Numerical assessment of Solar Collector with Finned Structure in Thermal Energy Storage System for Performance Enhancement

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Abstract

In the current study results are compared for the design configuration of proposed finned energy storage integrated with solar thermal collector. Modified collector design with integrated finned solar modules has been further analyzed for optimum design conditions. Multivariate analysis has been performed on geometric parameters (pitch, fin length, thickness) to further enhance the effectiveness of the system. Experimental investigation results provide optimal configuration with entropy generation rate as 0.37, discharging efficiency as 63.09%, charging efficiency as 68.81%, global thermal efficiency as 69.43 % and exergetic efficiency as 61.34%. Based on these experimental results, numerical analysis is done and correlations between performance parameters & geometry of newly designed finned PCM modules are developed. Consequently, thermal efficiency is projected to be improved by 21%. Charging efficiency, discharging efficiency are to be enhanced by 14% and 7%. Entropy generation rate and Exergetic efficiency are enhanced by 31% and 20% respectively for the optimum variables as fin length as 105mm, fin thickness to be 0.7mm and pitch as 60 mm with 4 number of fins.

Key Words: Solar collector; Energy storage; Phase change material; Efficiency.

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Nomenclature

A_C	Collector area, m^2	T_i	Inlet temperature of HTF (°C)
D	Tube outer diameter (m)	To	Outlet temperature of HTF (°C)
E	Exergy	Ts_{ur}	Simulator surface temperature (°C)
E_{xdest}	Exergy destruction	U_L	Collector overall heat constant, (W/ m^2)
f	Friction factor	V	Air velocity in m/s
F_R	Heat removal factor	x_b	Bottom insulation thickness(m)
h_a	Convective heat transfer coefficient for air (W/m^2. K)	Δt	Time (s)
Δh	Enthalpy change	P	Density
I	Radiation intensity (W/ m^2)	**Greek symbols:**	
K	Kelvin	η_c	Global thermal efficiency
k_Θ	Incident angle modifier	η_{ex}	Exergetic efficicency
k	Coefficient of flow velocity	T	Glazing transmission efficiency
k_b	Insulation conductivity at bottom (J/m.K)	A	Absorption constant of absorber plate
$\mathbf{l_f}$	Fin length (mm)	Ψ	Specific energy function (kJ/kg)
m	HTF Mass flow rate, (lpm)	**Subscripts:**	
n_f	Number of fins in one module	a	Ambient
N	Number of glazing plates	avg	Average
p_f	Pitch	ch	Charging
Q_s	Rate of exergy received	dest	Destruction
ΔS	Entropy change	dis	Discharging
T_a	Atmospheric temperature, (°C)	f	Fin
t_f	Fin thickness	i	Inlet

Acronym list:

ANN	Artificial neural network	GRNN	Generalized regression neural networks
CFD	Computational Fluid Dynamics	HMI penal	Human-machine interface penal
EPP	Expanded polypropylene	HTF	Heat transfer fluid
FEM	Finite element method	lpm	Litre per minute
FPSC	Flat plate solar collector	PCM	Phase Change Material
GA	Genetic Algorithm	RSM	Response surface method

1 Introduction

Sun is the eternal source of energy. The systems to collect or convert this energy are yet to be explored. Solar collector is the active method which is preferred due to its low cost and wide range of low temperature applications. But due to the low efficiency and effectiveness, the cost of the system is not justified. This consideration is driving the multi-objective analysis in this area. In this study we have experimentally analyzed the modified solar collector and further optimized the design parameters to enhance its performance. Design modification is followed by a newly designed absorber plate configuration of the solar collector for water heating. Experiment is performed on trapezoidal shaped absorber plate with finned thermal energy storage system at the bottom. The effects of key geometric parameters are investigated. Genetic algorithm using MATLAB is used for optimization to further enhance the performance of the system by predicting the best possible configuration of the system.

1.1 Literature survey:

A comprehensive review of the recent studies & their results have been discussed in this section. Saeed & Roghayeh [1] employed grey relational analysis by Taguchi to identify the ideal parameters for PCM melting time. The impact of different factors, like pitch and diameter, on the thermal performance of the storage system was examined. Eames & Adref [2] performed simulation on a solar based water heating system with slurries made by PCM. Hamed et al. [3] examined the effectiveness of solar collectors supported by various PCMs using numerical analysis of one-dimensional models (1D models). Result shows that unit with PCM attains lower outlet temperatures during the storing mode and higher outlet temperature during discharge mode in comparing a system without PCM. Carmona & Palacio [4] created the correlations needed to evaluate the integrated solar collectors with PCM using a dynamic thermal model. Keeping the environment in mind, two kinds of PCM are taken into consideration. This model has very low

error in comparison to experimental data in context to the temperature measurement. Moreover, Bilardo et al. [5] examined a PCM-based thermal storage unit with an integrated flat plate collector and heat pipes that were filled with methanol. For thermal modeling, a hybrid 1 dimensional 2 dimensional numerical model is applied, and it is found that this system is less efficient than similar systems. Harish et al. [6] [7] performance of a recently developed PCM storage system combined with a modified solar collector was experimentally studied. The PCM modules' internal fin structure was utilized. There was a notable increase in charging and discharging efficiency of 24% and 28%, respectively. Beemkumar et al. [8], investigated structures with fins and encapsulation to store thermal energy of the hot water from the solar accumulator. It has been determined that encapsulation offers superior performance at a lower cost. Li and Yu [9], performed numerical analysis of the cubic cavity under ambient conditions with a fin containing PCM. With the increase in sensible heat storage, a notable improvement in heat transfer performance is seen when fins are used. Mat et al. [10], investigated the rate of heat transfer between PCM and the heat transfer fluid as well as the ability of a single finned, three-pipe heat exchanger to melt PCM. Melting time was reduced by 43.3% when utilizing fins in an inner-outer arrangement as opposed to the standard design. Sciacovelli et al. [11], applied RSM & CFD to determine the performance of thermal energy storage of a shell and tube tree-shaped fin. Optimization results in the performance improvement by 24%. Islam et al. [12] used cylindrical fins to enhance the performance of a solar still. As a result, in performance of customized solar still, 41% more water is received from solar still. Verma et al. [13] developed an innovative spiral shaped tube type solar collector to enhance the thermal performance. Consequently, the thermal efficiency is increased by 21.94% and exergetic efficiency by 6.73%. Kumar et al. [14] conducted a numerical analysis to investigate the coated triangular solar air heater's performance. According to reports, efficiency can increase by up to 43%. Lapertot et al. [15] conducted a multi-objective optimization analysis for a solar collector in order to determine the ideal trade-off between collector efficiency and solar fraction. Dounia et al. [16] optimized the design parameters for the

integrated solar heater with PCM-based thermal energy storage system using computational fluid dynamics (CFD). Sheikholeslami et al. [17], Using a copper nanoparticle, a horizontal flat blade, and a fin shaped like a snowflake, the performance of nanoparticle aided thermal energy storage was examined. Finite FEM was used in a numerical manner. A noteworthy outcome was noted with the novel fin design fashioned like a snowflake. Kamkari and Shokouhmand [18], determined experimentally how fins affected a rectangular cavity filled with PCM in a horizontal direction. As a result of which Δt reduced by 18% and 37% for one and three fins respectively. Xu et al. [19] In order to improve the charging performance of PCM employing square cavity, optimum horizontal fins were created using a genetic algorithm and the CFD approach, taking into account affecting factors like fin placement, number, and thickness. This study has shown that, in cases when fin thickness is unconstrained, a uniform fin length is preferable; in the event that fin thickness is constrained, the optimal compromise in terms of fin numbers must have been chosen in accordance with fin length. Compared to straight fin geometry, a novel "L" shaped fin was utilized to shorten the charging time in a vertical PCM container by Wang et al. [20], numerically. The L-shaped fin was found to reduce charging time by 4%. This design's dimensions and placement were also numerically optimized. The impact of altering the fin material was examined by Tian et al. [21] in a rectangular enclosure. As a result of this the charging time was reduced by 41.6%, 41.0%, 40.1% and 37.2% using copper, aluminium, carbon steel and steel fins respectively. The performance of thermal storage tank with PCM modules was numerically simulated by Najafian et al. [22] Artificial Neural Network (ANN) technology. Melting time and design characteristics were connected. Because of this, the optimal top location is discovered, and adding more PCM lengthens the melting period. ANN was deployed by Kalogirou et al. [23] to predict the storage tank temperature levels for large solar storage systems. The results revealed that tank temperature with R^2 higher 0.96. Yaïci and Entchev [24] a back-propagation artificial neural network (ANN) was used to forecast PCM performance for home hot

water heating. With an accuracy of ± 3%, the temperatures of stratification were predicted. It was noted that the training R2 was 0.9986.

Aforementioned literature survey shows that many researchers have experimentally analyzed the different configurations of integrated collector with thermal energy storage system. The use of fins and their optimization has a noteworthy impact on the reviewed investigations. They then used a simulation to compare and optimize the energy storage performance of the existing systems. Affecting variables such as PCM type, component geometry, and heat transfer augmentation methods to facilitate easy fin analysis, has been explored yet. However, few shortcomings are observed during the literature survey.

Therefore, the purpose of this study is to develop the model for the newly designed finned thermal energy storage module to optimize the thermal performance of the integrated system. The highlights of this study defining the novelties of the proposed analysis are:

- Different configuration of fins geometry is studied in different conditions.
- Newly designed finned thermal energy storage system is considered in the present study.
- Regression analysis is performed in order to develop the governing function for performing the multi-objective optimization.
- Multi objective Genetic algorithm in MATLAB is used.
- Charging as well as discharging efficiencies are compared for existing design and optimized configuration

2 Physical model & Methodology

This section includes methodology comprising of apparatus for experimental investigation, working procedure and optimization methodology. Also, the detailed specifications of testing setup & GA optimization are discussed.

2.1.1. Experimentation

Test rig is having two sections. One is for simulator assisted solar collector and another is for finned PCM module below the collector for thermal energy storage as shown in Fig.1. Solar simulator with halogen lamps are used with the capacity form 1kW to 8kW moderation. Other penal options can be seen in Fig.1, as rotameter for flow measurement radiation control knob, HMI penal for HTF temperature control. Four channel data logger and six channel data logger with digital display are used for temperature measurement of finned PCM modules and collector plate temperature respectively. Fig. 2 demonstrates a schematic of complete setup in exploded and assembled view including real images also. One of the fins configurations is also shown in PCM module. Paraffin wax is filled inside the PCM module. Table 1 provides the specifications for the material used in setup preparation. In Table 2 setup specifications are demonstrated.

Table:1 Specifications of materials used in setup

Material	Description	Specification
Paraffin wax as PCM (procured from Platonic Nanotech Pvt. ltd Jharkhand-India)	Density in liquid state	875 kg/m^3
	Density in solid-state	965 kg/m^3
	Liquid phase Specific heat	1.8 kJ/kg ºC
	Latent Heat of fusion	174 kJ/kg
	Melting point temperature	57ºC
	Solid-phase Specific heat	2.3 kJ/kg ºC

	Thermal Conductivity	0.181 W/m ºC
Copper (99%) for absorber plate & PCM modules	Specific Heat	0.38 kJ/(kg K)
	Thermal conductivity	390 W/ m-K
EPP foam for back insulation	Thermal conductivity	0.046 W/m-K

Table:2 Experimental setup details

Description	**Specification**
Outer measurements of the collector	640 x 470 x 72 mm^3
HTF tank capacity	12 Liters
HTF tube	2 manifolds & 15 risers
HTF Pump power	500 W
Solar Simulator	1kW to 8kW
Rotameter	0.25 l/m to 5 l/m
Absorber plate temperature logger	Six-channel Digital
PCM module temperature logger	Four-channel Digital
PCM module dimensions	650*100*10 mm^3
PCM storage module	15 nos.
Pitch of HTF tubes	20 mm
HTF tube outer dia	12 mm
HTF tube inner dia	10 mm
Pitch ofHTF tubes	3.2 cm
Back insulation thickness	2.5 cm
Absorber plate thickness	1.2 mm
Mass of PCM used	4 kg



Figure 1 Experimental setup

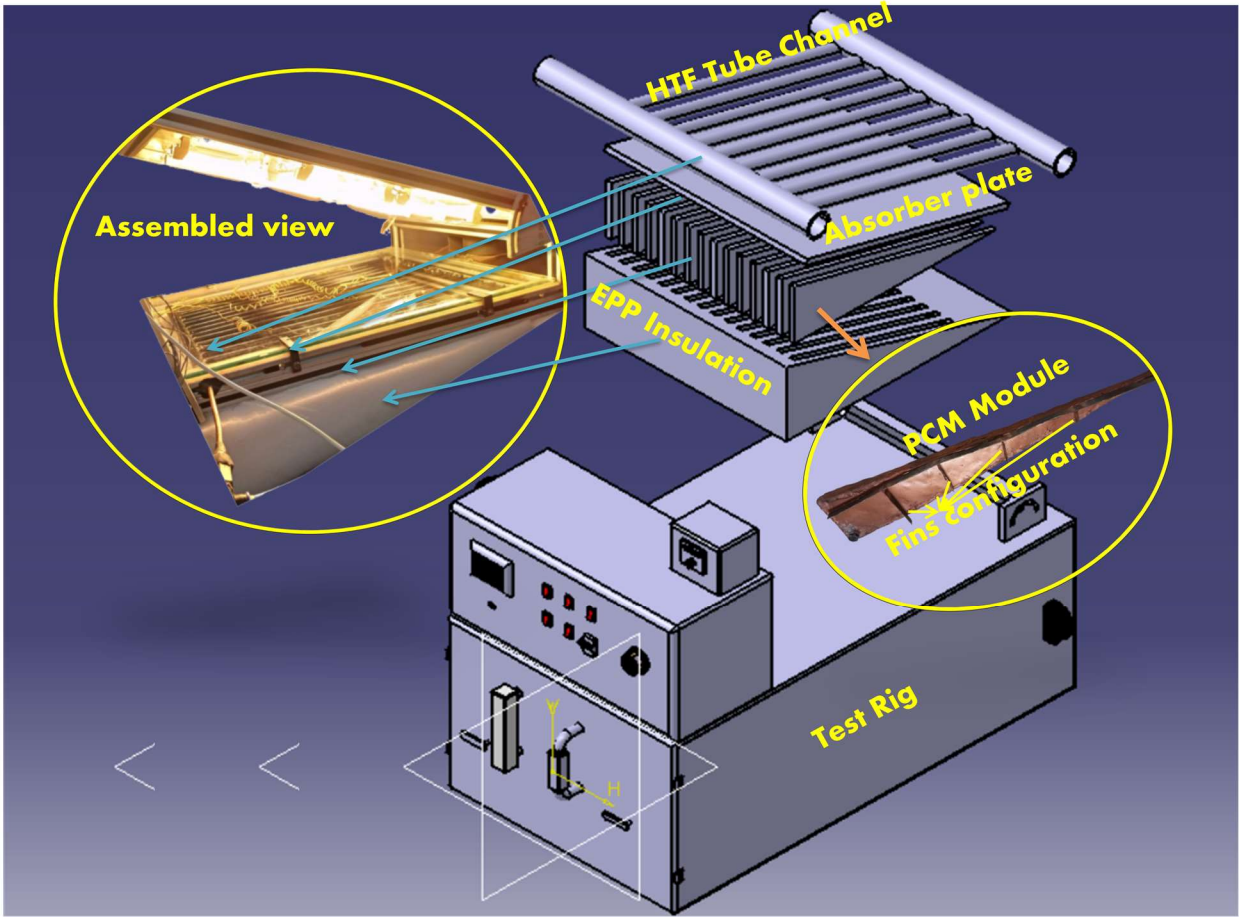


Figure 2 Exploded view of complete setup

2.1.2. Optimization using multi objective GA

In order to optimize the design parameters of finned PCM module, multi objective Genetic algorithm optimization technique is used for data reduction and to find the optimum response as well as geometric variables. Five objective functions have been selected on the basis of most influencing characteristics during energy analysis, which are instantaneous charging efficiency, instantaneous discharging efficiency, entropy generation rate, exergetic efficiency, thermal efficiency of the system. Developed objective functions as mentioned in equations (27) to (31), are developed on the basis of

experimental investigation for the following set of fins combination selected (Table 3). Regression analysis is performed to develop these correlations using MS excel and explained in next section.

Table 3 Geometrical specifications used in the experiments

Sr. No.	Geometric parameters	Set A	Set B	Set C
1	Fin pitch (mm)	140	100	60
2	Fin length (mm)	120	100	80
3	Fin thickness (mm)	0.5	1.5	2.5

GA algorithm provides suboptimal solutions and combines several suboptimal solutions by the crossover, mutation and cloning, to find the optimal solution among all suboptimal solutions. So other specifications such as crossover fraction value is selected as 0.8 for maximum probability, population type is selected as double vector, adaptive feasible function is used for mutation, single point crossover function is selected with forward migration for optimization.

3 Mathematical modeling

In this section governing equations with their boundary condition are defined. Correlations are developed for geometrical parameters of finned PCM module using curve fitting in MS Excel based on experimental data of observed analysis.

3.1 For proposed finned PCM module

Energy analysis

During discharging phase

$$mc_p\left(T_{out}-T_{in}\right)+m_p c_p\left(dT_{P,avg}/dt\right)+U_L\left(T_{P,avg}-T_e\right)T=Q_{dis}c \quad (1)$$

During charging phase

$$mc_p\left(T_{out}-T_{in}\right)+m_p c_p\left(dT_{P,avg}/dt\right)+U_L\left(T_{P,avg}-T_e\right)T_c=\eta_o IA_c-Q_{ch} \quad (2)$$

3.2 Energy storage by finned PCM Collector

$$Q_u=A_C F_R I_t\left(\tau_o\alpha_o\right)-A_C F_R U_L\left(T_i-T_a\right)-\frac{m_{pcm}\times\Delta H_{m,pcm}}{\Delta t}\ (\text{for } T_m=T_{pcm}) \quad (3)$$

$$R_{tot}=\frac{1}{h_w}+\frac{x_{tube}}{k_{tube}}+\frac{x_p}{k_p} \quad (4)$$

$$Q_u=A_C F_R I_t\left(\tau_o\alpha_o\right)-A_C F_R U_L\left(T_i-T_a\right)-\frac{T_p-T_{pcm}}{R_{tot}}\times A_{pcm}\ (\text{for } T_m\neq T_{pcm}) \quad (5)$$

Energy stored by PCM modules during charging phase[25]

$$Q_{ch}=m_{pcm}\Delta H+m_{pcm}C_{p,l}\left(T_{fin.ch.pcm}-T_m\right)+m_{pcm}C_{p,s}\left(T_m-T_{ini.ch.pcm}\right) \quad (6)$$

Energy stored by PCM modules during discharging phase

$$Q_{dis}=m_{pcm}\Delta H+m_{pcm}C_{p,s}\left(T_{ini.dis.pcm}-T_m\right)+m_{pcm}C_{p,l}\left(T_m-T_{fin.dis.pcm}\right) \quad (7)$$

3.3 Efficiency of finned collector

Charging phase

$$\eta_\theta=\kappa_\theta F_R\left[\left(\tau_o\alpha_o\right)-\frac{U_L\left(T_i-T_a\right)}{I_t}\right]-\frac{T_p-T_{pcm}}{R_{tot}\times A_C\times I_t}\times A_{pcm}\ (\text{for } T_m\neq T_{pcm}) \quad (8)$$

$$\eta_\theta=\kappa_\theta F_R\left[\left(\tau_o\alpha_o\right)-\frac{U_L\left(T_i-T_a\right)}{I_t}\right]-\frac{m_{pcm}\times\Delta H_{m,pcm}}{\Delta t\times A_C\times I}\ (\text{for } T_m=T_{pcm}) \quad (9)$$

While discharging

$$\eta_\theta=\frac{mC_p\left(T_{out}-T_{in}\right)}{\left(\frac{T_p-T_{pcm}}{R_{tot}}\times A_{pcm}\right)}\quad (\text{for } T_m\neq T_{pcm}) \quad (10)$$

$$\eta_{\theta} = \frac{mC_p\left(T_{out} - T_{in}\right)}{\left(\frac{m_{pcm} \times \Delta H_{m,pcm}}{\Delta t}\right)} \quad \text{(for } T_m = T_{pcm}\text{)} \tag{11}$$

3.4 Exergetic investigation of finned PCM module

$$E_{x,heat} - E_{x,mass,out} - E_{x,mass,in} - E_{x,work} = E_{x,dest} \tag{12}$$

$$\sum(1-\frac{T_a}{T_{Sur}})Q_S - \sum m_{out}\psi_{out} + \sum m_{in}\psi_{in} - w = E_{x,dest} \tag{13}$$

$$\sum(1-\frac{T_a}{T_{sur}})Q_S - m\left(h_{out} - h_{in}\right) - T_a\left(s_{out} - s_{in}\right) = E_{xdest} \tag{14}$$

Where,

$$Q_S = I_t\left(\tau\alpha\right) = SA_c \tag{15}$$

Also,

$$\left(1-\frac{T_a}{T_{sur}}\right)I_t(\tau\alpha)A_C - mRT_a \ln\frac{P_{out}}{P_{in}} + mc_pT_a\ln\frac{T_{f,out}}{T_{f,in}} - mC_p\left(T_{f,out} - T_{f,in}\right) = Exdest \tag{16}$$

Where,

$$E_{xdest} = T_a \cdot S_{gen} \tag{17}$$

$$\eta_{ex} = 1 - \frac{T_a S_{gen}}{\left[1 - \frac{T_a}{T_s}\right]Q_s} \tag{18}$$

Exergy analysis of finned PCM module

$$E_{x,in} = mc_p\left[\left(T_{in} - T_{out}\right) - T_a\ln\left(\frac{T_{in}}{T_{out}}\right)\right] \textbf{[26]} \tag{19}$$

$$E_{x,out} = mc_p\left[\left(T_{out} - T_{in}\right) - T_a\ln\left(\frac{T_{out}}{T_{in}}\right)\right] \tag{20}$$

$$E_{x,stored} = mc_p\left(T_{in} - T_{out}\right)\left[1 - \frac{T_a}{T_m}\right] \tag{21}$$

$$\eta_{ex} = \frac{E_{x,out}}{E_{x,in}} \tag{22}$$

Reduced temperature parameter,

$$h = \frac{T_i - T_a}{I} \tag{23}$$

Stefan Number,

$$St = \frac{\text{Sensible heat}}{\text{Latent heat}} = \frac{c_p\left(T_{fo} - T_{fi}\right)}{\Delta H} \tag{24}$$

3.5 Correlations developed

Pitch, length, thickness, and number of fins are examples of finned geometrical characteristics that are obviously impacting parameters, as demonstrated by the experimental study.

for η_{ch}, η_{dis}, S_{gen}, η_{ex}, η_{Θ}. So following correlations are developed using MS excel for the boundary conditions as:

$$\left\{\begin{array}{c} 60mm \le p_f \le 140mm \\ 80mm \le l_f \le 120mm \\ 0.5mm \le t_f \le 2.5mm \\ 4 \le n_f \le 8 \end{array}\right\}$$

Correlation developed for charging efficiency of finned PCM module,

$$\eta_{ch} = 2\times10^{-18} \times p_f{}^{-0.024} \times l_f{}^{19.489} \times n_f{}^{0.0883} \times t_f{}^{0.0037} \times \exp\left(\left(\ln\left(t_f\right)\right)^2\right) \times \exp\left(-2.1073 \times \left(\ln\left(l_f\right)\right)^2\right) \tag{25}$$

Correlation developed for discharging efficiency of finned PCM module,

$$\eta_{dis} = 3\times10^{-43} \times p_f{}^{0.1923} \times l_f{}^{43.93} \times n_f{}^{0.19} \times t_f{}^{-0.0122} \times \exp\left(0.3428 \times \left(\ln\left(t_f\right)\right)^2\right) \times \exp\left(-4.7813 \times \left(\ln\left(l_f\right)\right)^2\right) \tag{26}$$

Correlation developed for entropy generation rate of finned PCM module based solar collector,

$$S_{gen} = 4\times10^{50} \times p_f{}^{-0.158} \times l_f{}^{-50.608} \times n_f{}^{0.6338} \times t_f{}^{0.3344} \times \exp\left(-0.303\times\left(\ln\left(t_f\right)\right)^2\right)\times \exp\left(5.4362\times\left(\ln\left(l_f\right)\right)^2\right) \quad (27)$$

Correlation developed for exergetic efficiency of finned PCM module based solar collector,

$$\eta_{ex} = 2\times10^{-65} \times n_f{}^{0.2793} \times l_f{}^{66.309} \times p_f{}^{-0.025} \times t_f{}^{-0.1053} \times \exp\left(0.6051\times\left(\ln\left(t_f\right)\right)^2\right)\times \exp\left(-7.2019\times\left(\ln\left(lf\right)\right)^2\right) \quad (28)$$

Correlation developed for thermal efficiency of finned PCM module based solar collector,

$$\eta_{\theta} = 10^{19} \times n_f{}^{0.1463} \times l_f{}^{-17.169} \times p_f{}^{0.025} \times t_f{}^{0.0669} \times \exp\left(-0.1383\times\left(\ln\left(t_f\right)\right)^2\right)\times \exp\left(1.8533\times\left(\ln\left(l_f\right)\right)^2\right) \quad (29)$$

As illustrated in Figure 3, the error intervals for thermal efficiency, charging efficiency, discharging efficiency, energetic efficiency, and entropy generation ratecorrespond to the aforementioned correlations: ±12%, ±11%, ±16, and ±14%, respectively. Figure displays the variance between the correlation results and the experimental outcomes. The correlation coefficients are 0.97, 0.95, 0.98, 0.96 and 0.96 for thermal efficiency, charging efficiency, discharging efficiency, exergetic efficiency and entropy generation rate respectively.

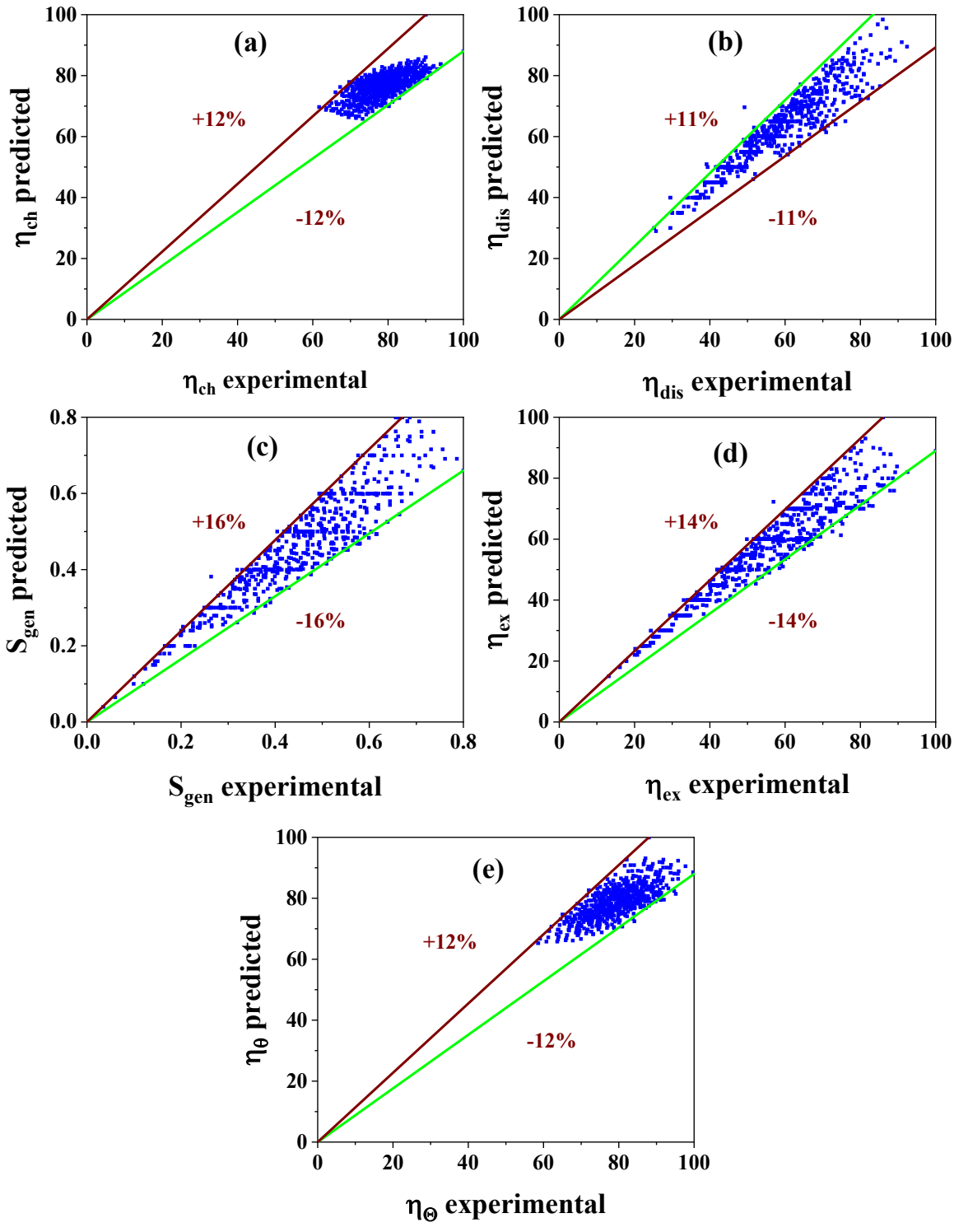


Figure 3 Comparison of experimental & correlation results

4. Results and Discussion

In this section experimentally obtained results and their performance on the thermal energy storage system with respect to numerically obtained results using GA are discussed. The data used for GA is considered for a constant value mass flow rate of 2.25 lpm and a constant irradiance of 1165 W/m^2. Corresponding to these value optimum geometric parameters for fins configuration and optimum response to the dependent variables are shown below in Table 4 & Table 5.

Table 4: Comparison of GA & experimentally obtained results of best of selected combinations

Sr. No.	Objective functions	Experimental Results	GA Obtained results
1	Thermal efficiency	69.34	84.21
2	Exergetic efficiency	61.43	73.64
3	Entropy generation rate	0.36	0.264
4	Discharging efficiency	63.9	67.53
5	Charging efficiency	68.18	78.74

Table 5: Geometric parameters GA Obtained

Number of fins	Fin length (mm)	Thickness (mm)	Pitch (mm)
4	105	0.7	60

So it can be observed that using these design parameters, entropy generation rate and exergetic efficiency is improved by 31% and 20% respectively. Charging efficiency, discharging efficiency and Thermal efficiency are improved by 14%, 7% and 21% respectively..

On the basis of results obtained from multi-objective GA, it has been identified that for the selected design of finned PCM module, pitch and thickness are the most influencing independent variable. So, thermal storage system performance of GA obtained results is

compared with respect to performance for different pitch and thickness combinations selected.

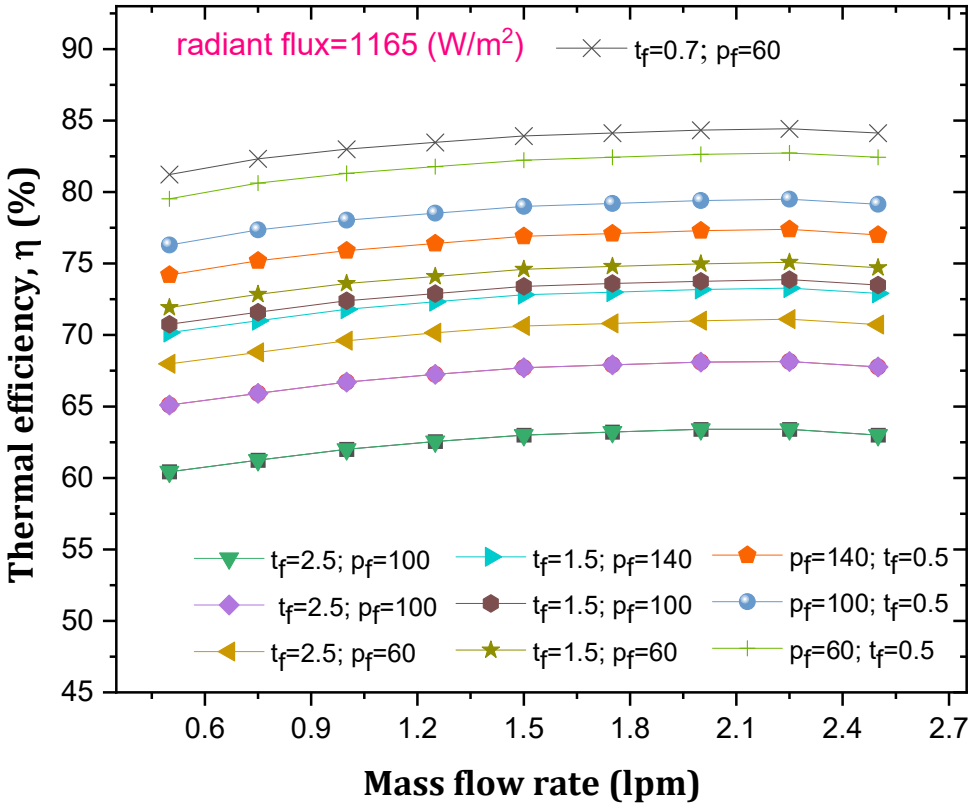


Figure 4: Comparison of thermal efficiency for several finned PCM storage system layouts at various mass flow rates

Figure 4 compares the thermal efficiency of various finned PCM storage system topologies at varying mass flow rates, taking into account all possible geometric combinations of fin thickness and pitch. It can be seen that a minimum pitch of 60 mm combined with the GA-predicted thickness of 0.7 mm results in a maximum efficiency of 84%, 21% higher than the experimental result. It is evident that when pitch decreases, the storage system's thermal performance increases. Hence, additional energy analysis is

carried out while keeping the minimum pitch (pf=60mm) constant and changing the thickness.

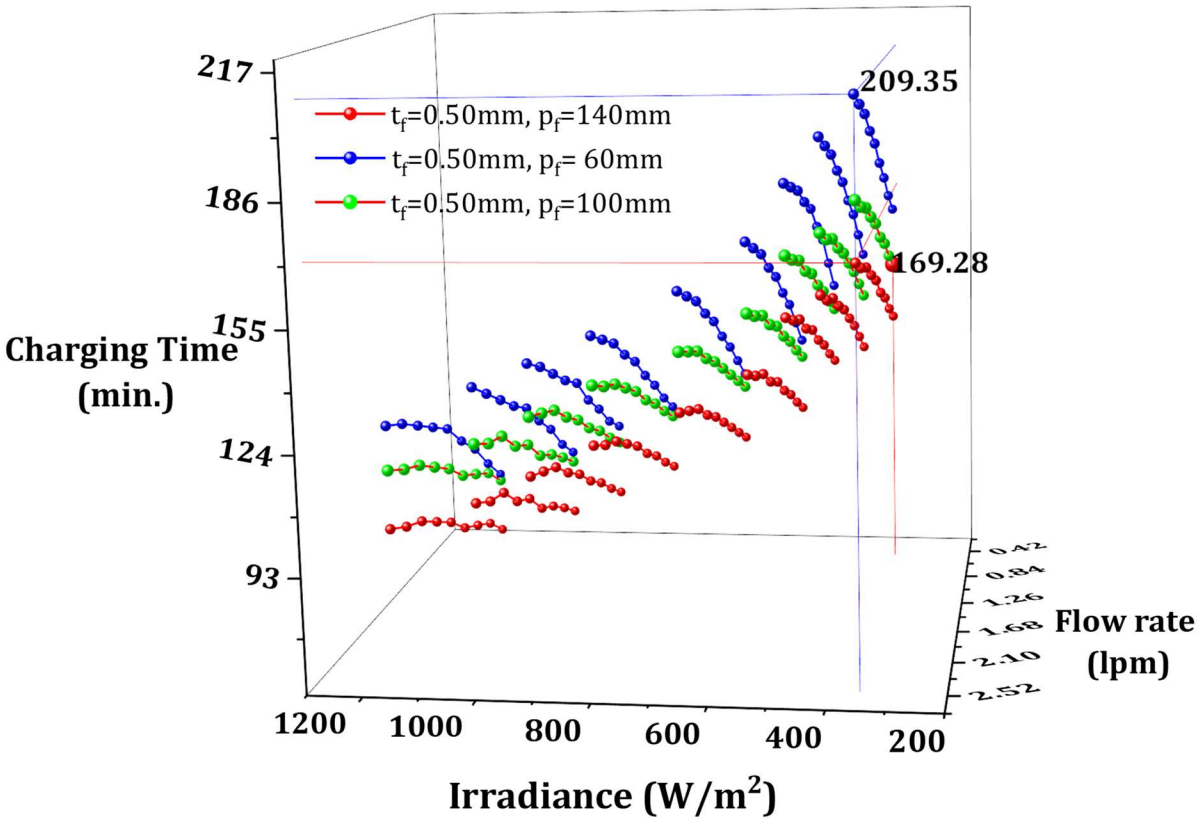


Figure 5: Comparison of storage time for various fin configurations in relation to pitch at various levels of solar irradiance

Fig.5 and Fig.6 demonstrates the decrease in charging and discharging times in relation to the fins' pitch reduction under certain intensities of solar radiation. Again, it is clearly depicted that the thermal performance of the finned energy storage system enhances with decrease of pitch.

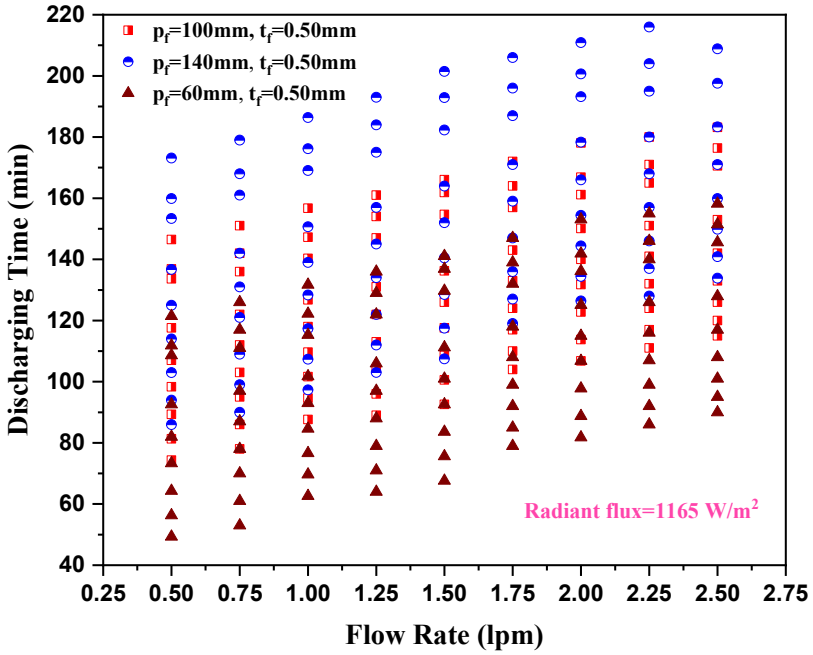


Figure 6: Comparing the discharge times for various fin configurations in relation to pitch at various radiant flux

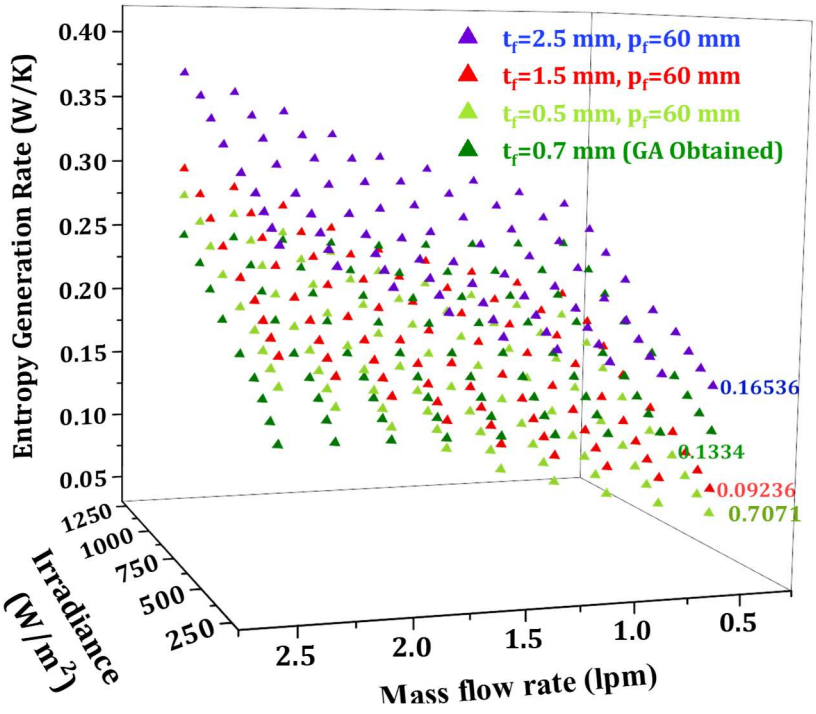


Figure 7: Entropy generation comparison of experimental results and numerically obtained fin geometry

Fig. 7 demonstrates decrement of entropy generation rate with decrement of fin thickness. However, based on GA research, it is anticipated that it will reach criticality at 0.7 mm, with a noteworthy 31% improvement. Therefore, 0.7 mm is the crucial thickness that will further improve the recently developed energy storage system.

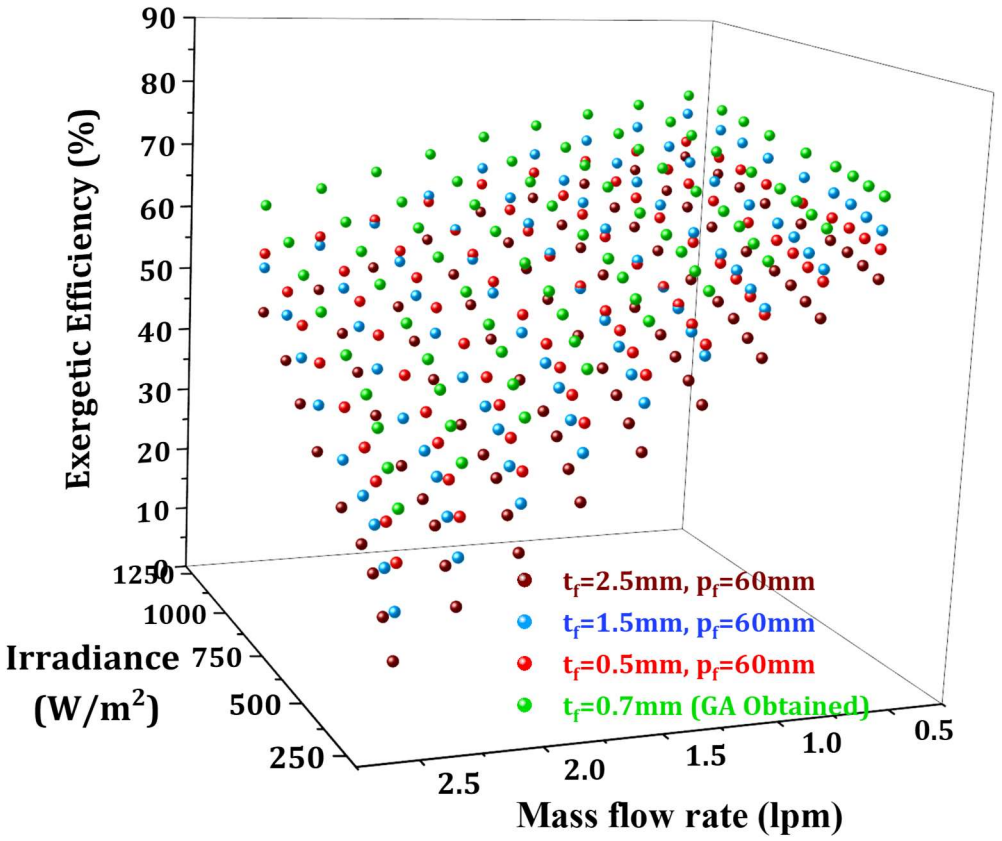


Figure 8: Exergy efficiency comparison for experimental results and numerically obtained fin geometry

Fig.8 further illustrates the essential fin thickness evidence. A 20% increase in exergetic efficiency is anticipated when this design configuration is employed, based on numerical study.

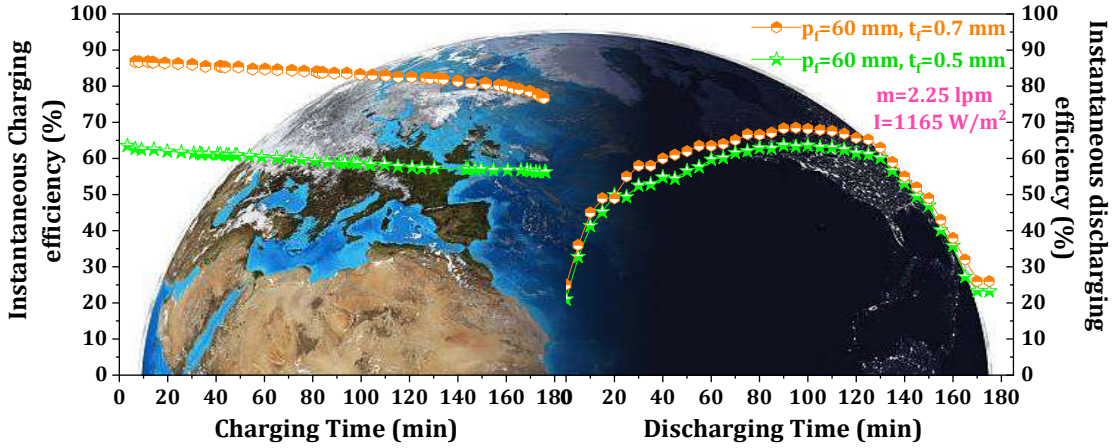


Figure 9: Comparison of the best experimental results' instantaneous storage percentage release efficiency with the fin geometry determined using GA

It is also endorsed by Fig. 9 When choosing the adjusted geometric parameters, the energy storage system's thermal performance will be improved by utilizing instantaneous efficiencies that optimize response. By choosing GA achieved fin thickness and pitch, charging efficiency has increased by 14% and discharging efficiency has increased by 7%.

5. Conclusion & future scope

In the present study numerical modeling and optimization using genetic algorithm is proposed for finned PCM modules. Exergy, entropy & efficiency equations are solved with the boundary conditions. Three different fins geometric parameters are examined using three different set of experimental levels. The new finned thermal energy storage module configuration is tested using additional optimization results. The final geometry and the overall performance of the various combinations are compared.

Aforementioned results are concluded as:

- Experimental investigation is performed to validate the thermal performance of newly designed finned PCM based thermal energy storage system. Nine configurations of fins geometry is used for energy analysis.
- As a result, configuration with fin thickness 0.5 mm, pitch 60 mm, fin length 105mm with 4 number of fins are proven best experimentally.
- The charging efficiency of 68.18%, the discharging efficiency of 63.9%, the entropy generation rate of 0.36, the exergetic efficiency of 61.43%, and the global thermal efficiency of 69.34% are the experimentally ideal responses.
- Based on these responses, regression analysis is performed in MS excel to develop the correlation between these performance parameters & geometry of newly designed finned PCM modules.
- Five correlations are developed having all four geometric parameters of fin skeleton defined such as thickness, pitch, numbers and length of fins.
- The correlations and bounds (geometric combinations used during experiments) with optimum GA parameters (crossover fraction as 0.8, population type as double vector, adaptive feasible function for mutation, single point crossover function with forward migration) are used to apply multi-objective GA technique for optimization and data reduction.
- Higher charging efficiency (78.74%), discharging efficiency (67.53%), entropy generation rate (0.264), exergetic efficiency (73.64%), and global thermal efficiency (84.21%) were the improved optimal answers obtained. It is therefore anticipated that thermal efficiency will increase by 21%. Exergetic efficiency and entropy generation rate are predicted to increase by 20% and 31%, respectively,

while charging efficiency and discharging efficiency are predicted to improve by 14% and 7%, respectively.

- optimal compromise among the variables With four numbers of fins, the thickness is 0.7 mm, the fin length is 105 mm, and the pitch is 60 mm.
- Fin thickness and pitch are found to be the influencing variables for the thermal performance of the system.

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