International Journal of Research in Engineering, Science and Management
Volume-1, Issue-12, December-2018
www.ijresm.com | ISSN (Online): 2581-5792

A Review on Automobile Equipment Cooling Through Engine Heat Sink - Rectangular Fins under Natural Convection

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***Abstract*: Among heat transfer augmentation techniques, passive cooling technique found more suitable for electronic cooling than active technique. In the last decades, intensive attentions were spent on miniaturizing the automobile and electronic devices because of high sophisticated micro- and nano-technology development. But heat dissipation is still major problem of enhancing the thermal performance of engine heat sink. Effects of thermodynamic properties like heat input, base-to-ambient temperature difference are also studied by many researchers. The prime objective of the present review is to study the convective heat transfer in rectangular fins. Data collected from earlier and present work on this related topic. Higher heat transfer enhancement obtained with vertically oriented bases than with horizontally oriented bases for fin arrays of the same geometry. Various experimental studies have been made to investigate effect of fin height, fin spacing, fin length and fin thickness over convective heat transfer. Some investigators make known sets of correlations screening the relation between various parameters of engine heat sink- fins. Experiments are taken by some researchers for upward and downward facing rectangular fins. Also, trivial investigation has been carried out for different angle of inclination of engine heat sink - fins. The sensitivity of inclination over geometric parameters found to be great importance. The paper focus on various experimental studies has been made to investigate effect of fin height, fin spacing, fin length, fin thickness, fin inclination and fin orientation over convective heat transfer.**

***Keywords*: angle of orientation, angle of inclination, convective heat transfer, engine heat sink, rectangular fins.**

1. Introduction

Many engineering systems generate heat during its task. On the off chance that this produced heat isn't dispersed quickly to its surrounding atmosphere, this may cause rise in temperature of the system components. This by-product causes genuine overheating issues in system and leads to system failure, so generated heat inside the system must be rejected to its surrounding to keep up system at recommended temperature for its efficient working [8]. Common convection is widely preferred technique for cooling and air-cooling is one of the most traditional methods. Because of lower heat transfer coefficient given via air, the utilization of extended surface called fin has been a need in the plan of air cooled heat exchangers. Plan of regular convection air-cooling system is basic and economic, the systems have high reliability and easy maintenance and there is no acoustic noise. The most well-known strategies for upgrading characteristic convection air-cooling are utilizing parallel-plate channels and different fins configurations. For the most part, fins divide in two classifications longitudinal and transverse have been used as the extended surface on the bare tubes. Because of better heat dissipation rate happen by advantage of transverse fins over longitudinal fins. The use of transverse fins has been more common. The transverse fins can be ordered principally into two kinds, Circular or Annular fins and Plate or Pin fins. The heat transfer rate from surface might be increased by increasing the heat transfer area A if the power contributions to the system and temperature limits are settled. This is because of a fundamental condition depicting such heat losses are given by $Q=h\times A\times(T_s-T_\infty)$ where, h = convection heat transfer coefficient, A = area of contact or exposure, T_s = Hot surface temperature, T_∞= Fluid temperature, equation is nothing but Newton's Law of Cooling. Since the heat transfer coefficient can't be freely controlled, a heat transfer enhancement might be achieved by increase the area is by using fins attached to base plate. This is one of the main reasons such alternatives are normally used. However, increasing the surface area may have some drawbacks, along these lines the design should be done precisely. Attaching fins does increase the surface area, but it also increases the resistance to flow of air. The heat transfer coefficients dependent on base area of fin may be less than that of the base plate. In the event that the decrease in the heat transfer coefficient is more than increase in the surface area, the total heat transfer rate will decrease. In this way, the enhancement choices must be carefully explored. The shape and size of the fins should be optimized. Available literature has demonstrated that different experimental and theoretical studies have been performed on fin arrays and vertical plates. Several experimental, simulation & numerical studies have been done on vertical parallel plates. Slanted plate channels have additionally been examined, but the usage of such configurations is limited [28].

A. Heat transfer and thermodynamics

The study of transfer phenomenon which includes transfer of momentum, energy, mass etc. has been recognized as a unified discipline of fundamental importance on the basis of thermodynamic fluxes and forces. The transfer of such phenomena occurs due to a conjugate force of temperature gradient, velocity gradient, concentration gradient chemical affinity etc. The transfer of heat energy due to temperature difference or gradient is called heat transfer (warm heat exchange). The investigation of transfer phenomenon which includes transfer of momentum, energy, mass etc. has been recognized as a unified discipline of fundamental importance on the basis of thermodynamic fluxes and forces. The transfer of such phenomena happens because of a conjugate force of temperature gradient, velocity gradient, concentration gradient chemical affinity etc. The transfer of heat energy because of temperature difference or gradient is called heat transfer.

B. Modes of heat transfer

The modes of heat transfer can be classified into 3 segments:
Conduction: Conduction refers to heat transfer between two bodies or two sections of similar body through atoms which are, more or less, stationary (fixed), as on account of solids.
Convection: At the point when energy transfers between solid and fluid system in motion, procedure is known as convection. On the off chance that the smooth movement is inspired by compressor (pum), it is called forced convection. If fluid motion is caused due to density difference, it is called normal or natural or free convection.
Radiation: Thermal radiation refers to radiant energy emitted by bodies by ideals of their own temperatures, coming about because of thermal excitation of atoms. Radiation is assumed to propagate in the form of electromagnetic waves.

C. Conceptual diagram of rectangular fin

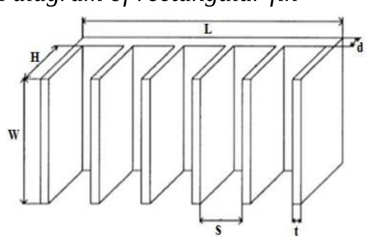

Fig. 1. Configuration geometry of HS with continuous rectangular short fin [28]

Where, L = length of fin array, W = width of fin array, d = fin base-plate thickness, t = fin thickness, s = fin spacing, H = fin height. The focus of this study is on free natural convection heat transfer from rectangular short fins. However, a lot of overview on pertinent literature within the area of natural heat transfer from fins is provided during this section. A range of theoretical expressions, graphical correlation, empirical equations are developed to represent the coefficients for natural convection heat transfer from vertical plates and vertical channels. These studies are principally centered on geometrical parameters of heat sinks (*HS*s) and fins, like fin length (L), fin width (W), fin base-plate thickness (d), fin thickness (t), fin spacing (S), fin height (H) as well as, fin directions [28]. The different orientation of *HS* shown in Fig. 2. [29].

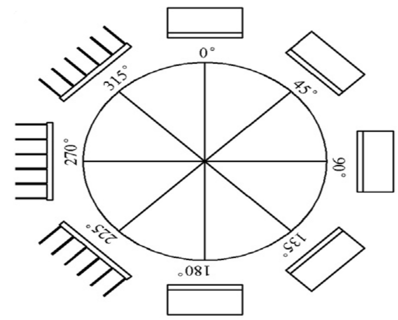

Fig. 2. Schematic diagram of the orientation of the HS [29]

D. Example of surfaces where fins are used

a) Refrigeration condenser tubes, b) Air cooled I.C. engine (ICE), c) Automobile radiator , d) Semiconductor devices, e) Reciprocating air compressors, f) Electric transformers.

E. Types of fin

Types of fin can be broadly classified: a) Rectangular profile Longitudinal fin, b) Rectangular profile Longitudinal fin, c) Trapezoidal profile Longitudinal fin, d) Concave parabolic Longitudinal fin, e) Rectangular profile Radial fin, f) Triangular profile Radial fin, g) Cylindrical Pin fin, h) Tapered profile Pin fin, i) Concave parabolic Pin fin.

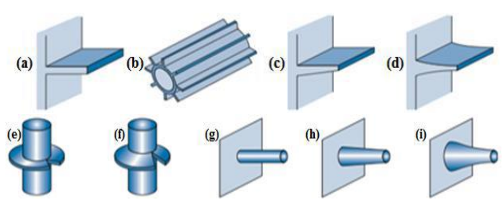

Fig. 3. Types of fins

F. Natural convection from finned surfaces

Finned surfaces of various shapes heat sinks (*HS*s) are used in automobile cooling & microelectronics cooling. One of most crucial parameters in designing *HS*s is fin spacing *S*. Closely packed fins will have greater surface area as for heat transfer, but smaller heat transfer coefficient (due to extra resistance of additional fins). A *HS* with widely spaced fins will have a higher heat transfer coefficient but smaller surface area. Thus, an optimum spacing S_{opt} exists that maximizes the natural convection from *HS* [31].

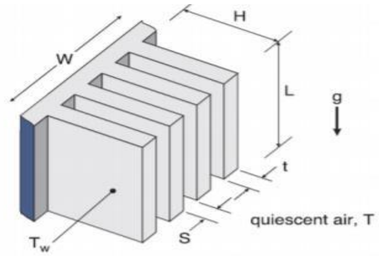

Fig. 4. A Vertical HS [31]

Consider a *HS* with base dimension *W* (width) and *L* (length) in which the fins are assumed to be isothermal and the *t* (fin thickness) is small relative to *S* (fin spacing). The S_{opt} (optimum fin spacing) for vertical *HS* is given by Rohsenow and Bar-Cohen as, $S_{opt}=2.71\times L/Ra^{1/4}$ where, *L*=characteristic length in *Ra* number. All fluid property is determined at film temperature. The convective heat transfer coefficient for optimum spacing can be found from, $h=1.31\times k/S_{opt}$. Note: as a result of above-mentioned “two opposing forces” (buoyancy and friction), *HS*s with closely spaced fins are not suitable for natural convection.

G. Fin performance

1) Fin Effectiveness (ε)

When effectiveness, $\varepsilon \geq 2$ used fins & $\varepsilon \leq 2$ not used fins. Because of effectiveness we used fins. Fin effectiveness is defined as the ratio between heat transfer rate with fin and heat transfer rate without fin.

$$\varepsilon = \frac{\text{heat transfer rate of fin (qf)}}{\text{heat transfer rate without fin(q)}} \quad (1)$$

1) Fin Efficiency

This is the ratio of fin heat transfer rate to the heat transfer rate of the fin if the entire fin were at base temperature.

$$\frac{\text{Actual heat transfer rate from fin (real situation)}}{\text{Ideal heat transfer rate from fin (ideal situation)}} = \frac{\text{qf}}{\text{qfin,max}} = \frac{\text{qf}}{\text{h}\times\text{Af}\times\Delta\text{T}} \quad (2)$$

Where, h = convection heat transfer coefficient $W/m^{2o}K$, A_f= area of fin m^2, ΔT = Temperature difference ^oK.

The document Starts from here. And the section 2 continues accordingly.

2. Literature review

A systematic literature search was performed at Google Scholar, Elsevier and Science Direct platforms to identify relevant studies involving review on convective (natural or free) heat transfer in rectangular fins experimentally, analytically & simulation produced in last 55 years. K.E. Starner, H. N. McManus [1] Studied extensive variety of review made in this paper initiating from pioneering trial work. They displayed normal heat-transfer coefficients for 4 fin arrays positioned with the base vertical, 45o and horizontal while dissipating heal to room air. The scope of geometric parameter variety was constrained to between fin partition separations (S) of 6.35 or 7.95mm, and fin heights (H) of 6.35, 12.70, 25.40, or 38.10 mm. Parameters kept constant were the fin length (L), thickness (t), and the width of the base plate (W). Just a single base-plate width to the fin length ratio, W/L=0.5 (W=127mm and L=254 mm), was utilized. The fins are analyzed as steady-temperature surfaces since the lowest fin efficiency encountered is greater than 98%. It found that coefficients for the vertical arrays fell 10 to 30% below those of likewise divided parallel plates. The 45o arrays yielded results 5 to 20% below those of the vertical. Two flow patterns are researched for the horizontal arrays, and it found that the coefficients could be diminished forcefully by preventing three-dimensional stream. Filino Harahap, Daru Setio [2] examined trial information for heat dissipation from 5 duralumin fin array on a level plane situated. They utilized fin length range 127 to 254mm, height 6.35 to 38.10mm, thickness 1.02 to 3.10mm and no. of fins per array 10 to 33. Impact of fin length and optimal inter-fin distance was explored. Hence, two sets of correlation were created demonstrating fin length and optimum fin spacing as prime function of thermal performance of HS. Additionally, studied range of fin detachment separations from 6.25 to 7.95mm the scope of fin base over excess temperature over the surrounding air temperature was very broad from 19.0±0.1oC to 125.0±0.1oC. F. Harahap, H. Lesmana [3] Investigate effects of miniaturizing the base plate measurements of vertically put together straight rectangular fin arrays on the steady-state heat-dissipation performance under dominant regular natural convection conditions. A correlation for scaled down vertically based straight rectangular fin arrays, which utilized the fin length as the prime geometric parameter, has been displayed based on the basis of the experimental conditions of this investigation. The miniaturization process was initiated from a square-based array of 49×49mm2 (maximum base area) and ended at a square-based exhibit of 25×25mm2 (minimum base area) with rectangular based arrays of fluctuating middle areas in between two inter-fin separation of 3 and 11mm were utilized. The impact of base plate orientation on the heat-dissipation performance was examined through comparison of present outcomes with those of an earlier work, in which the arrays were miniaturized with the base horizontally oriented. They concluded that effect of the parameter W/L on heat dissipation rate is relatively less for the vertically base array. Additionally, higher heat dissipation rate was observed for non-square base, same base area and orientation with fins parallel to short side of the base plate than fin parallel to longer side (W/L≤1) of the base. B. Yazicioglu, H. Yuncu [4] Explored steady-state natural convection heat transfer from aluminum vertical rectangular fins extending perpendicularly from vertical rectangular base experimentally. Different 30 fin configurations tested. Investigations performed for fin lengths of 250 and 340mm. Fin thickness was kept fixed at 3mm. Fin height and fin spacing fluctuated from 5 to 25mm and 5.75 to 85.5mm. Five heat inputs going from 25 to 125W supplied for all fin arrangements, hence; the base-to-ambient temperature differences were measured in order to evaluate the heat transfer rates from fin arrays. The results of trials show convective heat transfer rate from fin arrays depends on geometric parameters and base to ambient temperature difference. The separate roles of fin tallness, fin spacing and base-to-ambient temperature difference were investigated. It was found that, for a given base to ambient temperature difference, the convective heat transfer rate from fin arrays takes on maximum value as a function of fin spacing and fin height and an optimum fin spacing value which amplifies the convective heat transfer rate from the fin array is accessible for each fin height. H. Yuncu, G. Anbar [5] examined trial investigation of natural convection heat transfer from rectangular fin arrays on a horizontal base. An experimental set-up constructed and calibrated, 15 sets of fin-arrays and base plate without fins were tested in atmosphere. Fin height varied from 6mm to 26mm; fin spacing varied from 6.2mm to 83mm. The base to ambient temperature difference also varied independently and systematically with the power supply to heater going from 8W to 50W. Fin lengths and fin thicknesses fixed at 100mm and 3mm. They discovered given base to ambient temperature difference the convection heat transfer rate from fin-arrays takes on maximum value as function of fin spacing and fin height. For a given base to ambient temperature difference the enhancement of the convection heat transfer rate of fin-arrays relative to that for base plate without fins is strongly dependent on the fin spacing to fin height ratio and number of fins. They exhibited correlation relating the convection heat transfer rate of fin arrays relative to that for base plate without fins with the relevant non-dimensional parameters. S. Baskaya, M. Sivrioglu, M. Ozek [6] investigated parametric effect of horizontally oriented fin array over natural convection heat transfer. Examined effects of fin spacing, fin height, fin length and temperature difference between fin and surroundings on the natural convection heat transfer from horizontal fin arrays. They solved three dimensional (3-D) elliptic governing equations using a finite volume based computational fluid dynamics CFD code. They concluded that it is not possible to obtain optimum performance in terms of overall heat transfer by only concentrating on one or two parameters. The interactions among all the design parameters must be considered. They stated that to obtain optimum performance in terms of overall heat transfer, collaboration of all design parameters must be considered. They found that optimum fin spacing for L=127mm and L=154mm are Sopt=6 and 7mm, respectively. Q/Ab values found diminished with increase in fin length since stream pattern changes from single chimney to multiple chimney flow. L. Dialameh, M. Yaghoubi, O. Abouali [7] studied 128 fin geometries with short length and thick fins. Aluminum rectangular fins of 3mm<t<7mm with short length L≤50mm were tested. They illustrated two types of flow pattern in channel. They concluded that for maximum heat transfer, optimum value of fin spacing Sopt=7 for fin arrays with H/L≤0.24. They commented that for fin arrays with H/L>0.24 and S/L<0.2, air enters from fin end region while another range, air enters from middle parts of fin. They solved 3-D elliptic governing equations of laminar flow and heat transfer using finite volume scheme. Effect of various fin geometries and temperature differences on the convection heat transfer from the array was determined for Ra numbers based on fin spacing 192–6784 and applied correlations are developed to predict Nusselt numbers with corresponding non-dimensional parameters. H. M. Mobedi, H. Yuncu [8] studied numerically steady state convective heat transfer from fin array for Ra number based on fin spacing 120 to 39000. The length and height of fin are varied from 2mm to 20mm and 0.25mm to 7mm fin spacing. They developed finite difference code based on vorticity-vector potential approach to solve governing equations. They studied problem of 3-D laminar convective heat transfers with open boundaries. They concluded that H/L ratio is governing parameter for fluid field and flow pattern. Furthermore, for H/L≤0.25 and S≥10mm, flow field is up and down type flow pattern observed. Ilker Tari, Mehdi Mehrtash [9, 10 and 11] tested wide range of angle of inclination θ of HS with upward and downward orientations. By modifying Gr number with cosine of θ, they suggest the modified correlation which is best suited for θ interval of -60o≤θ≤+80o. They derived set of correlations of Nu number for both upward & downward natural convection from pin-fin heat sink (PFHS) by using large sets of experimental data from literature. Their correlations covered all possible inclination angles with accuracy less than 20%. Natural convection from horizontal and slightly inclined plate fin arrays is investigated. At small inclinations, noted that convection heat transfer rate remained almost same. They suggested Correlations are shown to be valid for the present and literature horizontal data with new sets of correlations is obtained. H, s & L of fin shown important parameters. Natural convection heat transfer from inclined plate-finned HSs is investigated. Correlation is verified with all available experimental data in literature. Stream separation and fin height plays most significant roles at high inclinations. V. Dharma Rao, S. V. Naidu, B. Govinda Rao, K. V. Sharma [12] studied laminar natural convection heat transfer from fin array containing a vertical base and horizontal fins theoretically formulated by treating the adjacent internal fins as two fin enclosures. The governing equations of mass, momentum and energy balance for fluid in two fin enclosures together with the heat conduction equations in the fins are numerically solved using Alternating Direction Implicit (ADI) method. They also computed heat transferred to ambient fluid from two end fins separately. Heat transferred by radiation is considered in the analysis. They compared numerical results with experimental data available in literature. The effects of system parameters such as base temperature, fin height, fin spacing on heat transfer rate from fin array are studied. Vinod Wankar, S. G. Taji [13] studied heated horizontal rectangular fin array under natural convection experimentally. The temperature mapping and the prediction of the flow patterns over the fin array with variable fin spacing is carried out. Dimensionless fin spacing to height (S/H) ratio is varied from 0.05 to 0.3 and length to height ratio (L/H)=5 were kept constant. The heater input to the fin array assembly is varied from 25 to 100W. The single chimney flow pattern is observed from 8 to 12mm fin spacing. The end flow is choked below 6 mm fin spacing. The single chimney flow pattern changes to sliding or end flow choking at 6mm fin spacing. The average heat transfer coefficient ha =2.52–5.78W/m2K is very small at 100W for S =5–12mm, ha=1.12–1.8W/m2K is very small at 100W for 2 – 4mm fin spacing due to choked fin array end flow was not sufficient to reach up to central portion of fin array and in the middle portion there was unsteady down and up flow pattern resulting in sliding chimney. Central bottom portion of fin array channel does not contribute much in heat dissipation for S=2–4mm. Improved ha significantly at higher spacing as compared to lower spacing region. The optimum spacing is obtained in between 8–10mm. They compared average heat transfer results with previous literature and showed similar trend and satisfactory agreement. Also proposed empirical equation to correlate average Nu number as a function of Gr number and fin spacing to height ratio. Charles D. Jones, Lester F. Smith [14] studied average heat transfer coefficients for natural convection cooling of arrays of isothermal fins on horizontal surfaces over wider range of spacing's experimentally. Also studied heat transfer coefficients for arrays of isothermal fins on horizontal surfaces have been established over a reasonably wide range of fin spacing, fin heights and temperature differences. Measured values are in fairly good agreement with the limited comparable data of Starrier and McManus [1]. Shivdas S. Kharche, Hemant S. Farkade [15] studies heat transfers and fluid flow associated with such arrays are of considerable engineering significance. They controlled mainly variable generally available to designer is geometry of fin arrays. They studied natural convection heat transfer from vertical rectangular fin arrays with and without notch at center had been investigated experimentally and theoretically. In lengthwise short array where single chimney flow pattern was present, the central portion of fin flat becomes ineffective due to the fact that, already heated air comes in its contact. Many researchers had been studied heat transfer through notch and without notched fins by using aluminum as material. Verities of researchers were carried out, focuses on heat transfer of copper as material for fin for greater heat transfer rate which was need of increased rate of modernization thus extent of copper is tested. Mahdi Fahiminia, Mohammad Mahdi Naserian, Hamid Reza Goshayeshi, Davood Majidian [16] tested vertical base plate under natural convection to determine heat transfer coefficient. Different configuration of the rectangular fins was tested, keeping base of fin array vertical. Experimentation was carried out for fixed value of fin length, fin height, fin width. They found that optimum fin spacing value decreases from 6.42mm to 5.84mm with increase in base to ambient temperature difference. The computational fluid dynamics (CFD) simulations were carried out using fluent software. It was found that convective heat transfer depends upon variation in fin spacing S, fin height h and base to ambient temperature difference. The natural convection coefficient increased substantially as the fins spacing was increased. It reached to maximum at optimum spacing Sopt. Further increase in fin spacing decreased the heat transfer rate. D. D. Palande, A. M. Mahalle [17] investigated steady state natural convection from HS with vertical base rectangular plate-fin HSs having parallel arrangement mounted on inclined base experimentally. Aluminum HS of 200mm length was modeled. Rectangular base was inclined for angle from 0° to 90° keeping upward facing fins. They studied effects of orientation of inclination on plate fin HSs. It was observed that at small inclinations from vertical as well as horizontal the convection heat transfer rate is not change significantly. S. D. Ratnakar, D. D. Palande [18] studied HSs were an extremely useful component used to lower the maximum temperature of various electronic devices during operation so as to increase their thermal efficiency and performance by passive cooling technique. Fins constitute an important and integral component of sinks. Plate fin HSs are used in varied applications owing to its low manufacturing cost, ease of manufacture and its economical way to dissipate unwanted heat. They investigated steady state natural convection is experimentally for 3 sets of vertically mounted fin HSs. Aluminum was used because of its high conductivity. Length and thickness of fin was kept constant at 200mm and 5mm. Fin height is successively increased as 10mm, 30mm, 50mm aspect Ratio for above 3 sets was 0.05, 0.15 and 0.25. Also investigated effect of varying height, heat input and aspect ratio, keeping length constant on heat transfer through HS. Burak Yazicioğlu and Hafit Yüncü [19] developed correlation to investigate optimum fin spacing of vertically based rectangular fin arrays. They developed new expression for prediction of optimal fin spacing for vertical rectangular fins protruding from vertical rectangular base. Range of base to ambient temperature difference was quite extensive, from 14ºC to 162ºC. The fin length range was from 100mm to 500mm, fin height from 5mm to 90mm, fin thickness from 1mm to 19mm & width of rectangular base plate from 180mm to 250mm. The average relative improvements were convection heat transfer rates from identically spaced fin arrays for fin heights of 5, 15 and 25mm are 37.44%, 39.01% and 41.28%, respectively. S. V. Kadbhane, D. D. Palande [20] studied steady state natural convective heat transfer from vertical rectangular fin array with isothermal and constant heat flux conditions experimentally. Natural convective heat transfer from rectangular vertical fin array can be enhanced by optimizing the geometrical parameters such as fin length, width, height, and spacing. Also orientation of fin array, affects the natural convective heat transfer rate. An experimental set up was constructed to test 25 different fin arrays. Fin length and thickness were kept constant at L=200mm and t=2.5mm respectively. Fin spacing was varied from 5.5 to 14.5mm and height was varied from 5 to 25mm. 5 different heat inputs ranging from 15W to 75W were supplied to all configurations. Experimentation revealed that optimization of geometrical parameters affects convective heat transfer rate. Effect of fin spacing on heat transfer rate was found more dominant than other geometrical parameters. It was observed that as fin spacing was increased, convective heat transfer rate also increases, reaches to maximum at a certain value of spacing known as optimum fin spacing and then decreases with further increase in spacing. Also observed that natural convective heat transfer rate is maximum for vertical orientation and it goes on decreasing as incline fin array from vertical to horizontal. Manuja Pandey, Utkarsh Prasad, Vineet Kumar, Nafish Ahmed [21] studied natural convection from vertical surfaces with large surface element is encountered in several technological applications of particular interest of heat dissipation in several forms. They found the best of different fin patterns by calculating the heat transfer rate. Type of fin pattern Parallel horizontal fin pattern, Parallel split pattern and V-fin array pattern was considered. They used Nichrome wire for heating purpose supplied with the stabilized A.C. supply. Controlled electrical heat input through Dimmerstat and measured with wattmeter. They determine fin pattern with highest heat transfer, i.e. fin provide greater cooling effect. Parallel horizontal fin pattern and V fin pattern has best effectiveness value which showed that heat enhanced by Split fin pattern greater than other two patterns. Surface area from heat transfer plays an important role, as area of Parallel horizontal fin pattern & V fin pattern same area which result in approximate similar values of effectiveness for both fin, whereas effectiveness of V fin pattern is slightly greater than parallel horizontal but in values of decimal. Yazicioğlu, Burak [22] conducted the heat transfer performance of rectangular fins on a vertical base in natural convection heat transfer. 30 fin configurations were tested. An optimum fin spacing value which maximizes the convective heat transfer rate from the fin array is made available for every fin height. The average relative improvements in the rates of convection heat transfer from identically spaced fin arrays for fin heights of 5mm, 15mm and 25mm are 37.44%, 39.01% and 41.28%, respectively. It is observed that the optimum fin spacing varies between 8.8mm and 14.7mm. Their conclusion reveals that the optimum fin spacing is sensitive to the variations in fin height, fin length and base-to-ambient temperature difference parameters. Kamil Mert Çakar [23] found optimum fin spacing from both numerically and experimentally. Natural convection from vertically placed rectangular fins is investigated numerically by means of commercial CFD program called ICEPAK. Examined effects of geometric parameters of fin on performance of heat dissipation from fin. He verified first models by simulating natural convection on vertically placed flat plate and comparing results with literature. He observed that convection heat transfer rate from fins increases with fin height h for given fin spacing s. Concluded experimentally Sopt value for vertical fin arrays is approximately 10mm and suggest a correlation for optimum fin spacing. A. A. Walunj, D. D. Palande [24] studied steady state natural convection from HS with narrow plate-fins having parallel arrangement mounted on inclined base was experimentally investigated. Aluminum HS with two different lengths 100mm and 200mm were modeled. Fin thickness was kept constant at 5mm. Fin height was selected 10mm, 20mm and 30mm for 100mm length of fin while it was 20mm, 40mm and 60mm for 200mm length of fin. HS was kept at aspect ratio of 0.1, 0.2 and 0.3. Rectangular base was made incline for 0°, 10°, 20°, 45°, 70°, 80° and 90° keeping upward facing fins. Heat input was varied from 60W to 100W. Effect of fin H, L & θ of base was determined. Range of angle of inclination θ was suggested showing equivalent heat transfer rate. Also, effect of aspect ratio over natural convection was examined. S. S. Sadrabadi Haghighi, H. R. Goshayeshi, Mohammad Reza Safaei [25] studied HS with 7 fins and 8.5mm fin spacing had lowest thermal resistance and highest natural convection heat transfer which can be considered as optimal design for plate pin-fin HS by comparing plate pin-fin HS and plate pin-fin HS (PFHS), it can be conclude that the plate cubic pin-fin HS has a better heat transfer rate and lower thermal resistance, in comparison with the plate pin-fin HS. Finally, they developed two empirical equations to correlate the average nusselt number as a function of studied parameters. They performed to measure heat transfer rate of plate pin-fin HS under regular convection. Ogie Nosa Andrew, Joel Oluwayomi Oyejide [26] studied importance of heat transfer by free natural convection can be found in many engineering applications such as energy transfer in buildings, solar collectors, nuclear reactors and electronic packaging. They carried out investigation and comparative analysis of heat transfer by natural convection on rectangular and triangular fins with and without circular perforation. A total of 6 specimens were used. Other materials that were used in this research work include four digital thermometers, one heating element, four thermocouple K-types and a power source. The fins used in this research work were welded to cylindrical pipe which served as HS. The heat supplied was maintained at 250oC and temperature drop through fin was recorded for duration of 30 minutes with intervals of 5 minutes. It was observed that the temperature dropped more rapidly with the triangular fins than the rectangular fin. Also, the rate of heat dissipation increase with a corresponding increase in the number of perforation. Xiangrui Meng, Jie Zhu, Xinli Wei, Yuying Yan [27] studied influence of mounting angle on heat dissipation performance of a HS under natural convection condition by numerical simulation and experimentally. They found HS achieves highest cooling power when mounting angle is 90o, reaches lowest when mounting angle is 15o which is 6.88% lower than 90o. Also found heat transfer stagnation zone is main factor that affects the cooling power of the HS, and its location and area vary with the mounting angle. It was identified that cutting the heat transfer stagnation zone was an effective way to improve the HS performance. A. Guvenc, H. Yuncu [28] studied natural convection heat transfer in rectangular fin-arrays mounted on a vertical base was investigated experimentally. An experimental set-up was constructed and calibrated to test 15 different fin configurations. Fin length and fin thickness were kept fixed at 100 and 3mm respectively, while fin spacing was varied from 4.5 to 58.75mm and fin height was varied from 5 - 25mm bases to ambient temperature difference was also varied through a calibrated wattmeter ranging from 10 to 50W. the results showed that fin spacing is the most significant parameter in the performance of fin arrays and for every fin height, for a given base to ambient temperature difference, there exists an optimum value for the fin spacing for which the transfer rate from the fin array is maximized. It was seen that higher heat transfer

Table 1
Summary of Experimental, Numerical & Simulation worked on Rectangular Fins through Natural Convection

Ref. No.	Year	Authors	Fin Material	Keywords	Work
1	1963	Starner and McManus	Aluminium	Natural convection, Rectangular fin	Flow patterns for each case were observed by using smoke filaments. Presented average heat-transfer coefficients for 4 fin arrays positioned with base vertical, 45º and horizontal while dissipating heal to room air.
2	2001	Filino Harahap, Daru Setio	Duralumin	Natural convection, Rectangular fin	Studied heat dissipation from horizontally oriented duralumin fin array. Investigated effect of fin length and optimal inter-fin distance.
3	2006	F. Harahap, H. Lesmana	Aluminium alloy	Natural convection, Rectangular fin	Investigate effects of miniaturizing base plate dimensions of vertically based straight rectangular fin arrays on steady state heat dissipation performance under dominant natural convection conditions.
4	2007	B. Yazicioglu, H. Yuncu	Aluminium	Natural convection, Rectangular fin	They provided an equation for optimum value of ratio of fin height to fin spacing and showed importance of fin spacing in their results. Reported Ratio of fin height to fin spacing varies with temperature.
5	1998	H.Yuncu, G.Anbar	Aluminium	Natural convection, Rectangular fin	Found given base to ambient temperature difference the convection heat transfer rate from fin-arrays takes on maximum value as function of fin spacing and fin height. Presents correlation relating the convection heat transfer rate of fin arrays relative to that for base plate without fins with the relevant non-dimensional parameters.
6	2000	S. Baskaya, M. Sivrioglu, M. Ozek	Aluminium	Natural convection,fin array, *CFD*, parametric study, heat transfer	Studied effects of fin spacing, fin height, fin length and temperature difference between fin and surroundings. Observe not possible to obtain optimum performance in terms of overall heat transfer by only concentrating on one or two parameters. Interactions among all design parameters must be considered
7	2008	L. Dialameh, M. Yaghoubi, O. Abouali	Aluminium	Heat transfer,Laminar flow,Numerical simulation,Natural convection, Heat transfer enhancement	Determine Effect of various fin Geometries and temperature differences. Observed two types of flow patterns in the channel of the fin arrays. Effect of various fin geometries and temperature differences on convection heat transfer from array determined for Ra numbers based on fin spacing 192–6784 and applied correlations are developed to predict Nusselt numbers with corresponding non-dimensional parameters.
8	2003	M. Mobedi, H. Yu¨ncu	Aluminium	Natural convection, Rectangular fin	Studied problem of three dimensional (*3-D*) laminar natural convection heat transfers with open boundaries. Numerically study steady state natural convection heat transfer from short fin array for Ra number based on *S* ranging from 120 to 39000.
9, 10, 11	2013	Ilker Tari, Mehdi Mehrtash	Aluminium	Plate fin array, Vertical *HS*, Natural convection, Electronics cooling	Tested wide range of angle of inclination with upward and downward orientations. By modifying Gr number with cosine of inclination angle, suggest modified correlation which is best suited for inclination angle interval of $-60^o \le \theta \le +80^o$.Natural convection from horizontal and slightly inclined plate fin arrays is investigated. Correlations for estimating convection heat transfer rates are suggested. The correlations are shown to be valid for the present and literature horizontal data with new set of correlations is obtained.
12	2007	V. Dharma Rao, S. V. Naidu, B. Govinda Rao, K.V. Sharma	Aluminium	Fin array, Natural convection, Heat transfer, Horizontal fins, Radiation, Vertical base	Studied effects of system parameters. Solved governing equations of mass, momentum and energy balance with heat conduction equations numerically using Alternating Direction Implicit (*ADI*) method.
13	2012	Vinod Wankar, S. G. Taji	Aluminium	Natural convection, Rectangular fin	Carried Temperature mapping and prediction of flow patterns over fin array with variable fin spacing.
14	1969	Charles D. Jones,Lester F. Smith	Aluminium	Natural convection, Rectangular fin	Studied average heat transfer coefficients for isothermal fins on horizontal surfaces over wider range of spacing's experimentally.
15	2012	Shivdas S. Kharche, Hemant S. Farkade	Aluminium,co pper	Natural convection, fin array	Tested heat transfer rate of copper fin for greater heat transfer rate which is need of increased rate of modernization. Copper gives more heat transfer rate than aluminum plate.

enhancement is obtained with vertically oriented bases than with horizontally oriented bases for fin arrays of the same geometry. Q. Shen, D. Sun, Y. Xu, T. Jin, X. Zhao [29] studied under natural convection mode found that intensive fin arrays were effectively affected by the orientation. Experimental and numerical study of the orientation effects on fluid flow and heat

International Journal of Research in Engineering, Science and Management
Volume-1, Issue-12, December-2018
www.ijresm.com | ISSN (Online): 2581-5792

Table 1 (Cont.)
Summary of Experimental, Numerical & Simulation worked on Rectangular Fins through Natural Convection

16	2011	Mahdi Fahiminia, Mohammad Mahdi Naserian, Hamid Reza Goshayeshi, Davood Majidian	Aluminium	Natural Convection, Vertical Surfaces, Simple Algorithm, Rectangular Fins	Found convective heat transfer depends upon variation in fin spacing, fin height and base to ambient temperature difference. Natural convection coefficient increased substantially as fins spacing was increased. It reached to maximum at optimum spacing S_{opt}. Further increase in fin spacing decreased the heat transfer rate.
17	2016	D. D. Palande, A. M. Mahalle	Aluminium	plate fin HS, Natural convection, Angle of Inclination	Studied effects of orientation of inclination on plate fin HSs. Observed at small inclinations from vertical as well as horizontal the convection heat transfer rate is not change significantly.
18	2015	S. D. Ratnakar, D. D. Palande	Aluminium	HSs, Fins, Natural Convection, Aspect Ratio	Use passive cooling technique. Investigated effect of varying height, heat input and aspect ratio, keeping length constant on heat transfer through HS.
19	2009	Burak Yazicioğlu and Hafit Yüncü	Aluminium	Optimal fin spacing, Extended surfaces, Natural convection	Developed correlation to investigate optimum fin spacing of vertically based rectangular fin arrays. Developed new expression for prediction of optimal fin spacing for vertical rectangular fins protruding from vertical rectangular base.
20	2016	S. V. Kadbhane, D. D. Palande	Aluminium	Natural convection, enhancement in heat transfer rate, geometrical parameters, angle of inclination, optimum fin spacing.	At isothermal and constant heat flux conditions. Revealed optimization of geometrical parameters affects convective heat transfer rate. Effect of *S* found more dominant than other geometrical parameter. Observed *S* increased, convective heat transfer rate also increases, reaches to S_{opt} and then decreases with increase in *S*. Natural convective heat transfer rate is maximum for vertical orientation and it goes on decreasing as incline fin array from vertical to horizontal.
21	2015	Manuja Pandey, Utkarsh Prasad, Vineet Kumar, Nafish Ahmed	Aluminium alloys	Cooling fins, heat transfer coefficient, heat transfer rate, effectiveness thermocouples.	Parallel horizontal fin pattern and V fin pattern has best effectiveness value showed heat enhanced by Split fin pattern greater than other two. Surface area plays important role, as area of Parallel horizontal fin & V fin same area which result in approximate similar values of effectiveness for both fin, showed effectiveness of V fin pattern is slightly greater than parallel horizontal but in values of decimal.
22	2005	Yazicioğlu, Burak	Aluminium	Optimal fin spacing, Extended surfaces, Natural convection	Good enhancement achieved by attaching fins to vertical flat plate. Optimum fin spacing depends on fin height, fin length and base to ambient temperature difference, but the dependence on fin length is not very significant.
23	2009	Kamil Mert Çakar	Aluminium	Natural convection, vertical rectangular fins, optimum fin spacing	Found optimum fin spacing from both numerically and experimentally studies. Natural convection from vertically placed rectangular fins is investigated numerically by commercial *CFD* program called ICEPAK. Examined effects of geometric parameters of fin on performance of heat dissipation from fin. He verified first models by simulating natural convection on vertically placed flat plate and comparing results with literature.
24	2014	A. A. Walunj, D. D. Palande,	Aluminium	plate-fins, narrow, aspect ratio, natural convection	Steady state natural convection from *HS* with narrow plate-fins having parallel arrangement mounted on inclined base experimentally investigated. Aluminum *HS* with two different lengths viz. 100*mm* and 200*mm* were modeled. Effect of fin height, fin length, inclination of base determined. Suggested range of angle of inclination was showing equivalent heat transfer rate. Also, effect of aspect ratio over natural convection examined.
25	2018	S. S. Sadrabadi Haghighi, H. R. Goshayeshi,Mohammad Reza Safaei	Aluminium	Natural convection heat transfer, Plate cubic pin fin *HS*, Fin spacing, Ra number	New designs of plate-fin and plate cubic pin–fin *HS*s were performed. Natural convection of airflow was measured over *HS*s experimentally. Studied effects of fin shape, spacing and numbers, heat input and Ra. Heat transfer enhancement of new-designed *HS*s is about 10% to 41.6%. Increasing number of fins cause lower thermal resistance.
26	2018	Ogie Nosa Andrew, Joel Oluwayomi Oyejide	Aluminium	Rectangular and Triangular Fins, Perforated, Natural Convection, Heat Transfer, Comparison	Studied importance of heat transfer by free natural convection found in many engineering applications such as energy transfer in buildings, solar collectors, nuclear reactors and electronic packaging. Observed that temperature dropped more rapidly with the triangular fins than rectangular fin. Also rate of heat dissipation increase with corresponding increase in number of perforation.

transfer of rectangular fin HSs under natural convection conditions are carried out. The performance evaluations for different rectangular fin HSs in 8 orientations are conducted. Denser fin arrays are found more sensitive to orientation. The experimental results agree well with the present prediction and previous experimental data. Correlations in a simple form Nu =

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27	2018	Xiangrui Meng, Jie Zhu, Xinli Wei, Yuying Yan	Aluminium	Natural convection heat transfer, *HS*, Mounting angle, Stagnation zone	Best performance is achieved at mounting angle 90^o for straight fin *HS*. A heat transfer stagnation zone with temperature difference less than 2^o*C* is identified. The heat transfer stagnation area reaches the maximum at the mounting angle of 15^o. Cutting heat transfer stagnation zone is effective way to improve *HS* performance.
28	2001	A. Guvenc, H. Yuncu,	Aluminium	Natural convection heat transfer	Natural convection heat transfers in rectangular fin-arrays mounted on a vertical base investigated experimentally. An experimental set-up was constructed and calibrated to test 15 different fin configurations. It's seen those higher heat transfer enhancements are obtained with vertically oriented bases than horizontally oriented bases for fin arrays of same geometry.
29	2014	Q. Shen, D. Sun, Y. Xu, T. Jin, X. Zhao	Aluminium	Natural convection, Orientation effect, Rectangular fin, *HS*, *LED*	Under natural convection mode found intensive fin arrays effectively affected by orientation. Study of orientation effects on fluid flow and heat transfer of *HS*s carried out experimentally and numerically. Performance evaluations for different rectangular fin *HS*s in 8 orientations conducted. Denser fin found more sensitive to orientation. Experimental results agree well with present prediction and previous experimental data. Proposed Correlations in simple form Nu = CR_{am} for various orientations. Exponent is found almost same in orientation of 45^o, 135^o, 225^o& 315^o.
30	2013	H. Zhang, L. Chen, Y. Liu, Y. Li	copper	*HS*, Micro channel, Chip cooling, Heat transfer, Porous metal, Metal–gas eutectic	Studied heat transfer performance of lotus-type porous copper *HS* experimentally. Copper selected as matrix metal because of high heat conductivity. Two methods taken to increase penetrative porosity of lotus-type porous copper: cutting section after fabrication & increasing pore growth length during fabrication.

CRam are proposed for various orientations seldom investigated before. The exponent m is found almost the same in orientation of 45^o, 135^o, 225^o & 315^o. Furthermore, computational results show mismatch between heat transfer area and natural convection flow, and the blockage of the convection flow are the two dominant factors that deteriorate heat transfer of the rectangular fin HSs. H. Zhang, L. Chen, Y.

Liu, Y. Li [30] studied heat transfer experimentally, performance of lotus-type porous copper HS. A special kind of micro-channel HS was made by using lotus-type porous (Gasar) metals with long cylindrical pores formed during unidirectional solidification of metal–gas eutectic system. Copper was selected as the matrix metal because of its high heat conductivity. The heat transfer performance of lotus-type porous copper HS with a length of 20mm along the axial direction of pores was studied on a testing platform designed and set up in this paper. The experimental results show that the lotus-type porous copper HS cooled by water has excellent heat transfer performance and a heat transfer coefficient of 5 W/cm^2 ^{o}K is attainable when the porosity is 29% and mean pore diameter is 400lm and is already able to meet the requirement for cooling high heat flow density CPU chips, so lotus-type porous copper HS has the feasibility of practical application. An even larger heat transfer coefficient of 9W/cm^2 ^{o}K can be reached after simply cutting the porous copper along the vertical direction of pore axis into four or eight equal sections aliened in the direction of pore axis, because that reducing the length of porous copper HS along the direction of pore axis will increase the penetrative porosity, result in increase of flow rate, and then enhance the heat transfer performance of the HS. Two methods could be taken to increase the penetrative porosity of lotus-type porous copper: one is cutting section after fabrication, and the other is increasing pore growth length during fabrication. Thus some methods have to be taken to increase the pore length and penetrative porosity when fabricating lotus-type porous copper HS.

A. *Summary*

As has been information gathered from present literature review, work has been accounted for on the topic of regular natural convection cooling with rectangular fin. Fin arrays are widely used in HS for cooling electronic parts by natural convection. The most well-known setups include even or vertical surfaces to which plate are attached. Such setups have been researched by numerous creators to decide their heat transfer performances. It was seen that; the greater part of the test takes a shot at such configurations don't cover an extensive variety of parameters. Also, none of the creators, who have performed trial chip away at rectangular fins on a vertical surface, related their outcomes.

3. Recommendations for future scope

In the coming future progressively advance materials can be utilized in order to upgrade the heat transfer rate. There is highly need to redesign the property in order to boost the performance of the system. There has work in such way yet at the same time there is tremendously need to do in this field. Some new co-relations can be delivered and attempted. New materials can be used to make fins to upgrade the heat transfer rate.

Table 2
Range of Geometrical Parameters

Ref. No.	Length of fin (*L*)	Base Width of fin (*W*)	Height of fin (*H*)	Thickness of fin (*t*)	Fin Spacing (*S*)	Optimum Fin spacing (S_{opt})	No. of fins (*N*)	Angle from Vertical (θ°)
1	127	254	6.35-25.4	1.02	6.35-7.95	-	-	0,-45,-90
2	177.5,250	6.35,13.1,23.9	13.5	1.02-3.10	6.25,6.35,6.40,7.35	-	10,13,17	-90
3	25,33,49	25,33,49	13.5	1	3,11	-	3,5,7,9,13	0
4	250,340	180	5,15,25	3	5.85,8.8,14.7,32.4,85.5	10.4-11.9	3,6,11,16,21	0
5	100	250	6,16,26	3	6.2,9.4,19,35,83	10.4,11.6,19.5	4,8,14,27,41	-90
6	127,254	-	6.3,13,25,38	-	6.3,8	6,7	-	0
7	7,12,25,50	-	7,12	3,7	4,7,10,12	7	-	-90
8	65,100,130,195	130	34,105,215	2.2	7	-	-	+90
9,10,11	250,340	180	5-25	3	5-85.5	11.75	-	0,4,10,20,30,45,60,75,80,85,90
12	250	-	10,20,30,40,50	-	7.3,16,32.3,58.75	-	-	0
13	200	100	40	2	2,3,4,5,6,8,10,12	9-11	-	-90
14	10.0	-	1.44	-	0.25	0.25-0.50	7	0
15	127	-	38	1	9	-	-	0
16	31.75	31.75	0.25,0.5,0.75,1	1	0.5,0.75,1	1	-	-90
17	200	-	5,10, 15,20, 25	-	5-20	9.5, 10.5	-	0,30, 45,60, 90
18	200	180	10,30, 50	5	-	-	-	0
19	100-500	180-250	5-90	1-19	2.85-85.5	-	-	0
20	200	-	5-25	2.5	5.5-14.5	9-11	25	0
21	200	200	40	3	-	-	5	0
22	250,340	180	5,15,25	3	5.75-85.5	8.8,14.7	3,6,11,16,21	0
23	250,340	180	5,15,25	3	4.5,7.3,16,32.3,58.75	10	5,8,14,25,34	0
24	100, 200	140, 155	10,20,30,40,60	5	10,7.5	-	10,13	0
25	70	50	45	1	5-12	8.5	5-9	0
26	94	130	-	3	-	-	6	0
27	150	76	50	5	-	-	7	0,15,30,45,60,75,90
28	100	250	26,16,6	3	6.2,9.4,19,35,83	-	41,27,14,8,4	0
29	123	157	50	2	6,8,13,23	-	7,11,16,20	0,45,90,135,180,225,270,315
30	20	32	-	5	-	-	-	0

4. Acknowledgement

I feel extraordinary delight to present this paper entitled “A Review on Automobile Equipment Cooling through Engine Heat Sink - Rectangular Fins under Natural Convection”. But it would be unjustifiable on my part if I don't acknowledge efforts of some of the people without the support of whom, this review would not have been a success. First and fore most I am particularly appreciative to my regarded guide Dr. D. D. Palande for their leading guidance in this topic. Additionally they have been persistent source of inspiration to me. In particular I might want to offer my sincere gratitude towards my Friends for always being there when I needed them most. Lastly I would like to thank my parents, whose love and guidance are with me in whatever I pursue. They are the ultimate role models. In particular, I wish to thank my loving and strong Father and Mother, chandrabhan jadhav and pushpa jadhav and my two wonderful Brother and Sister, dhananjay jadhav and yogini jadhav who provide unending inspiration.

5. Conclusion

This paper concludes that the A Review on Automobile Equipment Cooling through Engine Heat Sink - Rectangular Fins under Natural Convection.

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