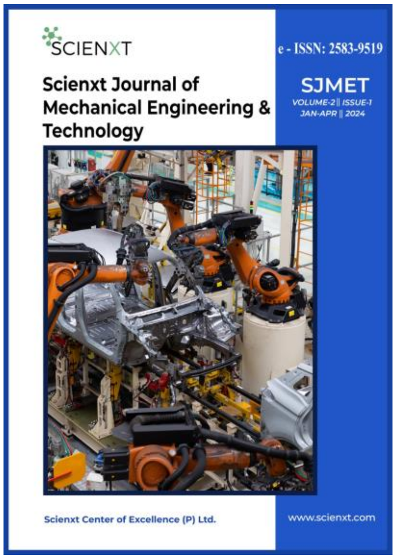

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Utilizing hybrid grey relational analysis for numerical analysis And multiple attribute decision-making optimization of flat plate pin fin heat sink

Suresh Kumar Badholiya[*1], Shivam Kesharwani[2], Aarti Kandekar[3], Dada Terdale[4], Harsh Singh Parmar[5], Hemant Kumar[6], Deepak Kachahe[7]

[1]Associate Professor, Department of Mechanical Engineering, Bhopal Institute of Technology & Science. Bhopal, India

[2,3,4,5,6,7] Student, Department of Mechanical Engineering, Bhopal Institute of Technology & Science. Bhopal, India

**Corresponding Author: Suresh Kumar Badholiya*
E-mail: Suresh.badholiya@gmail.com

Abstract:

The current investigation employs Grey Relational Analysis (GRA) to conduct multi-objective optimization of flat pin fins heat sinks. Through various simulations, including simulations numbered 03, 2, and 11, optimal configurations have been identified. Notably, simulation 03, characterized by specific dimensions (length = 70 mm, width = 70 mm, fin height = 10 mm, base height = 4 mm, fin thickness = 1.2 mm, and 30 fins), emerges as one of the top-performing setups. Additionally, an analysis reveals the significant influence of parameters such as fin length, width, height, thickness, and number on heat transfer efficiency. For instance, optimal values for maximizing the heat transfer coefficient include length = 80 mm, width = 70 mm, fin height = 10 mm, base height = 8 mm, fin thickness = 1 mm, with 30 fins. Conversely, minimizing pressure drop is crucial, with the optimal configuration characterized by length = 90 mm, width = 90 mm, fin height = 30 mm, base height = 6 mm, fin thickness = 0.8 mm, and 10 fins. These findings offer valuable insights for enhancing the performance of flat pin fins heat sinks across various thermal management applications.

Keywords:

Grey Relational Analysis (GRA), multi-objective optimization, flat pin fins heat sink, simulation, optimal configurations, heat transfer efficiency, heat transfer coefficient, pressure drop

1. Introduction:

Research on evaporation processes, particularly in solutions like urea and water, is of significant importance in both industrial applications and environmental systems. This paper aims to investigate the dynamics of urea-water droplet evaporation, with a focus on integrating the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) technique for optimization. The motivation for this research originates from the widespread agricultural utilization of urea-water solutions as fertilizers. As sustainable agricultural practices gain momentum, there is a growing need to understand and optimize the evaporation process to enhance nutrient delivery and mitigate environmental impact. Additionally, in automotive Selective Catalytic Reduction (SCR) systems, optimizing urea-water solution (UWS) evaporation is crucial for effectively reducing nitrogen oxides (NOx) emissions. Given the challenges posed by limited space and variable operating conditions in automotive SCR systems, precise control of UWS injection and evaporation is necessary for optimal performance.The study also explores evaporative self-assembly, a phenomenon where nonvolatile solutes precipitate onto a solid surface during evaporation. Inspired by the coffee-ring effect, this process finds applications in various fields such as microfluidic devices, biotechnology, and inkjet printing. Understanding the underlying mechanisms of evaporation-induced self-assembly contributes to the development of novel assembly methods.

The objectives of this research include investigating the evaporation characteristics of urea-water droplets, analyzing the impact of parameters like concentration and temperature on the evaporation process, and optimizing the process using the TOPSIS technique. By addressing these objectives, this study aims to enhance our understanding of evaporation processes in urea-water solutions and facilitate the development of more efficient and sustainable agricultural and automotive technologies. Fluid Dynamics, a subfield of fluid mechanics, encompasses the detailed analysis of fluid movement, including liquids, gases, and plasmas. Its applications span various industries such as engineering, medicine, and technology. Within fluid dynamics, specialized fields like aerodynamics, hydrodynamics, and thermal engineering address distinct aspects of fluid behavior. Thermal engineering, in particular, focuses on fluid flow, which is essential for understanding the motion and transfer of thermal energy. Refined approaches to optimizing flat fin heat sinks entail adjusting channel geometries to enhance heat transfer efficiency while mitigating pressure drop. Employing multi-objective optimization methodologies like GRA facilitates the identification of optimal design parameters for achieving superior thermal performance. Integral to this process are experimental investigations and simulation validation, which are instrumental in pinpointing the most effective structural arrangements for flat pin heat sinks.

2. Simulation study:

The temperature distribution within the solid region is determined by solving the steady conduction equation. The fluid flow is assumed to be steady, laminar, and incompressible. The governing equations for the flow field are represented by Equations 5.1 to 5.3. It is assumed that the viscosity, thermal conductivity, and specific heat capacity of the working fluid remain constant throughout the calculations, irrespective of temperature.

Momentum conservation equation is given as

$$\rho\vec{\psi}\cdot\nabla\vec{v}=\mu\nabla^2\vec{v}-\nabla P \qquad 1$$

Mass conservation or continuity equation is given as

$$\nabla\cdot(\rho\vec{v})=0 \qquad 2$$

Here, ρ is the density of the fluid and “is the velocity vector of the flow field.

Energy conservation equation for fluid is given as

$$\rho C_p\nabla\cdot(\vec{v}T)=k_f\nabla^2T \qquad 3$$

Energy conservation equation for solid is given as:

$$\nabla^2T=0 \qquad 4$$

Nusselt number:

$$Nu=\frac{hD_h}{k_{\mathrm{air}}}=\frac{qD_h}{\left(T_w-\frac{T_{\mathrm{in}}+T_{\mathrm{out}}}{2}\right)} \qquad 5$$

Pressure drops

$$\Delta P = P_{in} - P_{out} \qquad 6$$

2.1. Numerical methodology:

The computational analysis for all examples is performed using the commercial software ANSYS Fluent R19.1. Second-order upwind discretization techniques are employed for momentum and energy equations. The numerical solution method utilized is the Semi-Implicit Method for Pressure Linked Equations (SIMPLE). A viscous-laminar model is applied, considering Reynolds numbers ranging from 100 to 1000.

Table. 4.1: Materials properties of working fluid

	P ***(kg m^{-3})***	***k*** ***(kg m^{-3})***	***Cp*** ***(W m^{-1}K^{-1})***	***μ*** ***(kg m^{-1}s^{-1})***
Air	1.225	0.0242	1006.43	1.7894 e-5

	ρ (kg m^{-3})	k (W m^{-1}K^{-1})	C_p (J kg^{-1} K^{-1})	μ (kg m^{-1}s^{-1})
Air	1.225	0.0242	1006.43	1.7894 e-5

2.2. Modeling and results:

A standard aluminum heat sink, following the geometry specifications outlined in the design of experiment table, is simulated using ANSYS 19. The model comprises three distinct regions: the heat sink region, the source region, and the ground plane. The aluminum ground plane is modeled with dimensions of 150×135×1 mm, positioned beneath the heat sink at a distance of 5 mm. The typical flat plate heat sink, featuring "N" number of fins, is depicted in Fig. 1. A lumped port with an impedance of 50Ω is defined to represent the coupling between the processor and the heat sink. Additionally, there are no additional grounding points for the processor to mitigate radiation, thereby avoiding additional costs and space constraints

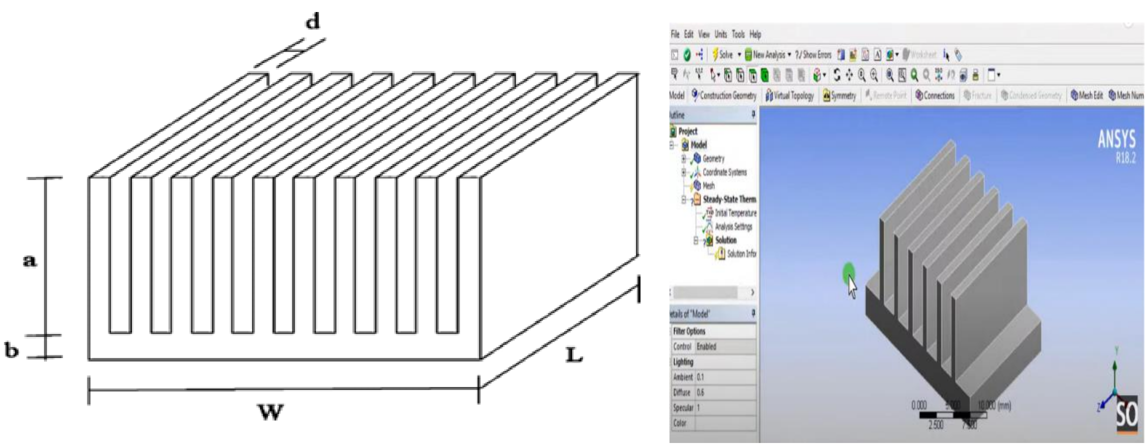

Figure. 1: CAD modeling of fin structure

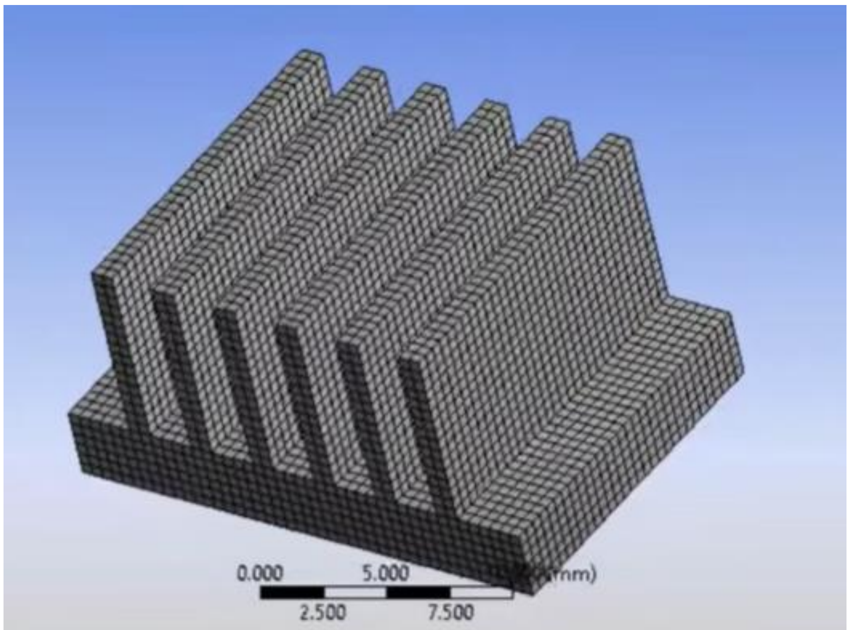

Figure. 2: Meshed structure

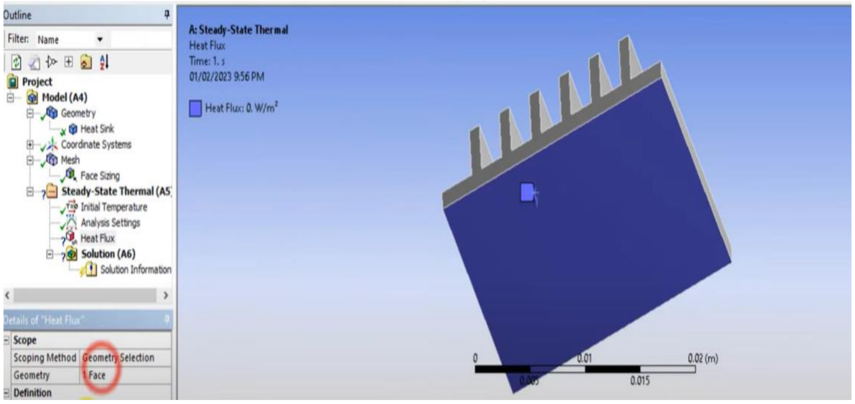

Figure. 3: Heat flux applied at surface

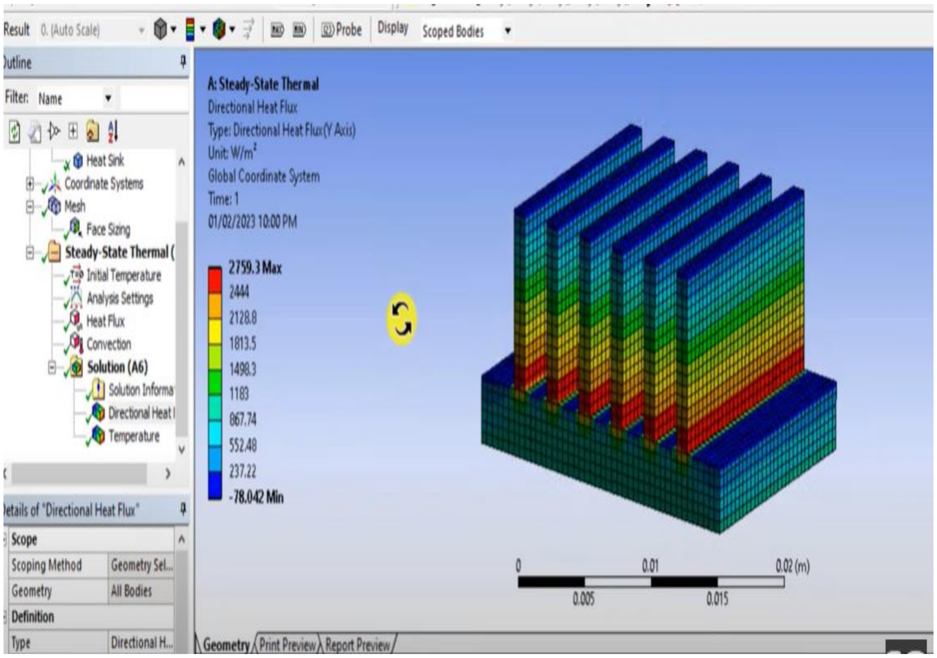

Figure. 4: Heat flux distribution

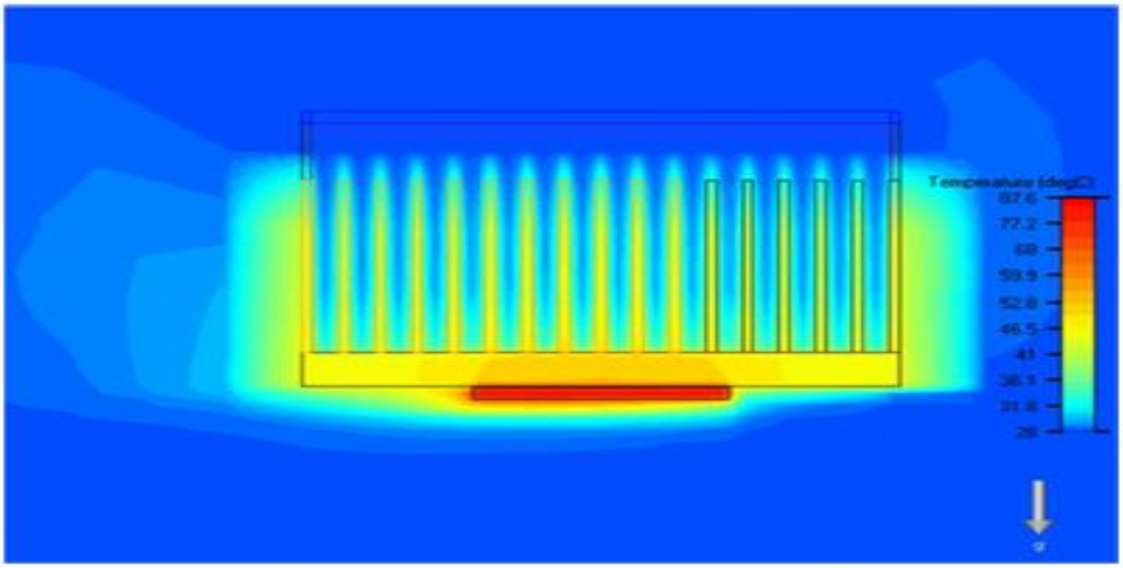

Figure. 5: Temperature distribution

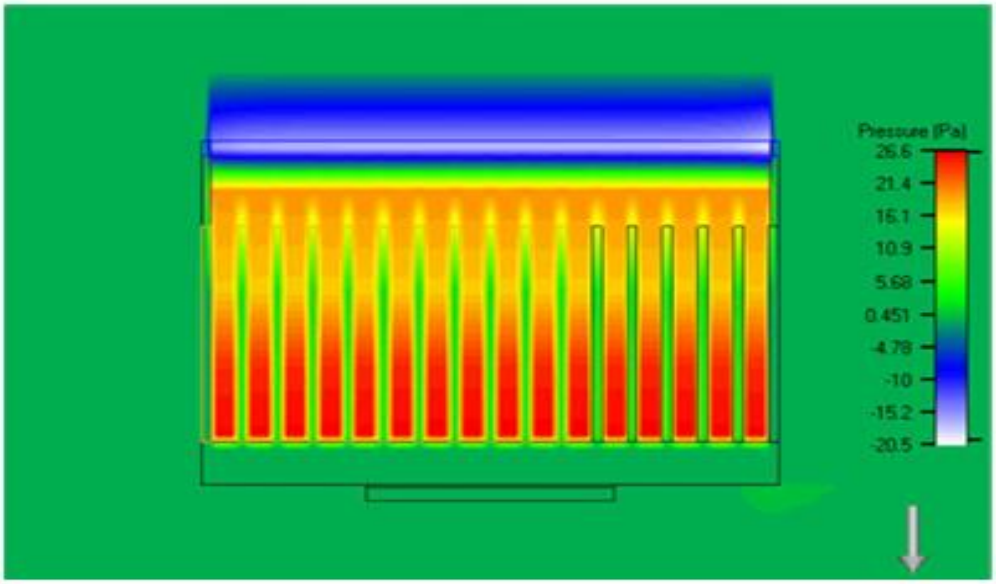

Figure. 6: Pressure distribution

3. Optimization result and discussion:

3.1. Simulation result:

Table. 2: Simulation results

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Navigator

Taguchi Design

Taguchi Design

WORKSHEET 2

Taguchi Design

Design Summary

Taguchi Array L27(3^6)
Factors: 6
Runs: 27

Columns of L27(3^13) array: 1 2 3 4 5 6

	C1	C2	C3	C4	C5	C6	C7	C8
	Length	Width	Fin height	Base Height	Fin thickness	No of fins	heat tranfer	pressure drop
1	70	70	10	4	0.8	10	38.682	31.6110
2	70	70	10	4	1.0	20	43.892	41.8210
3	70	70	10	4	1.2	30	49.232	62.2310
4	70	80	20	6	0.8	10	27.002	9.2710
5	70	80	20	6	1.0	20	33.732	14.4910
6	70	80	20	6	1.2	30	30.892	24.4710
7	70	90	30	8	0.8	10	23.122	3.1810
8	70	90	30	8	1.0	20	23.382	5.7910
9	70	90	30	8	1.2	30	23.031	11.6510
10	80	70	20	8	0.8	20	38.602	16.7410
11	80	70	20	8	1.0	30	46.282	34.5510
12	80	70	20	8	1.2	10	35.752	13.7210
13	80	80	30	4	0.8	20	32.322	6.7010
14	80	80	30	4	1.0	30	24.792	12.0810
15	80	80	30	4	1.2	10	22.812	4.3410
16	80	90	10	6	0.8	20	34.942	18.2510
17	80	90	10	6	1.0	30	37.088	24.1110
18	80	90	10	6	1.2	10	35.036	18.0740
19	90	70	30	6	0.8	30	25.172	14.4710
20	90	70	30	6	1.0	10	24.092	5.4310
21	90	70	30	6	1.2	20	27.432	17.5410
22	90	80	10	8	0.8	30	36.822	40.7710
23	90	80	10	8	1.0	10	30.292	28.6210
24	90	80	10	8	1.2	20	30.292	28.6210
25	90	90	20	4	0.8	30	23.112	10.0291
26	90	90	20	4	1.0	10	22.902	5.5410
27	90	90	20	4	1.2	20	24.392	9.1910

4. Topsis optimization:

flat plate pin fin heat sink simulated values are optimize using Grey regression analysis, ANOVA and the effects of individual welding process parameters on the selected quality characteristics are calculated separately and presented in following section. The average value and S/N ratio of the response characteristics for each variable from different level are calculated from the simulated data.

4.1. S/N ratio:

On the basis of characteristics three SN (Signal to Noise) ratios are available mainly lower the better, higher the better and nominal the better. In this proposed research higher the better are used for heat transfer, and lower the better for pressure drop.

SN ratio for "lager is better" $SN_L = -10\log\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y^{i^2}}\right.$ 7

Smaller is Better SN ratio for "smaller is better"

SN_s ratio for "Smaller is better" $SN_s = -10log\sum_{i=1}^{n} y^{i^2}$ 8

Nominal is better

SN_n = 10 Log10 (square of mean / variance) 9

4.2. Data pre-processing:

Heat transfer co-efficient and pressure drop are the dominant response in flat plat fin attachment that decides the heat transfer. For the "Higher-the-better and lower the better" characteristic, the initial sequence may be normalized as follows:

$$x_i^* = \frac{x_i(k) - x_{imin}(K)}{x_{i\,max}(k) - x_{imin}(k)} \qquad 10$$

Where, xi (k)* and x (k) are the sequence after the data preprocessing and comparability sequence respectively, k=1 for temperature; i=1, 2, 3…, 9 for experiment numbers 1 to 27 Calculate grey relational grade (calculate GRG)

Table. 3: GRG values

Exp No.	*GRG*
1	0.497875
2	0.626116
3	1
4	0.303902
5	0.37848
6	0.388835
7	0.253484
8	0.265489
9	0.282763
10	0.436749
11	0.616386
12	0.395824
13	0.339532
14	0.296653
15	0.256111
16	0.403052
17	0.447021
18	0.403367
19	0.307311
20	0.269193
21	0.334769
22	0.531238
23	0.401322
24	0.401322
25	0.278003

26	0.261247
27	0.284272

4.3. Evaluate the ranking based on GRC value:

Table. 4: Ranking of performance parameters

Exp No	*Rank*
1	5
2	2
3	1
4	18
5	14
6	13
7	27
8	24
9	21
10	7
11	3
12	12
13	15
14	19
15	26
16	9
17	6
18	8
19	17
20	23
21	16

22	4
23	10
24	10
25	22
26	25
27	20

5. Conclusion:

In present study following are the results and concluding remarks which have been obtained during the above research attempt:

- Grey relational analysis (GRA) method is used for multi objective optimization of flat pin fins heat sink.
- The top three experiments for the flat pin fin heat sink are simulation number 03 (length = 70 mm, width = 70 mm, fin height = 10 mm, base height = 4 mm, fin thickness = 1.2 mm and number of fins are 30), Simulation no 2 (length = 70 mm, width = 70 mm, fin height = 10 mm, base height = 4 mm, fin thickness = 1 mm and number of fins are 20) and simulation no 11 (length = 80 mm, width = 70 mm, fin height = 20 mm, base height = 8 mm, fin thickness = 1mm and number of fins are 30).

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