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Experimental and Numerical Analysis of Rotating Radiator for Dry Cooling System

***C. Uma Maheswari*[*1]*, R. Meenakshi Reddy*[2] *and K. Hemachandra Reddy*[3]**
[1]*Research Scholar, Department of Mechanical Engineering,*
Jawaharlal Nehru Technological University, Anantapuramu-515002 (Andhra Pradesh), India.
[2]*Associate Professor, Department of Mechanical Engineering,*
G. Pulla Reddy Engineering College, Kurnool-518007 (Andhra Pradesh), India.
[3]*Chairman, Andhra Pradesh State Council of Higher Education, (Andhra Pradesh), India.*

(Corresponding author: C. Uma Maheswari)
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ABSTRACT: Cooling plays the main role in major thermal power sources. The main heat exchange source in an automobile is the Radiators whereas heat exchangers like cooling towers, condensers are used for other thermal sources to exchange the heat from the source to the sink. Many researchers have designed for effective cooling with less evaporation of coolant. The objective of this paper is to design a rotating radiator for a dry cooling system to dissipate the optimal amount of heat. As compared with many recent types of research the problem of scaling and bio fossil problems in the water used thermal power plants, the usage of the radiator with water used with an anti-scaling agent gives a better result. A numerical and experimental study was done to obtain the best design of the radiator that suits the 1KW generator set. MATLAB coding was done to study the optimal design of the radiator by studying the effects of design parameters such as width, the height of tube and fin, number of tubes and fins, mass flow rate of water and air, velocity of air. TAGUCHI Design optimization was done using MINITAB software. The Numerical-CFD analysis was carried in ANSYS for optimized design modeled in SOLIDWORKS. The experimental set up was prepared for the optimal design and compared with the numerical analysis and found that parameters such as fin width, number of tubes, and velocity of air plays the major role in heat transfer rate. It was found that as the width of the fin, number of tubes, and air velocity increases the heat transfer rate increases. The experimental investigation was studied by varying the inlet water temperature, the mass flow rate of water, and the rotating speed of the shaft. The results show that as the water mass flow rate increases the water outlet temperature increases, and as the speed of the rotating shaft increases the water outlet temperature decreases. Hence it is proved that to obtain better efficiency of getting more heat transfer rate, the water mass flow rate should be decreased and shaft speed should be increased.

Keywords: CFD analysis, MATLAB-coding, Optimization, Radiator, Taguchi.

Abbreviations: FVA, Flow-Induced Vibration Analysis; BBO, Biogeography-based optimization; NDDCT, natural draft dry cooling towers; CFD, Computational Fluid Dynamics.

I. INTRODUCTION

Heat transfer is a major task that takes place in power plants and automobile engines. The device that is used to exchange the heat between two different temperature fluids separated by a solid wall body is the heat exchangers. Heat exchangers have used for either cooling (refrigerators) or heating (space heating) applications. Researchers are designing a lot of heat exchangers for various applications. Among the coolants, water is an inexpensive resource for most of the industries. One type of heat exchanger which can reduce water evaporation is the Dry cooling towers and save water in the eco-friendly environment. Radiators are also working on the principle of removing heat with very less water evaporation. Nowadays to improve the efficiency of the heat exchange, radiators are attached to the dry cooling tower.

The theoretical thermal analysis of the radiator was focused on using the ε-NTU method and validated by the approach of 1D simulation [1]. The design of the shell tube heat exchanger was optimized by a simplified approach called flow-induced vibration analysis (FVA) [2]. Biogeography-based optimization (BBO) algorithm was developed for optimizing the design of a shell and tube heat exchanger [3]. The validation of the radiator design was focused on finite element analysis. The experimental test was used to validate the size and heat rejection [4]. The characteristics of the thermo-flow were developed for a large scale dry cooling system by a Physical-mathematical model and the design was optimized for the safe operation [5]. By using the rotating wind deflectors and the optimal design the performance can be improved for the air cooling tower [6]. A 3D numerical model was developed by varying the inflow air direction for a vertical two-pass column radiator of a natural draft dry cooling towers (NDDCT) [7]. The theoretical approximation was analyzed on a transient startup to study the effect of crosswind on (NDDCT) and validated with numerical and experimental analysis for a better performance of a hybrid power generation when combined with photovoltaic and concentrated solar thermal power plants [8]. The different types of cooling towers were reviewed and the aerodynamics, heat, and mass transfer were investigated for middle size power plants [9]. The thermal efficiency of an air-cooled condenser was studied experimentally with three pass steam circulation and found the resistance to the formation of ice in a dry cooling system [10]. Entransy dissipation-based optimization method was used to improve the performance of the indirect dry cooling system by optimizing the flow of the circulating water [11].

The energy balances were coupled between the water that circulates and the exhaust steam and developed a computational model to investigate the heat transfer and flow of air. This improves performance due to the configurations of interior and exterior windbreaker [12]. The start-up is found to be faster when the temperature of the inlet air with increased velocity was investigated [13]. The effect of wind deflectors such as airflow and heat transfer was studied by simulating a 3D CFD model for aluminum exchanged surface condenser in an indirect air cooling tower [14]. The performance of a dry cooling tower can be enhanced by using the rotating radiator that can reduce the power consumption of the forced fans and water evaporation [15]. The performance of the cooling system can be improved by using anti-freezing liquids or Nanofluids. The advantage of utilizing the coolants is its reduced evaporation rate and it can be recirculated at a faster rate. Many studies proved that as per the convenience of the application the weight, the thickness of the radiator can be designed [16]. The pumping power and the Reynolds number of the working fluid were also selected based on the performance required for the radiator application [17]. The tube material of the radiator should be selected as non-hazardous, non-pollutant to avoid the problem of scrap accumulation [18]. Investigation on the effect of structural patch on the multiple posts in the geometry of circular and rectangular was made and found that compared to rectangular patch the circular was more effective [19]. The efficient temperature distribution in the radiator can be obtained by balancing the water flow according to the dimension of pipes and control valves [20]. The power handling capacity and wall losses can be reduced by designing the radiator with the narrow beam [21]. The radiator designed should be inexpensive, more durability, and gives efficient cooling. The potential cooling can be maximized by optimizing the design parameters such as length, specification of the hydraulic pump [22]. The weight of the radiator is reduced and made compact thus the fuel consumption of the automobile engine can be reduced and increase the durability of the radiator parts [23]. The efficiency of the radiator can be improved by the level of the conduction in between tubes and fins of the cooling system and the optimal design of the lauver angle, number, and length of fins [24]. When the grooves count increases in the flat tube radiator, the pressure drop and heat transfer increases [25].

The objective of this paper is to study the performance of the optimal designed rotating radiator that can be used in a dry cooling tower to dissipate the optimal amount of heat. A numerical and experimental study was done to obtain the best design of the radiator that suits the 1KW generator set. MATLAB coding was done to study the optimal design of radiator by studying the effects of design parameters such as width, the height of tube and fin, number of tubes and fins, mass flow rate of water and air, velocity of the air and compare the different sizes of radiator design to obtain the maximum heat transfer process. TAGUCHI Design optimization was done using MINITAB software. The Numerical-CFD analysis was carried in ANSYS for optimized design modeled in SOLIDWORKS. The pressure drop and water mass flow rates are varied to study the changes in the outlet temperature of the water. The experimental set up was prepared for the optimal design and compared with the numerical analysis and found that parameters such as fin width, number of tubes, and velocity of air plays the major role in heat transfer rate. It was found that as the width of the fin, number of tubes, and air velocity increases the heat transfer rate increases.

II. METHODS AND METHODOLOGY

Table 1 shows the outlet temperature of air and water obtained due to the varied input parameters of radiator core sizes that are considered for designing and developed by MATLAB coding for the theoretical calculations. Matlab software was used to be more convenient to write the program for the theoretical analysis [27].

A. Optimization of design

Minitab-16 software was used to optimize the design parameters by varying the factors such as height and width of tube & fin, number of tubes, number of fins, air velocity, the mass flow rate of air and coolant using Taguchi method. A column of L27 (3 × 9) Array was selected for Taguchi Orthogonal Array Design. Table 2 exhibits the varied parameters selected for optimization that are loaded in Minitab-16 software and Table 3 shows the Taguchi orthogonal array of 27 rows and 9 columns of data that are obtained from theoretical calculations developed in MATLAB coding for getting the varied final water outlet temperature (K) and air outlet temperature (L). An optimized nominal water outlet temperature was obtained from the Taguchi analysis for all the input data.

Table 4, shows the optimized parameter value obtained for further modeling for CFD analysis and experimental tests.

Table 1: 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.	The 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.	The mass flow rate of coolant	1kg/s		
10.	Air inlet temperature	30°C		
11.	Water inlet temperature	80°C		
12.	Air outlet temperature obtained	53.65°C	58.65°C	60.42°C
13.	Water outlet temperature obtained	66.04°C	63.09°C	63.18°C

Table 2: Parameters varied for optimization.

Cell	Parameters	Values varied		
A	The inner diameter of the 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
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 3: 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 4: Optimized nominal parameter values.

Cell	Parameters	Optimized nominal value
A	The inner diameter of the 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℃**
L	Air outlet	**59.47℃**

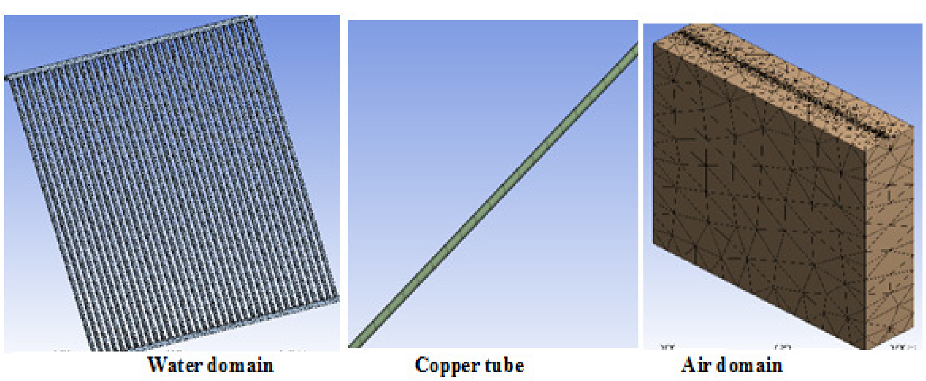

Fig. 1. Model created in Solid works.

B. Numerical Analysis

Modeling. The obtained optimal design parameter sizes are taken for developing the solid models in SOLIDWORKS for radiator tubes, fins, and developed the water path and airflow path as water domain and air domain.

Created models are imported to Ansys –a workbench for performing CFD analysis. Fig. 1 shows the geometry model of the water domain, copper tube, and air domain created for analysis.

Meshing. They created a solid model that was meshed in I**C**EM-**C**FD available in Ansys software and the type of mesh used is tetrahedral volume mesh. Table 5 presents the number of nodes and elements created for the domains of air, **c**opper tube, and water.

Table 5: Elements and nodes of each domain.

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

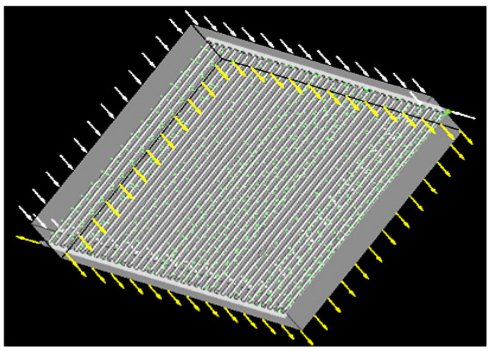

Fig. 2. The boundary condition of the model.

Boundary Conditions. The boundary condition of the model meshed is presented in Fig. 2 that has been imported to **C**FX-Pre and created three domains. Air velocity of 2 m/s was applied for air inlet and average static atmospheric pressure for an outlet. The water mass flow rate of about 10 kg/sec was applied for water inlet at 80°C temperature and 10 bar pressure and outlet with 1 atm static pressure. The free slip wall was selected for mass and momentum. CFD analysis was computed to obtain the water outlet temperature by varying the inlet pressure of about 10, 5, and 2.5 bar and varying the water mass flow rate of about 10, 5, 2.5, 2, 1.5, and 1 kg/sec.

C. Experimental Analysis

This experimental set up was considered to cool the hot water delivered from a 1 MW diesel Generator which is used as a power generator. Fig. 3 represents the schematic diagram of the experimental setup and the photograph of the set up constructed. It consists of two radiators placed at the two ends of the radiator support frame for balancing during rotation. The radiators are downflow type flattened tubes are used. Aluminium tubes and aluminium fins are selected for effective heat transfer. The pressure cap is used for maintaining the pressure drop for increasing the heat transfer rate. If the radiators are to be used for higher capacity more than 5 MW copper tubes and aluminium fins are recommended. The radiators are rotated with the help of electric motor 1.5 HP with the gearbox and 3 stepped pulley assembly. The speeds of the rotating shaft can be varied by changing the belt position in the stepped pulley. The hot water from the heat source is pumped through the foot valve and sent to the radiator which is rotating. The digital tachometer was used to measure the rotating speed of the shaft. Digital thermocouples of T-type copper constantan were used to measure the inlet temperature in the water tank and the outlet temperature of the cooled water collected from the radiator. The water mass flow rate is controlled by operating the pressure valve and the flow rate can be measured by the rotameter of 0-15L/min capacity. The experiment was done by heating the water with an electric rod heater of capacity 0 to 6 KW. The ambient air temperature and air velocity were measured. The radiators used are downflow with tubes and fins materials as aluminium and copper respectively. The specifications of the radiators are taken from the optimized values of the 'Analysis of Design Parameters of Radiator' [15]. The experiments were conducted by varying the water mass flow rate, speed of rotating radiator shaft, and inlet hot water temperature. As compared with many recent types of research the problem of scaling and bio fossil problems in the water used thermal power plants; the usage of the radiator with water used with an anti-scaling agent gives a better result [26].

The ambient air temperature was 40°C, the inlet water temperature was varied as 90, 80, 70, 60, and 50°C. The water mass flow rate considered was 1, 5, and 10 kg/s. The speed of the rotating shaft is controlled to produce the opposing air velocity of 1 to 10 rpm by incrementing 1rpm.

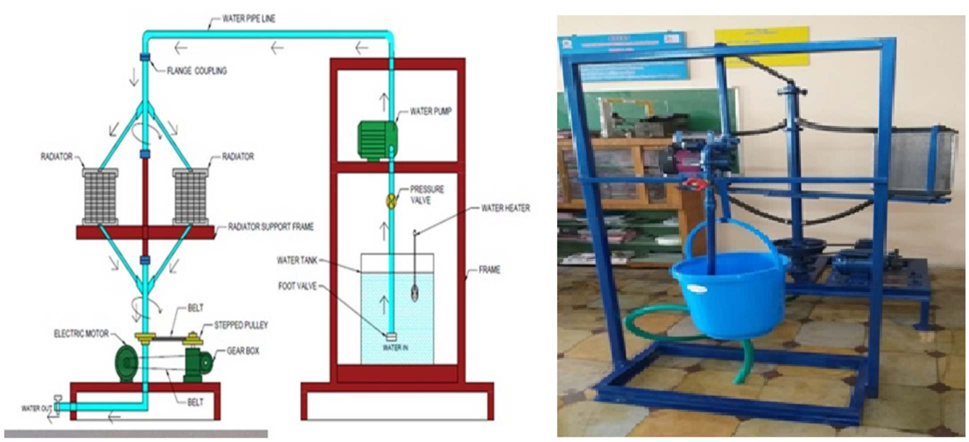

Fig. 3. Schematic and photograph of the experimental setup.

III. RESULTS AND DISCUSSIONS

A. Post-Processor Results

Fig. 4 shows the velocity vector of the air and water domain for the particular boundary conditions. Fig. 5 shows the pressure contours and Fig. 6 represents the Temperature contours of water from initial to final mass transfer.

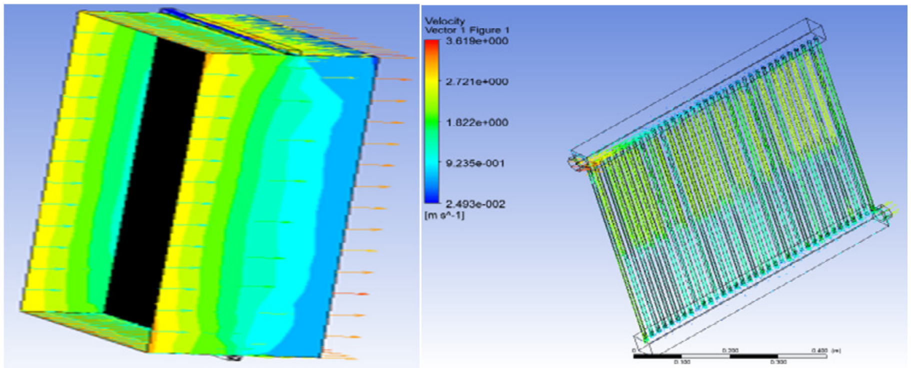

Fig. 4. The velocity vector of air and water.

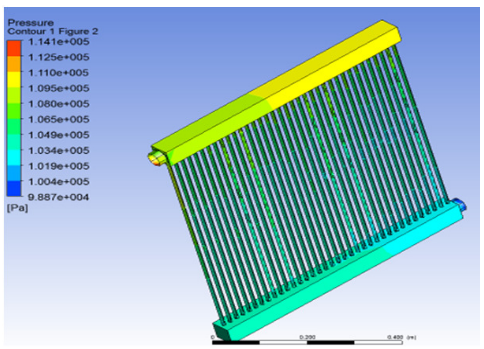

Fig. 5. Pressure contours .

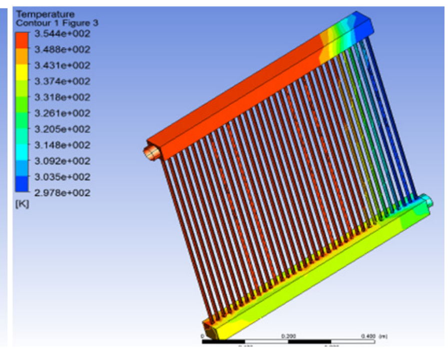

Fig. 6. Temperature contours.

B. Experimental Results

The experimental investigation was studied by varying the inlet water temperature, the mass flow rate of water, and the rotating speed of the shaft. The results show that as the water mass flow rate increases the water outlet temperature increases, and as the speed of the rotating shaft increases the water outlet temperature decreases. Hence it is proved that to obtain better efficiency of getting more heat transfer rate, the water mass flow rate should be decreased and shaft speed should be increased. The results were analyzed and compared with a 1 MW diesel engine dry cooling tower commercially available in the industrial markets. By varying the inlet pressure and water mass flow rate the temperature of the water was computed. Table 6 and Fig. 7 shows 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. The cooling system is designed such that it is easy to handle and compact [28].

Fig. 8 represents the graphical representation of all the design parameters with correspondent to water outlet temperature and Fig. 9 represents the comparative study with the air outlet temperature. It was observed that compared to other parameters the width of the fin, number of tubes, and air velocity plays a major role in the heat transfer rate. 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. At 40℃ ambient air temperature,10kg/s water mass flow rate, and air velocity of 20m/s, the water inlet temperature are varied for both dry cooling tower and rotating radiator. Fig. 10 shows the water outlet temperature of both the cooling system and found that the radiator has more efficient compared to the commercially manufactured dry cooling tower. The water loss is 2% in the dry cooling system due to spillage, drift, blowdown, and evaporation. But the water loss in the radiator is very negligible. The outlet temperature of the rotating radiator was compared with the dry cooling tower and found that the rotating radiator is more effective than the dry cooling tower. Pressure drop plays a very important role in big radiators. The heat transfer rate increases due to the pressure drop [26].

Thus the outlet water temperature gets decreased more with the pressure drop in the rotating radiator. The mass flow of water is shared by the number of radiators i.e. two in this experimental study and the air mass flow rate is increased due to sharing by heat exchangers. The capacity and number of motors required are also reduced in this setup as fan motors are required in the dry cooling tower but the motor is required to rotate the shaft only. The electric power required to run the fan is also reduced due to the reduction of forced fan motors. Table 7 and Fig. 11 represents the water inlet and outlet temperatures compared between dry cooling systems with rotating wind deflectors. Fig. 12 shows the improved efficiency of the rotating radiator than wind deflectors for a varied rotating velocity [6].

Table 6: Water outlet temperature for varying water mass flow rate and pressure drop.

Water Mass flow rate in kg/sec	Inlet pressure in bar		
	10	5	2.5
10	48.946°C	46.631°C	44.625°C
5	47.2°C	45.255°C	43.258°C
2.5	43.696°C	42.394°C	40.354°C
2	41.148°C	39.229°C	38.293°C
1.5	35.9°C	35.939°C	35.97°C
1	33.415°C	33.512°C	33.664°C

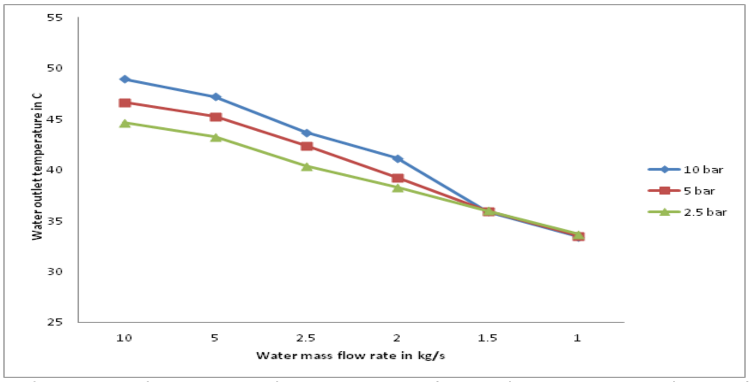

Fig. 7. Graph representing water outlet temperature for varying pressure and mass flow rate.

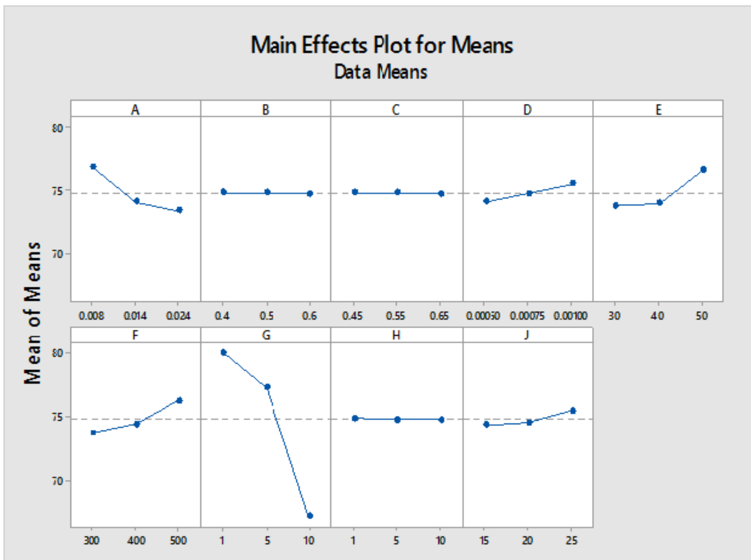

Fig. 8. Mean effect of parameters to water outlet temperature.

Fig. 9. Mean effect of parameters to Air outlet temperature.

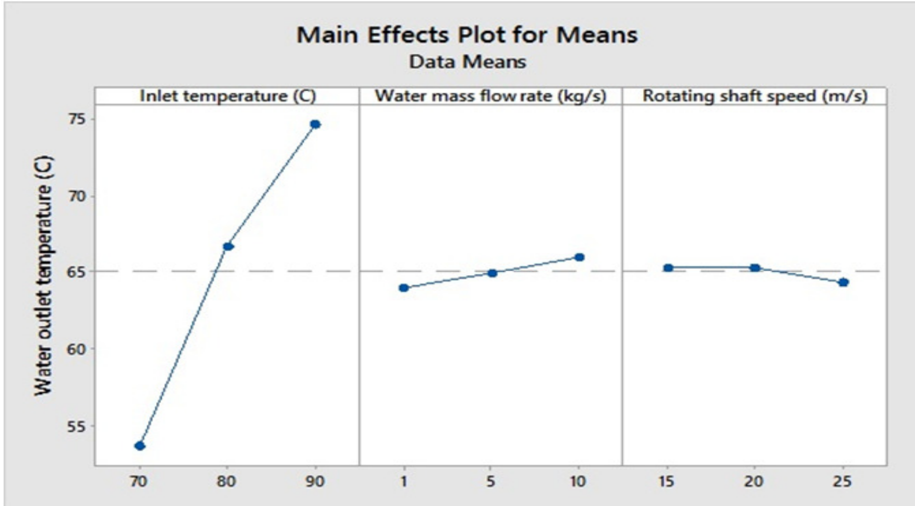

Fig. 10. The graphical response of water outlet temperature with varying the input parameters.

Table 7: Water outlet temperature for dry cooling tower and rotating radiator.

	Water inlet temperature in C				
	90	80	70	60	50
Dry cooling tower	77	68	57	48	39
Rotating radiator	75	66	54	45	36

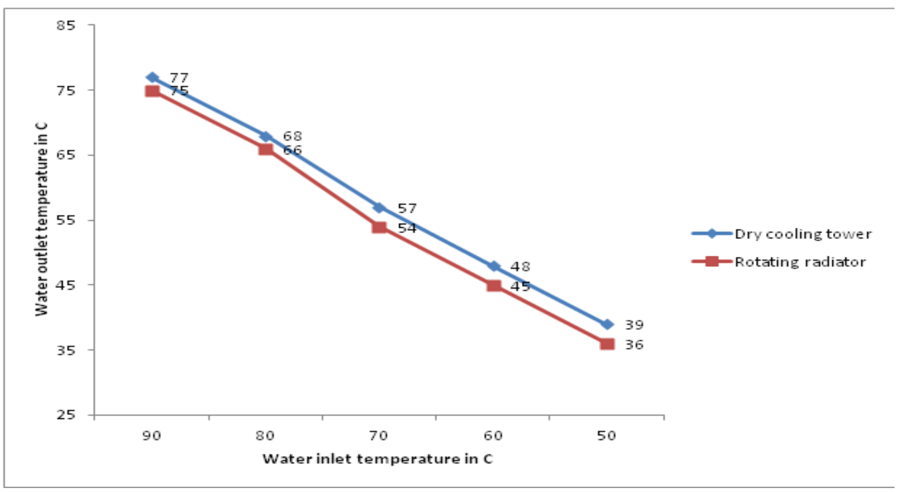

Fig. 11. Comparison of water outlet temperature.

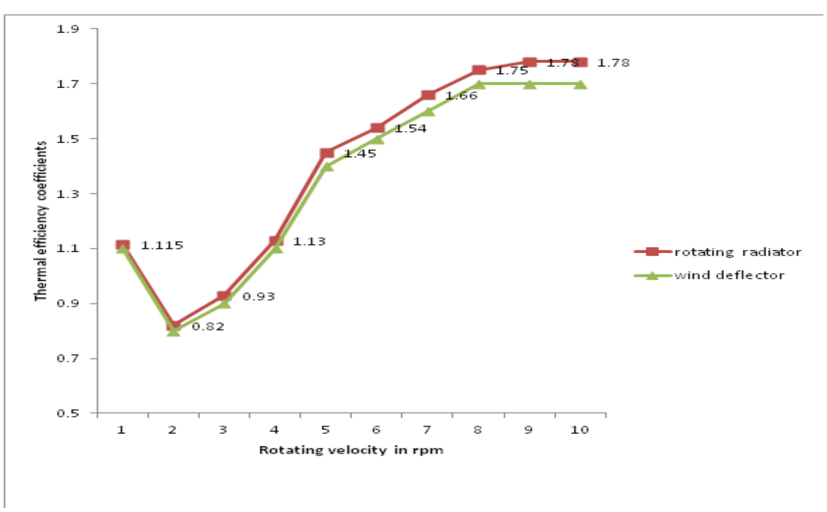

Fig. 12. Comparison of thermal efficiency of rotating radiator with wind deflectors [6].

IV. CONCLUSION

A theoretical analysis for different sizes of radiator cores was carried out in MATLAB coding. CFD analysis was done using Ansys Workbench to obtain the heat transfer in tubes for the airflow by varying the water mass flow rate and pressure drop. Optimization was made in MINITAB using the TAGUCHI method. The effect of design parameters such as width, the 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 the 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.

From the above numerical analysis and optimization, the best size of the radiator was designed and required input parameters are considered to obtain the water outlet temperature.

An experimental investigation was done to compare the water outlet temperature of the rotating radiator with the dry cooling tower available commercially in the industries. Compared to usual dry cooling towers used in industries the rotating radiator gives better efficiency as the water outlet temperature is decreased. As a result, it was found that the water loss is controlled and the efficiency is also improved.

V. FUTURE SCOPE

The work can be extended by using anti-freezing liquids of nano coolants to improvise the thermal efficiency and life of the radiator parts to avoid scaling in the core tubes.

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Conflict of Interest. The authors declare no conflict of interest.

REFERENCES

[1]. Krunal Suryakant Kayastha, (2015). CFD simulation of heat transfer analysis of automobile radiator using helical tubes. *International journal of engineering research and development, 11*(1): 24-35.

[2]. Raj Kumar Yadav, Rahul Kankane, and Sandhya Yadav, (2015). Parametric Optimisation Of Heat Exchanger with the help of the Taguchi method A-Review. *International Journal of Mechanical Engineering and Technology, 6*(10): 140-144.

[3]. Chintan, D. Patel, Prashant Sharma, and Amitesh Paul, (2014). Parameter optimization of shell and tube type heat exchanger for improve its efficiency. *International Journal of Engineering Research and Science & Technology, 3*(1), 11-18.

[4]. Amrutkar, P. S., and Patil, S. R. (2012). Automotive Radiator Sizing, and Rating – Simulation Approach. IOSR *Journal of Mechanical and Civil Engineering,* 01-05.

[5]. Xinming Xi, Lei Yang, Yanan He, Lijun Yang, and Xiaoze Du, (2014). Optimal design of large scale dry cooling tower with consideration of off-design operation. *Energy Procedia, 61*, 190–193.

[6]. Xueping Du, Dongtai Han, and Qiangmin Zhu, (2018). Heat Transfer Enhancement of the Air-Cooling Tower with Rotating Wind Deflectors under Crosswind Conditions.

[7]. Zhao, Y. B., Guoqing Long, Fengzhong Sun, Yan Li, and Cuijiao Zhang, (2014). Numerical study on the cooling performance of dry cooling tower with vertical two-pass column radiators under crosswind. Applied Thermal Engineering, 1-12.

[8]. Peixin Dong, Xiaoxiao Li, Kamel Hooman, Yubiao Sun, Jishun Li, Zhiqiang Guan, and Hal Gurgenci, (2019). The crosswind effects on the start-up process of natural draft dry cooling towers in dispatchable power plants. *Int. Journal of Heat and Mass Transfer, 135*: 950–961.

[9]. Hemmasian Kashania, M. M. and Dobrego, K. V. (2013). Heat and Mass Transfer In Natural Draft Cooling Towers. J. of Engg. *Physics and Thermophysics, 86*(5):1072-1082.

[10]. Milman, O. O., Ptakhin, A. V., Kondratev, A. V., Shifrina, B. A. and Yankov, G. G., (2016). Startup of Air-Cooled Condensers and Dry Cooling Towers at Low Temperatures of the Cooling Air. *Thermal Engineering, 63*(5): 329–335.

[11]. Sun, J., Yuan, K., and Yang, L. J., (2015). Distribution optimization of circulating water in air-cooled heat exchangers for a typical indirect dry cooling system on the basis of entransy dissipation. *Science China Technological Sciences, 58*(4): 617–629.

[12]. Lei Chen, Lijun Yang, Xiaoze Du, and Yongping Yang. (2016). Performance improvement of the natural draft dry cooling system by interior and exterior windbreaker configurations. *International Journal of Heat and Mass Transfer, 96*: 42–63.

[13]. Peixin Dong, Xiaoxiao Li, Zhiqiang Guan, and Hal Gurgenci. (2018). The transient start-up process of natural draft dry cooling towers in dispatchable thermal power plants. *International Journal of Heat and Mass Transfer, 123*: 201–212.

[14]. Tao Wu, Huimin Wei, Zhihua Ge, Lijun Yang, and Xiaoze Du. (2019). Cooling water mass flow optimization for the indirect dry cooling system of thermal power unit under variable output load. *International Journal of Heat and Mass Transfer, 133*: 1–10.

[15]. Uma Maheswari, C., Meenakshi Reddy, R., and Hemachandra Reddy, K., (2017). Analysis of Design Parameters of Radiator, Research Journal of Pharmaceutical. *Biological, and chemical sciences, 8*(3): 35-44.

[16]. Keiji Oda, Yuichi Imasaka, Tomoya Yamauchi, Yoshihiro Nakane, Akira Endo, and Yasuhiro Yamaguchi. (2004). Deuterized Radiator for Detection of High-Energy Neutrons with Plastic Nuclear Track Detector. *J. of Nuclear Sci. and Tech., 41*(4): 514-517.

[17]. Akash, A. R., Abraham Satyanand, Pattamatta Arvind, and Das Sarit, K. (2018). Experimental assessment of the thermo-hydraulic performance of automobile radiator with metallic and non-metallic nanofluids. *Heat Transfer Engineering, 41*(3): 235-251.

[18]. Barakat, M. A., and Mahmoud, M. H. H. (2000). Recovery of Metal Values from Car-Radiator Scrap. *Separation Science and Technology, 35*(14): 2359-2374.

[19]. Tapas Chakravarty, and Asok De FIETE. (1999). Investigation of Modes Tunable Circular Patch Radiator with Arbitrarily Located Shorting Posts. *IETE Technical Review, 16*(1): 109-111.

[20]. Jørgen Christiansen., (1981). Balancing radiator systems, Batiment International. *Building Research and Practice, 9*(3):144-144.
[21]. Cullen, A. L. (1949). B.Sc. XXXVII. Channel section waveguide radiator. The London, Edinburgh, and Dublin *Philosophical Magazine, and Journal of Science, 40*(303):417-428.
[22]. Yair Etzion, and Evyatar Erell., (2011). Low-Cost Long-Wave Radiators for Passive Cooling of Buildings. *Architectural Science Review, 42*(2): 79-85.
[23]. Zeinali Heris, S., Shokrgozar, M., Poorpharhang, S., Shanbedi, M., and Noie, S. H., (2014). Experimental Study of Heat Transfer of a Car Radiator with CuO/Ethylene Glycol-Water as a Coolant. *J. of Dispersion Science and Technology, 35*(5): 677-684.
[24]. Jafar Mahmoudi (2006). Modeling of Flow Field and Heat Transfer in a Copper- Base Automotive Radiator Application. *International Journal of Green Energy, 3*: 125-141.
[25]. Kyoung Woo Park, and Hi Yong Pak. (2002). Flow and Heat Transfer Characteristics in Flat Tubes of a Radiator. Numerical Heat Transfer- Part A: Applications: *An Int. J. of Computation and Methodology*, *41*: 119-40.
[26]. Gorman, J. M., Carideo, M., Sparrow, E. M., and Abraham, J. P., (2015). Heat transfer and pressure drop comparison of louver and plain finned heat exchangers where one fluid passes through flattened tubes. *Case Studies in Thermal Engineering,* 5: 122-126.
[27]. En-long, Guang-wu, W., Chong-qiang, L., Zhi-min, L., and Bo-you, L., (2019). Application of a Dry Water Cooling System Combined with Air Cooler and Refrigeration Unit. *2019 IEEE Sustainable Power and Energy Conference (iSPEC),* Beijing, China, 1455-1463,
[28]. Abhishek Sharma, Alka Bani Agrawal, and Nitin Shrivastava, (2018). Solar Energy based Refrigeration System using Peltier Device. *International Journal of Theoretical & Applied Sciences, 10*(1): 110-116.

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