator.
- Low noise refrigerators can be developed using Peltier technology.
- Better insulation to the unit helps in retaining the low temperatures for more duration.

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BIOGRAPHIES

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