International Engineering Research Journal

Experimental Study of Natural Convection Heat Transfer with HorizontalRectangular Fin Array Using Various Knurling Patterns on Fin.

Shashikant V. Raut, Basavraj S. Kothavale, and Rahul Chikurde.

†Shashikant V. Raut,Mechanical MIT-college of Engineering, SPPU Pune, India
‡Basavraj S. Kothavale,Mechanical MIT-college of Engineering, SPPU Pune, India
†Rahul chikurde,Mechanical MIT-college of Engineering, SPPU Pune, India

Abstract

Natural Convection heat transfer from horizontal rectangular fin array with various knurling patterns is studied experimentally to find the effect of varying surface roughness on the heat transfer rate. The experimental parametric study is performed to investigate the effect of knurl produced surface roughness of fin on heat transfer rate. The parameters like knurling height from base, knurling depth and fin spacing might affect the flow characteristics and hence will be investigated to find the efficiency and fin effectiveness of rectangular fins and also effect on heat transfer coefficient. The knurling is usually accomplished using one or more very hard rollers that contain the reverse of the pattern to be imposed.

The result of this study shows that there are some important geometric factors related to knurling affecting the design of fin arrays and also augmentation of natural convection heat transfer is observed.

Keywords: *Natural Convection, Heat transfer, Fin array, Knurling patterns, horizontal plate fin, Fin Spacing.*

1. Introduction

Now World facing a problem of cooling for many electronic application but with requirement of space and power. In passive cooling or Natural convection is required or optimum solution for this problem of cooling. Many researchers are working on natural convection and develop the new cooling system for required application. In that various types of cooling system is based on application. In natural convection various type of heat exchangers are available like plate fin heat exchangers, shell and tube type heat exchangers, heat pipe technology also in that Nano fluid using in heat pipe. Which type cooling system are suitable for particular application is based space for the cooling system, power for cooling system also cost of cooling system is one factor for it. Now a days the electronics products are very chip in size and area so the many cooling system are not suitable for this particular application and also some electronic components are not space for fan and blower so the for that the force convection and other more bulky system is not suitable for the electronic cooling application. The one most effective system is heat pipe technology is also suitable for the application but the cost of heat pipe is more expensive than the other cooling system. For that particular application the fin array is most suitable for electronic application. Many researchers study on plate fin array up to 19th century for many fin array develop with the varying a various parameters. In that the fin array basically are two types are plate fin array and pin fin array. Many research's working on the two types of fin array with the all including application are various parameter of finarray likefin spacing, fin height, fin thickness, fin length and fin base thickness also the varying the load under the natural convection.

One of them the F. Harahap and H.N.Mcmanus working on natural convection fin array in the mid of 20th century. In that research they select the horizontal rectangular fin array heat transfer under the natural convection. They study about the flow pattern of smoke over the fin array basically two type of flow pattern study in natural convection first one is single chimney flow pattern and second one is multi chimney flow patterns also they varying a parameter like fin spacing, fin height, fin thickness, fin length and fin base thickness for the various load.(F. Harahap et al. 1967). Another one is SenolBaskaya et al. studied on horizontal rectangular fin array under natural convection in that they studied on only on fin parameter. They varying the fin length, fin spacing and fin height and shows the effect of all fin parameters on the heat transfer coefficient also studied the numerical study of the experimentation. (SenolBaskaya et al. 1999).

IlkerTari and Mehdi Mehrtash studied on plate fin array. They studied on different point of view like inclination of fin array the main aim is that what is effect of inclination angle of plate fin heat sink under natural convection. They used various angle for heat link like -60^0,-65^0,-70^0,-75^0,-80^0,-85^0 and -90^0 for the vertical fin array also they varying fin height and load and result analysis is according to Nusselt Number that mean the effect of fin parameters and angle of inclination on heat transfer and also create the correlation of Nusselt Numbers for that particular inclination of plate fin array for vertical. (IlerTari et al. 2013). Also the SalilaRanjan Dixit and D P Mishra are studied on horizontal rectangular fin array with inverted notched fin array under the natural convection. They compare the unmatched and notched fin array and heat transfer through notched fin array under natural convection. Also varying the various parameter like fin spacing depends on fin spacing number of fin is decided. Also produced various no of configuration with variation of fin spacing and no of fin and also the no of channels. Also varying the load like 20w, 50w, 75w and 100w. They conclude the increasing the fin spacing also increase heat transfer coefficient and notched fin better performance than the UN notched fin. (SalilaRanjan Dixit et al, 2013).

In above research topic is Experimental Study of Natural Convection Heat Transfer with Horizontal Rectangular Fin Array Using Various Knurling Patterns on Fin in that case the is effect of various knurling patterns on heat transfer in horizontal fin array. Knurling pattern on plate fin is like that the roughness on plate fin. The various types of knurling pattern like straights knurl (AA), 30^0 right hand knurling ($BR30^0$), 45^0 right hand knurling ($BR45^0$), 30^0 left hand knurling ($BL30^0$), 45^0 Left hand knurling ($BL45^0$)and Diamond knurling. In that the knurling angle is actually the helix angle is along the vertical plane. In that case used straight knurling for the experimentation on plate fin. In that experimentation used horizontal rectangular fin array and also varying various parameter of knurling patterns and also varying fin parameter like fin spacing.

2. Experimental Setup

The experimental setup was constructed as per requirement, simplicity and practicability and also considering the some uncertainty. In that case used rectangular hood for the experimentation. The rectangular plate fin having length 20cm, height 4cm and thickness is 2mm are fixed. And varying fin spacing knurl depth, knurl height and load variation. Also the used some instruments like wattmeter, Electrical heater, Dimmer stat, Thermocouple, Temperature indicator and servo stabilizer.

Table 1 Instruments

Sr. No	Instrument Name	Quantity
1	Wattmeter	1
2	Electrical Heater	3
3	Dimmer Stat	1
4	Thermocouple	17
5	Temperature Indicator	1
6	Servo stabilizer	1

The Electrical heater is circular shape type is having 10mm diameter. The three circular heater are used for heating with various load. The fin having three circular hole at bottom side with keep a distance 5cm each. The various material are available for fin and spacer like copper and aluminum. The material selection depending on thermal properties of material. Copper having higher thermal conductivity than the aluminum but copper is more expensive. Also the diamond having higher thermal conductivity than copper and aluminum also due to lattice vibration but diamond is lot expensive. Because of that aluminum is best material for the plate fin and spacers. The plate fin 2D geometry as shown in fig.

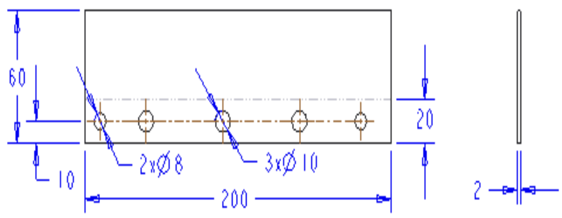


Fig.1 Geometry of plate fin

The two small hole with 8mm diameter for nut and screw fitting.

2.1 Fin array configuration

The fin array configuration depends on fin array area. The fin array area is 20×11 cm. Depending on fin area fin configuration are develop. The variation of fin spacing knurling depth and knurling pattern height. With all considering parameter developed 21 different geometry with combination of all fin parameter and knurl parameter like knurl height or knurl depth.

Table 2 Variation of Fin Spacing Knurl Depth and Height and load.

Sr No.	Fin parameter	Specification of parameter
1	Fin spacing	1. 8mm 2. 10mm 3. 12mm
2	Knurl Height	1. Full both side 2. $3/4^{th}$ both side 3. Lower half both side
3	Knurl Depth	1. 0.5mm 2. 0.25mm
4	Load	1. 25W 2. 50W 3. 75W 4. 100W

Fig.2 Fin Array.

2.2 Procedure of Experimentation

For calculating the radiation losses perfectly black the fin or blackening the plate fin with help of kerosene lamp. For calculating maximum radiation losses with the help of maximum emissivity. For maximum radiation losses gives the accurate convective heat transfer. Give the heating load by the help of Dimer stat. This are the specification of dimmer stat Radio Electric Pvt. Ltd., Mumbai make, 2 Ampere maximum, Max. Load – 2 kVA, Input – 240 V, 50 Hz at C-B, Output – 0 to 270 V at C-E. There are Seventeen thermocouple used for the temperature measurements. This are the thermocouple specification 36 gauge, Teflon coated, Copper- Constantan,Taken from same spool and few calibrated for ice point and steam point using hypsometer, Temperature Range:(-) 168.9 to (+) 390^{0}C EMF (mV): (-) 5 to 21 mV , IS 2056:1962. The servo control is used for the controlling the load. There are four load variation like 25W, 50W, 75W, 100W by using of dimmer stat. in that seventeen thermocouple first five is used for the measuring fin temperatures, and next four is located for measuring atmospheric temperatures and other eight are used for measuring syporex block having with thermal conductivity0.157W/mKtemperatures for measuring conduction loss calculation. The experimental set up as shown in fig.

Fig.3 Experimental set up for horizontal rectangular Fin Array.

In that fig shows the experimental set up for horizontal rectangular fin array. There is one control box with the temperature indicator, wattmeter and dimmer stat also the temperature controller for controlling the all seventeen temperature and shows in temperature indicator with number wise. In the experimentation the fin height 4cm, fin length20cm and fin thickness 2mm is kept constant all 21 Geometry configuration but only some thickness are changes because of straight knurling pattern on fin. The another fin thickness is depends on the roughness depth i.e. the 0.5mm depth that at other than crest the thickness will be 1mm because of 0.5mm each side roughness depth and at crest is 2mm fin thickness.

2.3 Data Analysis

In that case for calculating the convective heat transfer we need to calculate the conduction losses and radiation losses and the total is supplied by the heater. That mean convective heat transfer is equal to

$$Q_{conv} = Q_{input} - (Q_{conduction} + Q_{radiation}) \quad (1)$$

The conduction heat transfer is the heat transfer into the syporex box with the all side. In that conduction case the area is important factor for the calculating conduction heat transfer so the area of base surface and area of fin array placed surface.

$$Q_{conduction} = -kA\frac{dT}{dx} \quad (2)$$

In case of radiation the emissivity of plate fin is consider 0.92 because of fin with perfect blackening with the help of kerosene lamp. The area is considered as total exposed area of the fin array. The Stefan Boltzmann constant value considered also the taking average fin temperature T_{avg}. For the higher temperature the radiation losses will be increase with increasing the temperature because of that at 25W radiation losses is minimum and 100W load the radiation losses is maximum. There for the losses increase with the increasing the load.

$$Q_{radiation} = \in\sigma A_s [T_s^4 - T_\infty^4] \quad (3)$$

For thecalculate the radiation lossesthe difference between the fourth poweraveragetemperature to the fourth poweratmospherictemperature.
Also calculating theaverage heat transfercoefficient to from the newtons law of cooling correlation. In that case the total exposedarea of fin array to be considered.

$$h_a = \frac{Qconv}{A_e \times \Delta T} \quad (4)$$

By using this equation to calculate the average heat transfer coefficient for all different 21Geometry. Also calculate the base heat transfer coefficient by using the base area for the further calculation.
After that nusselt number is important for the further calculation. By using the correlation for nusselt number with help of average heat transfer coefficient

and the characterize length. In that case the characterize length is the considered as fin height. Depending on heat transfer coefficient like average heat transfer coefficient and based heat transfer coefficient the average nusselt number or base nusselt number obtained. For nusselt number calculation equation is given below

$$Nu_a = \frac{(h_a \times H)}{k} (5)$$

This the équation for the average nusselt number based on the average heat transfer coefficient. Also like basenusselt number depending on the basenusselt numbers.

2.4 Experimental Validation

The experimental validation is more important because of the validation gives the conformation of correctness of experimentation. The experiment is an ultimatum but the validation is gives the information about the right Path because of that validation is more important. The two correlation chose for the experimental validation first is defined by Allan D Kraus this correlation for horizontal plate fin under natural convection in Extended Surface Heat Transfer book. And second one is correlation for horizontal based fin array defined by FilinoHarahap in 2001. For considering this two equation value match with experimental with in less than 10% distraction. The correlation for horizontal plate fin array under natural convection is

1. Correlation Horizontal plate under natural convection
$$Nu = 0.27Ra^{1/4} \quad (5)$$
2. Correlation for horizontal based fin array.
$$Nu = C(Gr'\mathrm{Pr})^a \quad (6)$$

$$Gr' = \frac{g\beta\Delta TS^3}{\vartheta^2} \quad (7)$$

The values constant c and a is given below. The Gr' is the modified grashof number for using in above correlation. In that case the load in watt.

Table 3 Experimental validation for 8mm fin spacing.

8 mm Fin Spacing			
Load	Experimental	Allan Kraus	FilinoHarahap
25	5.346	5.1093	4.909
50	5.831	5.69	5.3204
75	6.35	5.9545	5.8923
100	6.23	6.1447	5.8947

Table 4 Experimental validation for 10mm fin spacing.

10 mm Fin Spacing			
Load	Experimental	Allan Kraus	FilinoHarahap
25	5.862	5.3085	5.7244
50	6.35	5.676	6.129
75	6.724	6.1949	6.4057
100	6.719	6.145	6.368

Table 5 Experimental validation for 12mm fin spacing.

12mm Fin Spacing			
Load	Experimental	Allan Kraus	FilinoHarahap
25	7.333	6.2511	6.9873
50	8.425	7.7691	7.9553
75	8.711	8.1843	8.346
100	8.706	7.8561	8.159

This are all experimental values comparing with the Allan D Kraus and FilinoHarahap for different fin spacing like 8mm, 10mm and 12 mm. the difference between the two correlation and the experimental values with 10%. So the experiment is valeted for flat plate. The knurling pattern on plat fin no any correlation for that the experimental validation based on the Horizontal flat plate fin array.

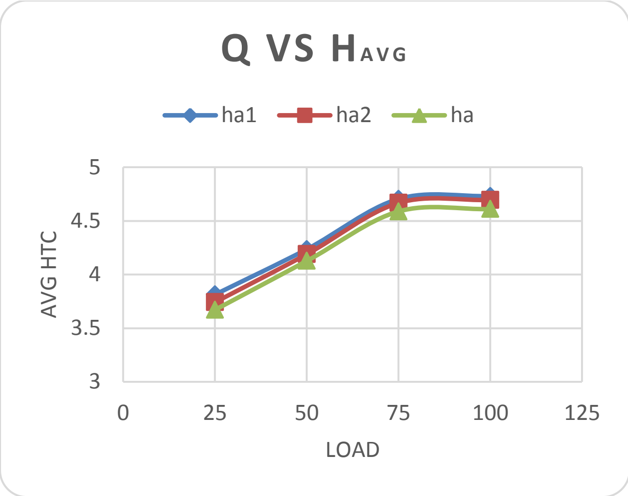
3. Result and Discussion

In this experimentation consideration fin parameter as well as knurling parameter so total no of 21 different Geometry formed form combination of fin parameter and knurling parameter. Depending on this parameter the some results are plotted like average heat transfer coefficient verses load in Watt.

3.1 Result Analysis for Full Knurl both side

3.1.1 Results for 8mm Fin Spacing.

In the 8mm fin spacing of fin array comparing with flat fin knurl fin of 0.5mm Depth and 0.25mm Depth. In this results the average heat transfer coefficient is nearly closed or lower than the 10mm and 12mm fin spacing results. In 8mm fin spacing the air flow is steady in conduction is dominated in 8mm fin spacing because of closed distance between the two parallel plates. The conduction in done in air to air contact.In this graph ha is the heat transfer coefficient for flat plate, ha1 is for knurling pattern on fin with 0.5mm Depth and ha2 is for knurling pattern on fin with 0.25mm depth.

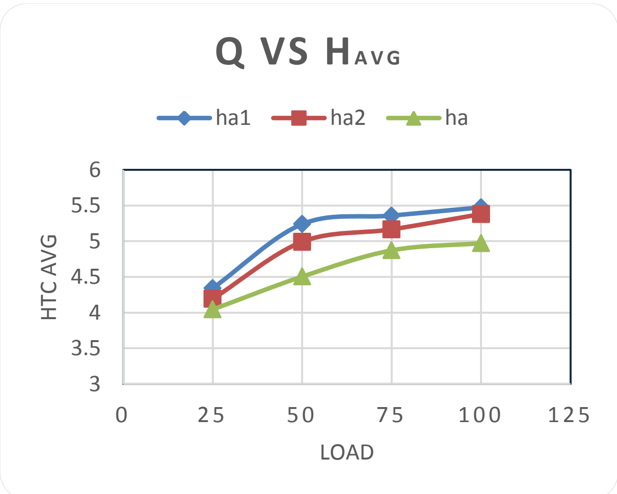


Graph 1 for 8mm Fin Spacing Q vs. Havg

In this graph ha is the heat transfer coefficient for flat plate, ha1 is for knurling pattern on fin with 0.5mm Depth and ha2 is for knurling pattern on fin with 0.25mm depth.

3.1.2 Results for 10mm Fin Spacing

In the 10mm fin spacing of fin array comparing with flat fin knurl fin of 0.5mm Depth and 0.25mm Depth. In this 10mm fin spacing the heat transfer coefficient in between the 8mm fin spacing and 10mm fin spacing. Because of in 10mm fin spacing distance between two plats is 2mm more than the 8mm fin spacing because of that the convection dominated the conduction between two plats fin. That's the 10mm fin spacing is better performance than 8mm and also the variation between the flat plate and knurl fin more than 8mm fin spacing and 12mm fin spacing. In this graph ha is the heat transfer coefficient for flat plate, ha1 is for knurling pattern on fin with 0.5mm Depth and ha2 is for knurling pattern on fin with 0.25mm depth.

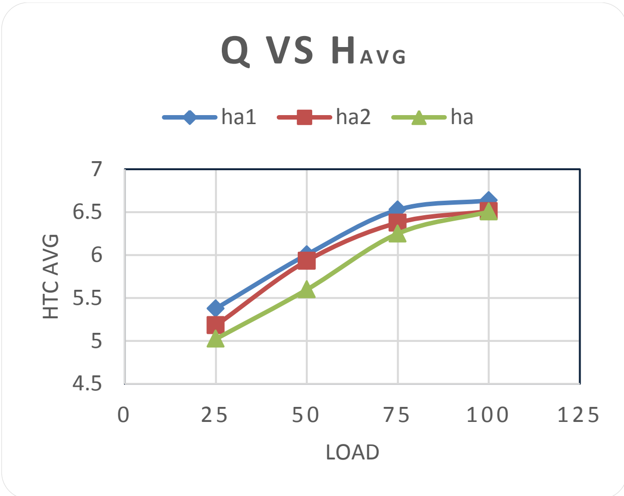


Graph 2for 10mm Fin Spacing Q vs. Havg

The above two graph shows the all value of average heat transfer coefficient is increase lineally with increasing the load. In this graph more difference between the flat plat and full knurling plate ate 25W is the 16.35% incrementing performance of full knurl both side with 0.5mm Depth.

3.1.3 Results for 12mm Fin Spacing.

In the 12mm fin spacing of fin array comparing with flat fin knurl fin of 0.5mm Depth and 0.25mm Depth. In the 12mm fin spacing the convective heat transfer coefficient is more than the 8mm and 10mm fin spacing because of the distance between the two plats is more than the 8mm and 10mm fin spacing. There for the convection completely dominated the conduction between airs the boundary layer formation is beneficial in 12mm fin spacing.



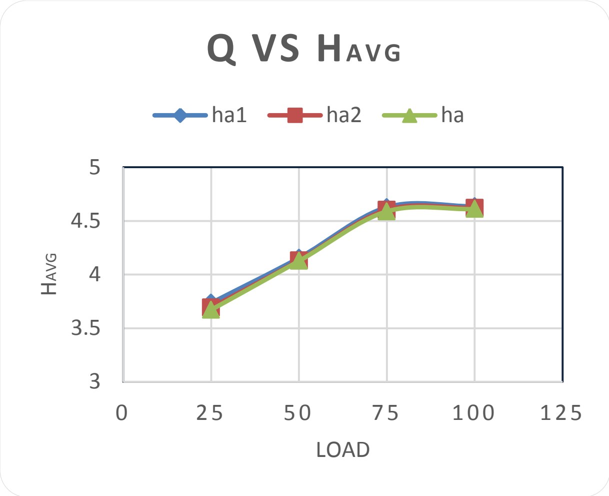
Graph 3for 10mm Fin Spacing Q vs. Havg

In that case also maximum deflection or increment for 25W load and also the all average convective heat transfer coefficient increase lineally for flat or full knurl both side i.e. 0.5mm and 0.25mm depth.

3.2 Result *Analysis for Full Knurl both side*

3.2.1 Results for 8mm Fin Spacing.

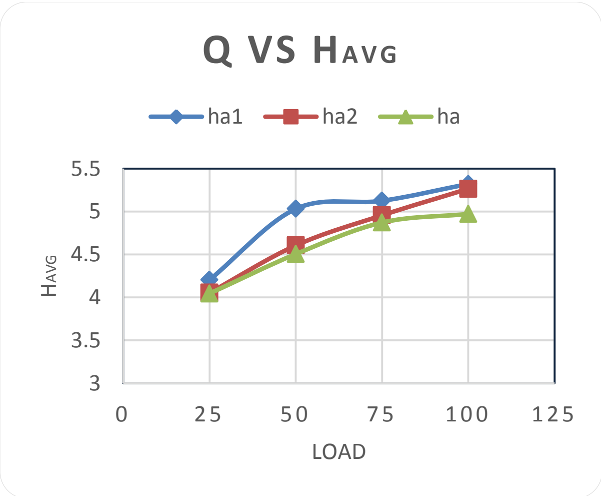
In the 8mm fin spacing of fin array comparing with flat fin knurl fin of 0.5mm Depth and 0.25mm Depth. In this results the average heat transfer coefficient is nearly closed or lower than the 10mm and 12mm fin spacing results. In 8mm fin spacing the air flow is steady in conduction is dominated in 8mm fin spacing because of closed distance between the two parallel plates. The conduction in done in air to air contact.In this graph ha is the heat transfer coefficient for flat plate, ha1 is for knurling pattern on fin with 0.5mm Depth and ha2 is for knurling pattern on fin with 0.25mm depth.



Graph 4 for 8mm Fin Spacing Q vs. Havg

3.2.2 *Results for 10mm Fin Spacing.*

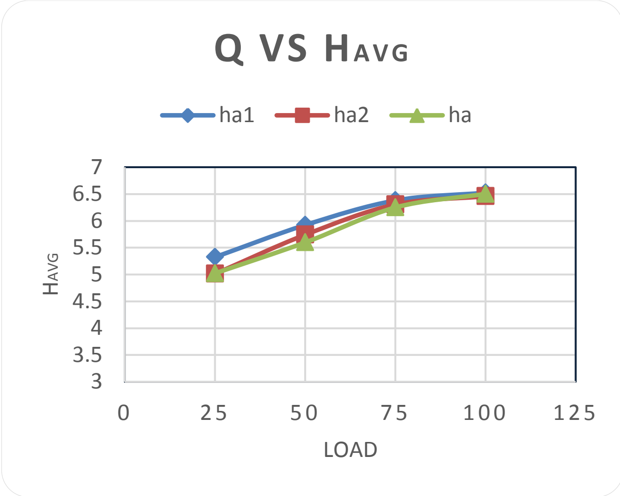
In the 10mm fin spacing of fin array comparing with flat fin knurl fin of 0.5mm Depth and 0.25mm Depth. In this 10mm fin spacing the heat transfer coefficient in between the 8mm fin spacing and 10mm fin spacing. In that maximum average heat transfer coefficient achieve at the maximum load with 0.5mm knurl depth.



Graph 5 for 10mm Fin Spacing Q vs. Havg

3.2.3 Results for 12mm Fin Spacing.

In the 12mm fin spacing of fin array comparing with flat fin knurl fin of 0.5mm Depth and 0.25mm Depth. In the 12mm fin spacing the convective heat transfer coefficient is more than the 8mm and 10mm fin spacing because of the distance between the two plats is more than the 8mm and 10mm fin spacing. There for the convection completely dominated the conduction



Graph 6 for 12mm Fin Spacing Q vs. Havg

Conclusions

The conclusion are drawn basis on the experimental data of flat plate fin array and full knurl both side with 0.5mm and 0.25mm depth of knurl.

1) The full knurl both side better performance than flat plat with the maximum increment 16.35% in 10mm fin spacing for 25W load.
2) Also the average increment 10% in all fin spacing. All the convective heat transfer coefficient increase linearly.
3) The full knurl both side fin array with 0.5mm depth better performance than the 0.25mm depth fin array and flat plat fin array. 0.25mm depth fin array convective heat transfer coefficient is in between the flat plat fin array and 0.5mm depth knurl both side fin array.
4) The maximum convective value noticed at the 12mm fin spacing at 100W is 6.63. The convective heat transfer coefficient increase the increasing load after 75W the heat transfer coefficient is slightly increase at 100W because of the for higher temperature radiation losses increase slightly.
5) In that all configuration the average heat transfer coefficient increase with increasing fin spacing also increasing with increasing knurl depth and alsoincreasing with increasing load.

References

Leonardo Micheli, K.S. Reddy, Tapas K. Mallick, "Thermal effectiveness and mass usage of horizontal micro-fins under Natural convection" *Applied thermal engg* 97(2016) 39-47.
SenolBaskaya, MecitSivrioglu, Murat Ozek, "Parametric study of natural convection heat transfer from horizontal rectangular fin arrays" *Int. J. Therm. Sci.* (2000) 39, 797–805
Shashikant V. Raut, Basvraj. S. Kothavle,"Study on Thermal Performance of Micro Fin Heat Sink under Natural Convection–A Review",*International Journal of Current Engineering and Technology*(2017) E-ISSN 2277 – 4106, P-ISSN 2347 – 5161

Li-Hao, Tai-Her yang, Sih-Li chen, "Influence of inter-fin base length on thermal performance of free hanging horizontal Base heat sinks." *International Journal of Thermal Sciences* 84 (2014) 164-174.
F. Harahap. N. Mcmnus, JR." Natural convection heat transfer from Horizontal Rectangular fin Arrays".*ASME*,(1967),32-38.
M. Yousaf, S. Usman, "Role of Surface Roughness during Natural Convection." *World Journal of Engineering and Technology* (2015) 3, 140-148
Leonardo Micheli a,⇑, K.S. Reddy b, Tapas K. Mallick, "General correlations among geometry, orientation and thermal performance of natural convective micro-finned heat sinks" *International Journal of Heat and Mass Transfer* 91 (2015) 711–724.
Leonardo Micheli, K. S. Reddy, Tapas K. Mallick, "Plate micro-fins in natural convection: an opportunity for passive concentrating photovoltaic cooling." *Energy Procedia* 82 (2015) 301 – 308
Guei-jang Huang, Shwin-Chung Wong, Chun-Pei Lin, "Enhancement of natural convection heat transfer from horizontal Rectangular fin arrays with perforations in fin base" *International Journal of Thermal Sciences* 84 (2014) 164-174.
M. Dogan, MecitSivrioglu, OnderYılmaz, "Numerical analysis of natural convection and radiation heat transfer from various shaped thin fin-arrays placed on a horizontal plate-a conjugate analysis." Energy Conversion and Management 77 (2014) 78–88.
Pankaj Singh, Anil K. Patil, "Experimental Investigation of Heat Transfer Enhancement through Embossed Fin Heat sink under Natural Convection" *Experimental Thermal and Fluid Science* 1777(14)00253-2.
IlkerTari*, Mehdi Mehrtash, "Natural convection heat transfer from horizontal and slightly inclined plate-fin heat sinks." *Applied Thermal Engineering* 61 (2013) 728e736
Allan D Kraus, "Extended Surface Heat Transfer.",(2001),1-1086
Warren M. Rohsenow, James P. Hartnett, Young I. Cho, "Handbook of Heat Transfer.", Third Edition, *Mcgrraw-hill,* 1-I.14
https://en.wikipedia.org/wiki/plate_Heat sink.