ISSN: 0975-8585

Research Journal of Pharmaceutical, Biological and Chemical Sciences

Analysis of Design Parameters of Radiator.

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ABSTRACT

Radiators are the main source of heat exchange in automobile engines. Sizes of the radiator play the major role in deciding quantity of heat removal. The objective of this paper is to design an optimal size of a radiator that dissipates maximum amount of heat exchange in best design. Different sizes of radiators are considered from various branded companies of automobile cars. The effect of design parameters such as width, height of tube and fin, number of tubes and fins, mass flow rate of water and air, velocity of air were varied for different sizes of radiators. Theoretical design calculation with various design parameters is developed in MATLAB coding and optimization of design parameters was executed in MINITAB software using TAGUCHI method. The optimized design is modeled in SOLIDWORKS and CFD analysis is verified in ANSYS. From the theoretical and numerical analysis it was observed that compared to other parameters the width of fin, number of tubes and air velocity plays the major role in heat transfer rate. It was found that as the width of fin, number of tubes and air velocity increases the heat transfer rate increases.
Keywords: CFD analysis, MATLAB-coding, Optimization, Radiator, Taguchi.

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INTRODUCTION

Heat transfer plays the major role in the mechanical engineering field. Major heat transfer takes place in power plants and automobile engines. Heat exchangers are the devices used to transfer the heat between two fluids flowing at different temperatures separated by a solid wall. Application of heat exchangers can be used for either cooling (refrigerators) or heating (space heating) the required fluid. Heat exchangers can be classified into many types based on the fluids flow direction such as parallel flow, cross flow or counter current flow. Heat exchangers can also vary on the design of construction with numbers of tubes, presence of hot plates. Radiators are used as the cooling device where the hot coolant from the engine is cooled by the air forced by the motion of the vehicle. Lots of research is going on designing the heat exchangers for particular applications. Amrutkar et al. [1] focused on thermal analysis of radiator theoretically using ε-NTU method and its validation by 1D simulation approach. Shravan et al. [2] presented a simplified approach to optimize the design of Shell Tube Heat Exchanger [STHE] by flow induced vibration analysis [FVA]. Amin Hadidi et al. [3] developed a new shell and tube heat exchanger optimization design approach based on biogeography-based optimization (BBO) algorithm. Pawan et al. [5] focused radiator design validation through finite element analysis as well as size and heat rejection validation by experimental test.

THE OBJECTIVE OF THIS PAPER IS TO OPTIMIZE THEORETICAL AND NUMERICAL ANALYSIS AND COMPARE THE DIFFERENT SIZES OF RADIATOR DESIGN TO OBTAIN THE MAXIMUM HEAT TRANSFER PROCESS. THE PRESSURE DROP AND WATER MASS FLOW RATES ARE VARIED TO STUDY THE CHANGES IN THE OUTLET TEMPERATURE OF WATER.

THEORETICAL ANALYSIS

The different sizes of radiators are considered from various automobile industries which are available in SERCK and are tabulated in Table.1. From the Table 1, the core sizes are considered for design and MATLAB coding was developed for the theoretical calculations. The input parameters of one set of radiator size are shown in Table 2.

Table 1: Radiator core sizes of different Branded Automobile Companies

S. No	Branded Company	Model	Radiator Core size in mm.		
			Height	Width	Thickness
1	AUDI	AUDI	635	416	34
2	BMW	BMW	600	458	32
3	DAEWOO	Chevrolet Cruze	500	378	16
4	FORD	Escape	700	448	26
5	HONDA	Odyssey RA6	450	708	16
6	HYNDAI	Truck	570	528	26
		H100 Bus	445	568	26
		H100 Mini Bus	400	568	26
		Accent	360	468	16
		Tucson/ Sportage	640	458	22
		Santa-FE-2.4-1.6V	670	478	16
7	I SUZU	Trooper 3.1	500	608	26
8	MAZDA	Mazda M3 BK5P	670	368	16
9	MITSUBISHI	Outlander	700	408	16
10	NISSAN	Infiniti Armada Titan Q56	597	668	69
11	RENAULT	Megane TD	585	398	36
12	SUZUKI	2.7L V6	475	598	26
13	TOYOTA	Corolla ZZ E12	600	348	16
14	VOLKSWAGON	Golf / Bora	650	398	26

ISSN: 0975-8585

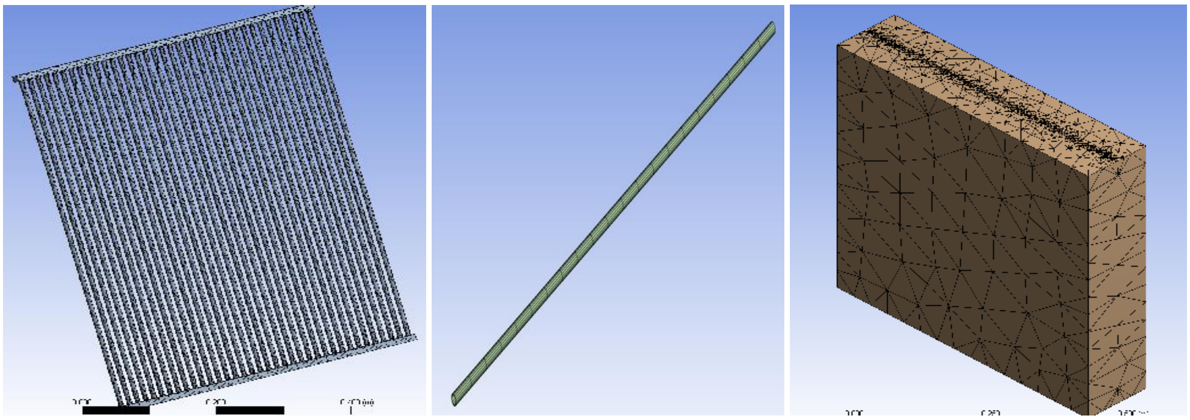
Table 2: Selected design of Radiator

S. No	Parameters	Values varied		
1	Height of Radiator core	0.6m	0.5m	0.4m
2	Width of Radiator core	0.65m	0.55m	0.45m
3	Thickness of Radiator core	0.01m	0.02m	0.03m
4	Aluminium fin thickness	0.001m	0.00075m	0.0005m
5	Copper tube outer diameter	0.009m	0.015m	0.025m
6	Copper tube inner diameter	0.008m	0.014m	0.024m
7	Number of tubes	36		
8	Number of fins	300		
9	Mass flow rate of coolant	1kg/s		
10	Air inlet temperature	30 ^{0}C		
11	Water inlet temperature	80^{0}C = 353K		
12	Air outlet temperature obtained	53.65^{0}C = 326.65K	58.65^{0}C = 331.65K	60.42^{0}C = 333.42K
13	Water outlet temperature obtained	66.04^{0}C = 339.04K	63.09^{0}C = 336.09K	63.18^{0}C =336.18K

NUMERICAL ANALYSIS

Modeling:

Using the above design the solid models are created in SOLIDWORKS and imported to ANSYS – workbench for performing CFD analysis. Figure1 shows the geometry model of water domain, copper tube and air domain created for analysis.



Water domain ***Copper tube*** ***Air domain***

Fig 1: Model created in Solid works

Meshing

The solid model was meshed in I**C**EM-**C**FD using tetrahedral volume mesh. Table3 shows the number of nodes and elements of the air, **c**opper tube and water domains.

Table 3: Elements and nodes of each domain

Domain	Nodes	Elements
Air	9552	43986
Copper tube	12096	22176
water domain	7354	13350

Boundary Conditions

Figure2 shows the boundary condition of the meshed model which is imported to **C**FX-Pre and three domains were created. Air inlet is applied with air velocity of 2 m/s and out let at average static pressure of atmospheric. Water inlet is applied with 10 kg/sec mass flow rate at inlet temperature of about 80^0C inlet pressure of 10 x 10^5 N/$m^2$and outlet with static pressure of 1 atm. Mass and momentum is selected with free slip wall. CFD analysis was performed to compute the water outlet temperature by varying the inlet pressure of about 10, 5 and 2.5 x 10^5 N/m^2 and varying the water mass flow rate of about 10, 5, 2.5, 2, 1.5 and 1 kg/sec.

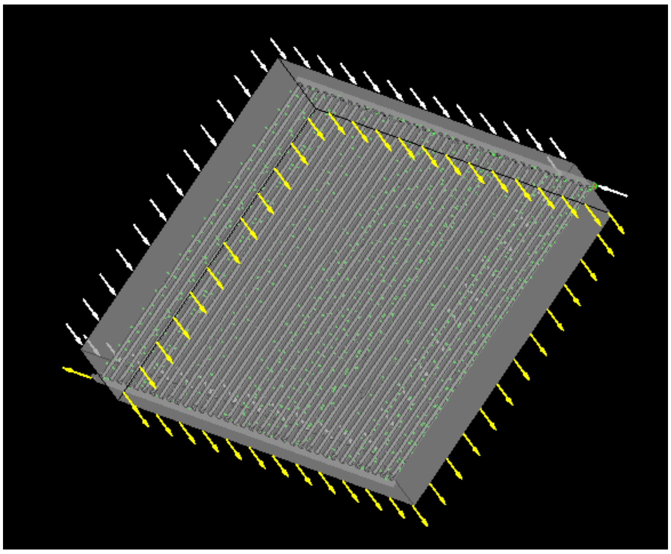


Fig 2: Boundary condition of the model

Figure3 shows the velocity vector of air in horizontal direction and water domain in vertical direction for the particular boundary conditions. The velocity of air is more in the inlet and gets decreased to atmospheric at the outlet.

Post-Processor Results:

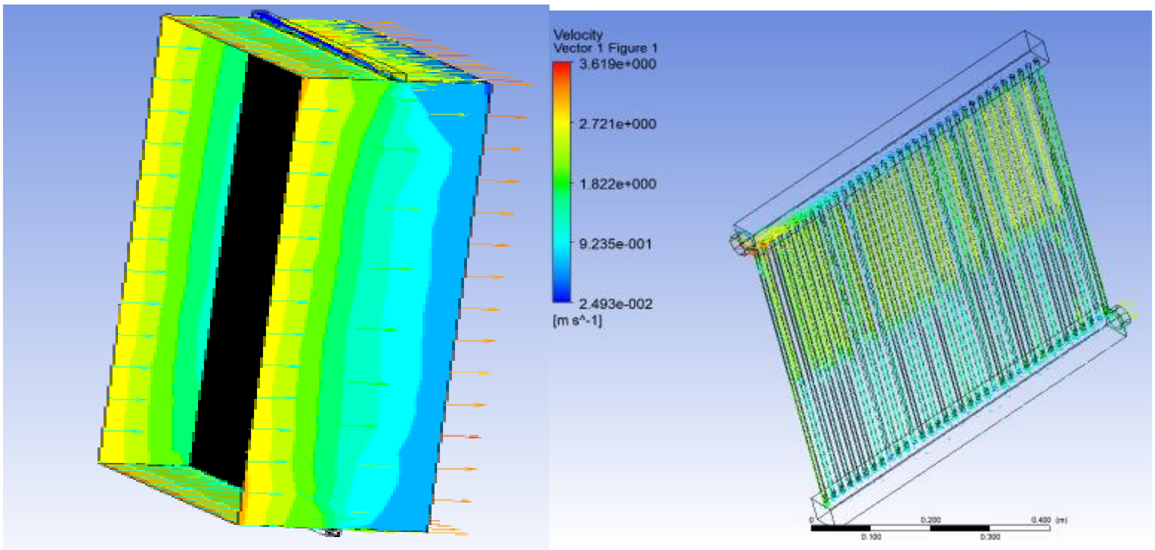


Fig 3: Velocity vector of air and water

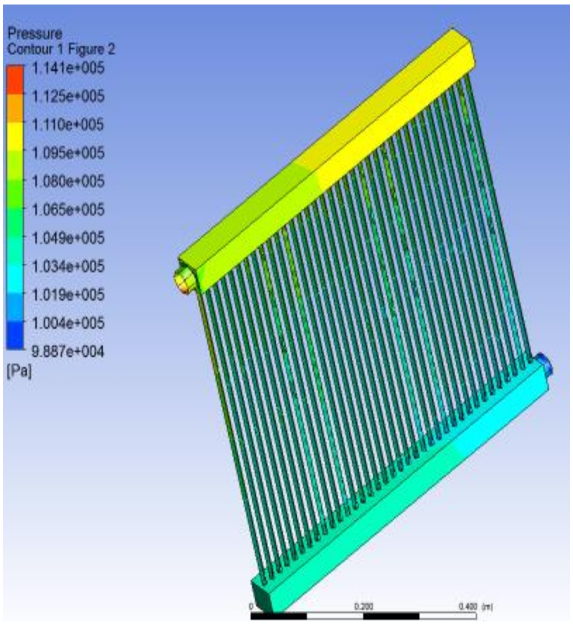


Fig 4: Pressure contours

Figure4 shows the pressure contours which is maximum in the inlet and gets decreased at the inlet and figures 5 represents the Temperature contours of water from initial to final mass transfer. The water temperature is maximum in the inlet and gets decreased gradually downwards to the outlet.

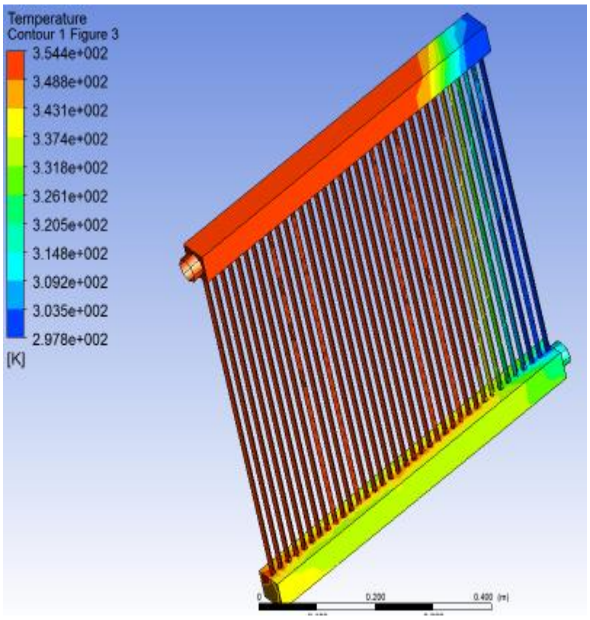


Fig 5: Temperature contours

RESULTS AND DISCUSSIONS

By varying the inlet pressure and water mass flow rate the temperature of water was computed. Table 4 and figure 6shows the outlet water temperature for varying pressure drop and water mass flow rate. The data proves that as the water mass flow rate decreases the outlet temperature decreases and as the pressure drop increases the water temperature decreases.

Table 4: Water outlet temperature for varying water mass flow rate and pressure drop

Water Mass flow rate in kg/sec	Inlet pressure in $*10^5$ N/m^2		
	10	**5**	**2.5**
10	321.946 K	317.631K	317.625K
5	320.2K	316.255K	316.258K
2.5	316.696K	313.394K	313.354K
2	314.148K	311.229K	311.293K
1.5	308.9K	308.939K	308.97K
1	306.415K	306.512K	306.664K

Table 5: Parameters varied for optimization

Cell	Parameters	Values varied		
A	Inner diameter of tube	0.008m	0.014m	0.024m
B	Height of tube	0.6m	0.5m	0.4m
C	Length of fin	0.65m	0.55m	0.45m
D	Height of fin	0.001m	0.00075m	0.0005m
E	Number of tubes	30	40	50

ISSN: 0975-8585

F	Number of fins	300	400	500
G	Air mass flow rate	1 kg/s	5 kg/s	10 kg/s
H	Water mass flow rate	1 kg/s	5 kg/s	10 kg/s
J	Air Velocity	15 m/s	20 m/s	25 m/s

Table 6: Taguchi Orthogonal Array Design OF L27

	A	B	C	D	E	F	G	H	J	K	L
1	0.008	0.6	0.65	0.001	30	300	1	1	15	**79.99**	**30.022**
2	0.008	0.6	0.65	0.001	40	400	5	5	20	**78.66**	**34.53**
3	0.008	0.6	0.65	0.001	50	500	10	10	25	**73.85**	**40.42**
4	0.008	0.5	0.55	0.00075	30	300	1	5	20	**79.99**	**30.04**
5	0.008	0.5	0.55	0.00075	40	400	5	10	25	**78.41**	**35.38**
6	0.008	0.5	0.55	0.00075	50	500	10	1	15	**72.24**	**43.16**
7	0.008	0.4	0.45	0.0005	30	300	1	10	25	**79.99**	**30.12**
8	0.008	0.4	0.45	0.0005	40	400	5	1	15	**77.44**	**38.68**
9	0.008	0.4	0.45	0.0005	50	500	10	5	20	**71.28**	**44.77**
10	0.014	0.6	0.55	0.0005	30	400	10	1	20	**63.85**	**57.37**
11	0.014	0.6	0.55	0.0005	40	500	1	5	25	**79.99**	**30.003**
12	0.014	0.6	0.55	0.0005	50	300	5	10	15	**76.29**	**42.55**
13	0.014	0.5	0.45	0.001	30	400	10	5	25	**66.67**	**52.6**
14	0.014	0.5	0.45	0.001	40	500	1	10	15	**79.99**	**30.02**
15	0.014	0.5	0.45	0.001	50	300	5	1	20	**77.81**	**37.44**
16	0.014	0.4	0.65	0.00075	30	400	10	10	15	**64.71**	**55.91**
17	0.014	0.4	0.65	0.00075	40	500	1	1	20	**80**	**30.001**
18	0.014	0.4	0.65	0.00075	50	300	5	5	25	**77.63**	**38.03**
19	0.024	0.6	0.45	0.00075	30	500	5	1	25	**76.94**	**40.37**
20	0.024	0.6	0.45	0.00075	40	300	10	5	15	**63.15**	**58.56**
21	0.024	0.6	0.45	0.00075	50	400	1	10	20	**79.99**	**30.04**
22	0.024	0.5	0.65	0.0005	30	500	5	5	15	**75.57**	**45.01**
23	0.024	0.5	0.65	0.0005	40	300	10	10	20	**62.61**	**59.47**
24	0.024	0.5	0.65	0.0005	50	400	1	1	25	**79.99**	**30.04**
25	0.024	0.4	0.55	0.001	30	500	5	10	20	**76.75**	**41**
26	0.024	0.4	0.55	0.001	40	300	10	1	25	**65.81**	**54.06**
27	0.024	0.4	0.55	0.001	50	400	1	5	15	**79.99**	**30.01**

Table 7: Optimized nominal parameter values

Cell	Parameters	Optimized nominal value
A	Inner diameter of tube	0.024m
B	Height of tube	0.5m
C	Length of fin	0.65m
D	Height of fin	0.0005m
E	Number of tubes	40
F	Number of fins	300
G	Air mass flow rate	10 kg/s
H	Water mass flow rate	10 kg/s

J	Air Velocity	20 m/s
K	Water outlet temperature	**62.61 ˚C= 335.61K**
L	Air outlet	**59.47 ˚C =332.47K**

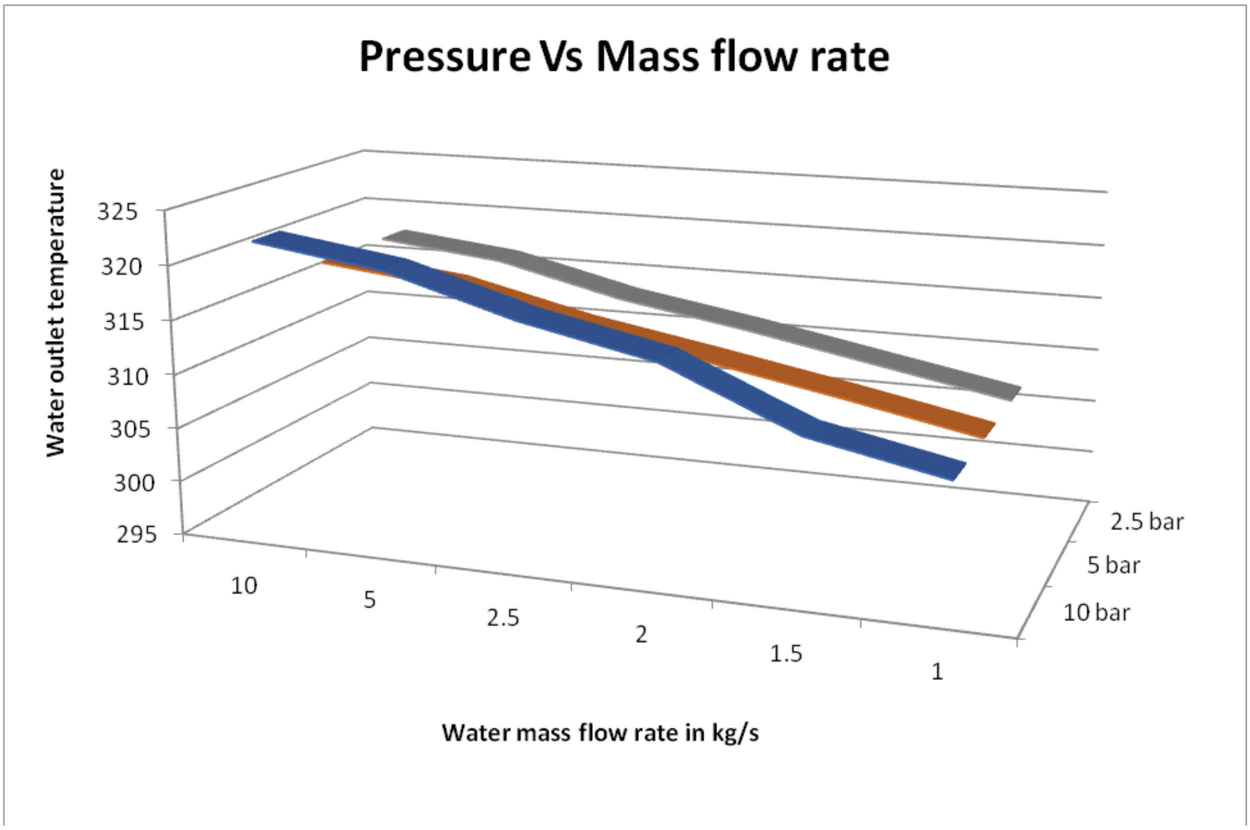


Fig 6: Graphical representation of water outlet temperature for varying pressure and mass flow rate

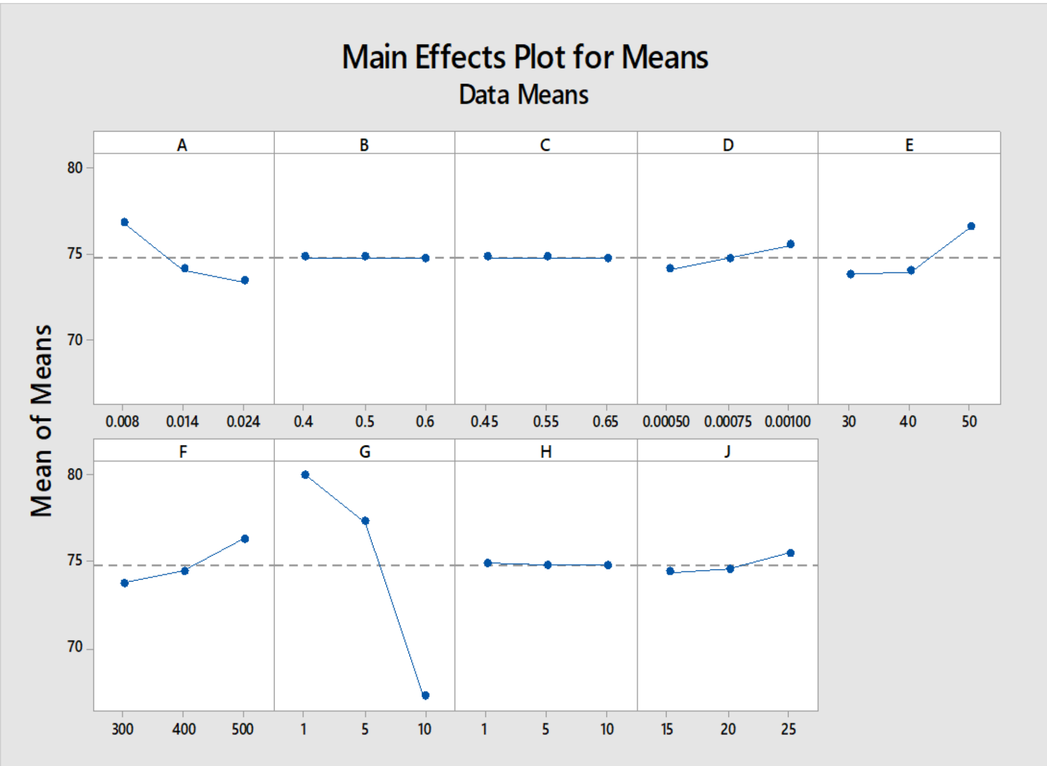


Fig 7: Mean effect of parameters to water outlet temperature

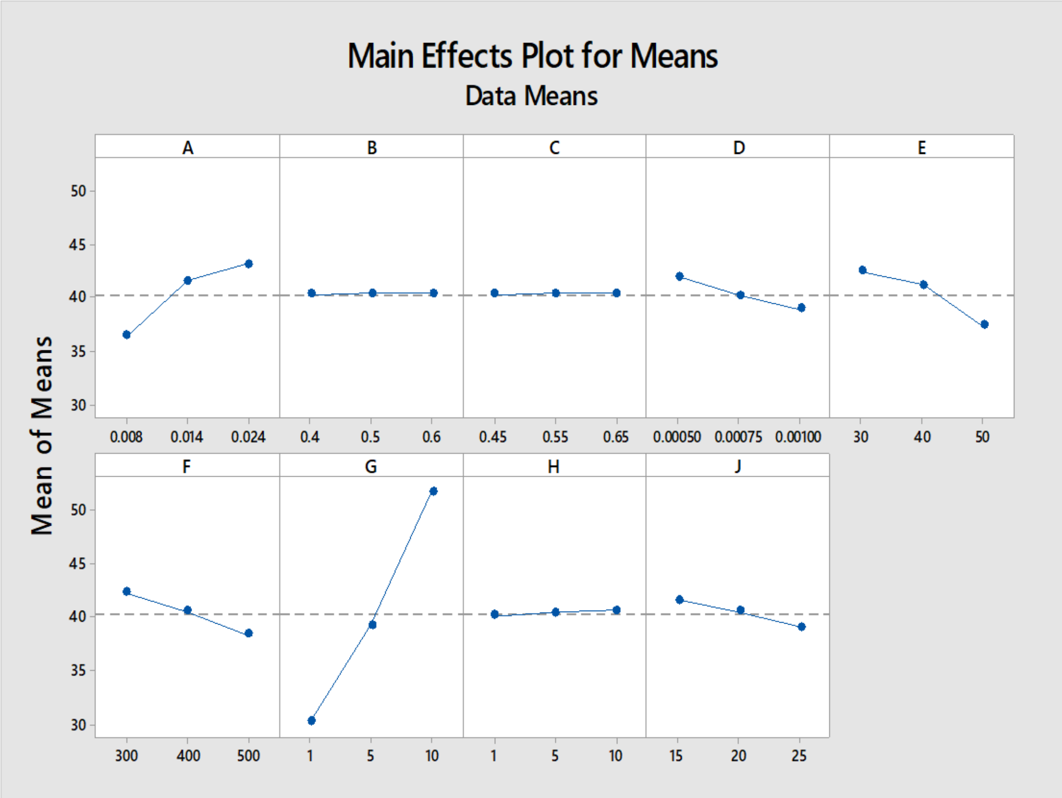


Fig 8: Mean effect of parameters to Air outlet temperature

Optimization of design

The design parameters are optimized by varying the factors such as width and height of tube & fin, number of tubes, number of fins, air velocity, mass flow rate of air and coolant using Taguchi method in Minitab 16 software. Taguchi Orthogonal Array Design was selected with Columns of L27 (3**9) Array.

The varied parameters for optimization are listed in the Table 5. These parameters are loaded in Minitab and Table 6 shows the Taguchi orthogonal array of 27 rows and 9 columns of data that are obtained which are entered in MATLAB coding for getting the varied final water outlet temperature (K) and air outlet temperature (L). Taguchi analysis was done for all the input data and optimized for the nominal water outlet temperature. The nominal best value is presented for all the factors.

Figure7 represents the graphical representation of all the design parameters with correspondent to water outlet temperature and Fig 8 represents the comparative study with the air outlet temperature. It was observed that compared to other parameters the width of fin, number of tubes and air velocity plays the major role in heat transfer rate. Table 7, presents the optimized nominal parameter value for further modeling and CFD analysis and experimental test. From the Fig. 8, it can be observed that compared to other parameters the maximum heat transfer rate is obtained as the width of the fin, number of tubes and air velocity increases.

CONCLUSION

A theoretical analysis for different sizes of radiator was carried out in MATLAB coding. CFD analysis was done using Ansys Workbench to obtain the heat transfer in tubes for the air flow by varying the water mass flow rate and pressure drop. Optimization was made in MINITAB using TAGUCHI method. The effect of design parameters such as width, height of tube and fin, number of tubes and fins, mass flow rate of water and air, velocity of air were varied for different sizes of radiators and found that as the width of fin, number of tubes and air velocity increases the heat transfer rate increases. By varying the inlet pressure and water mass flow rate it proved that as the water mass flow rate decreases the outlet temperature decreases and as the pressure drop increases the water temperature decreases.

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