Numerical Simulation of Natural Convection Heat Transfer from Interrupted Rectangular Fins

Dr. Ali A. F. Al- Hamadani
Lecturer
Department of Mechanical Engineering
College of Engineering -University of Wasit
Email: alirudhaengmec@ uowasit.edu.iq

Dr. Abbas Jassim Jubear
Lecturer
Department of Mechanical Engineering
College of Engineering-University of Wasit
Email: a.aljassanai@uowasit.edu.iq

ABSTRACT

Numerical simulations have been investigated to study the external free convective heat transfer from a vertically rectangular interrupted fin arrays. The continuity, Naver-Stockes and energy equations have been solved for steady-state, incompressible, two dimensional, laminar with Boussiuesq approximation by Fluent 15 software. The performance of interrupted fins was evaluated to gain the optimum ratio of interrupted length to fin length (γ_{opt}). The different geometric parameters of project are assumed such as ratio of interrupted length to the fin length and the ratio of thickness to the fin length at different temperature. Results show the employment of fin interruption technique for resetting the boundary layer, which was causing reduced in thermal resistance. It was also concluded heat flux and heat transfer coefficient direct proportional with the temperature difference. Another significant parameter is the value of γ which has most advantageous at equal or less 25 after that there is not any significant on the value of Nu. The enhancing of thermal performance of the fin and the reduction of the weight of it as a result of adding interruption to a vertical fin.

Key words: fins; heat transfer; interrupted fins; natural convection.

نمذجة رقمية لانتقال الحرارة بالحمل الحر من خلال زعانف غير متصلة مستطيلة المقطع

د. علي عبد الرضا فرحان
مدرس
قسم الهندسة الميكانيكية
كلية الهندسة-جامعة واسط

د. عباس جاسم جبير
مدرس
قسم الهندسة الميكانيكية
كلية الهندسة-جامعة واسط

الخلاصة

تم اجراء محاكات عددية على انتقال الحارة بالحمل الحر من خلال جدار احادي عمودي ذو زعانف غير متصلة مستطيلة المقطع. تم حل معادلات الاستمرارية، Naveries-Stokes والطاقة باستخدام برنامج Fluent15. لدراسة وحساب أداء الزعانف المنفصلة والحصول على أفضل نسبة بين الطول المتقطع الى الطول الزعنفة. تم أستخدام نموذج مستقر ، ثنائي الأبعاد لا أنضغاطي حيث تم حل المعادلات الحاكمة باستخدام نموذج Boussiuesq. خلال هذه الدراسة تم فرض عدد من المتغيرات الهندسية المختلفة مثل النسبة بين طول المتقطع الى طول الزعنفة، وسمك الزعنفة الى طولها عند درجات حرارة مختلفة. ان من أبرز النتائج التي تم التوصل اليها، ان استخدام الزعانف المتقطعة يعمل على حصول تقطيع في الطبقة المتاخمة الحرارية المتكونة على الزعانف والذي يعمل على تقليل المقاومة الحرارية. وجد ان الفيض الحراري ومعامل أنتقال الحرارة يتناسب مع الفرق في درجات الحرارة. وجد ايضا ان من اهم المتغيرات المؤثرة الاخرى هي قيمة γ حيث تكون ذو ناثير فعال على قيمة عدد Nu عندما $25\geq \gamma$. اما بعد هذه القيمة فان تأثيرها قليل. ان الزعانف الغير متصلة مستطيلة المقطع تزيد من الاداء الحراري وكذلك تعمل على تقليل وزن المصدر مما يؤدي الى تقليل كلفة التصنيع.

الكلمات الرئيسية: زعانف, انتفال الحرارة , الزعانف المقطعة , الحمل الحر

1. INTRODUCTION

Natural convection phenomena in enclosures is essential for reliable performance of high power density electronics. Buoyancy driven flows have many applications in a widely preferred phenomena for it. The Natural convection is one method of rejected heat, which little expensive, discreet and most dependable. The heat generated in electronics devices can be controlled by using Fin. In the design of efficient cooling system generally 55% of failure mechanisms in electronic devices are related to thermal effects. **Mostafaviet et al., 2013,** Presented compact relationship for the Nusselt number based on geometrical parameters for interrupted fins. A two-dimensional numerical model for investigation of fin interruption effects by using COMSOL Multiphysics software. The results show that interrupted fins enhance the thermal performance of the heat sink and reduce the weight of it. **Pathaket et al., 2013,**studied numerically using FLUENT 6.3, it was concerned with heated wall from the rectangular shape with a finned base plate to simulate the behavior of air under natural convection. It investigated different fin length and spacing. It concluded the fin number (i.e., decreasing fin spacing S/H) significant on the Nu. This value of Nu reaches a high value at certain values of (S/H) and with extra increased the number of fins, Nu starts to reduction.

Edlabadkaret et al., 2008, Submitted a numerical analysis using Computational Fluid Dynamics (CFD) software, FLUENT, for free convection together to a vertical heated plate in ambient air temperature. It was observed that among the three V-type partition plates, subjected to computational analysis, 900 V-partition plate gave the maximum heat transfer enhancement at 12% and 15.27% for vertical and horizontal partition plate respectively. **Wankar, and Taji, 2012**, developed experimental setup to study the effect of free convection on rectangular fin model. The experimental parameters of this study were fin spacing, height and heater input. The wide range of length and spacing was tested with temperature difference. The study concluded that the Natural convection manner enhanced the transfer of heat with fin spacing 9-11 mm. It is noticed experimentally that the values of Nusselt based on ambient or Nusselt based on base where reached maximum value 7.86 and 58.35 respectively. Further, both Nusselt enhanced 81% and 27% respectively. **Sukumar R. S. et al., 2013,** Studied different models which icontained continuous, interrupted and interrupted fins with holes by using CFD simulation models. The study concluded that the interrupted fins are efficient than continuous, also find the better performance when used interrupted fins with hole as a result make reduction of fin’s weight.

2. PROBLEM STATEMENT

A schematic of the considered heatsink geometry with interrupted rectangular is shown in Fig. 1. The growth of boundary layer already started when the wall is heated immediately, at the surface of the adjoining fins. At the long channel the boundary layer is continuously especially when the fins/channels are sufficiently long creating fully developed channel flow. **Bejan**, **1984**, Interrupted fins dislocate the thermal boundary layer growth, maintaining a thermally developing flow system, which result a higher natural heat transfer coefficient.

In this study the Fluent software **ANSYS Fluent** has been implemented to investigate the performance of 2-D interrupted fins and the effects of fin interruption, then finding of an optimum fin interruption to fin length ratio and fin length to fin thickness. It started by using the existing analytical models **Bar-Cohen and Rohsenow, 1984**, and **Tamayol et al., 2011** .The idea is to decouple the effect of fin spacing from the fin interruption. In the present study, it has been used the optimum fin spacing value of 9.5 mm according to Rosenhow-Bar-Cohen model, **Bar-Cohen and Rohsenow, 1984**.

3. NUMERICAL ANALYSIS

Advanced solver technology provides fast, accurate CFD results, flexible moving and deforming meshes, and superior parallel scalability. Computational Fluid Dynamics (CFD) procedures solve all the interacting governing equations in a coupled manner, albeit in a finite framework. With a careful use of CFD, its results could be used to validate those of the theoretical models, at least qualitatively.

3-1 Modelling in GAMBIT

For the simulation part, the model is designed by using GAMBIT 2.4.6 for this configuration. This software is provided with the advanced geometry and meshing tools. The functions of GAMBIT are design the two dimensional (2-D), setup the boundary condition for each edge and faces, and provide the meshing analysis for each configuration. The data are for heat sinks with fin length of L = 1400 mm and fin spacing of S = 9.5 mm. The interrupted fins have been modeled with the various values of ζ which represents the ratio of the fin length l, to the fin thickness t, (ζ = 5, 7.5,10 and 15) and with various values of γ which represent the ratio of the interrupted length, G to the fin length, l, (γ =5, 10 and 30) as shown in **Fig.1**.

The numerical examination of the flow behavior of air under the steady state condition has been studied at both the inlet and outlet of interrupted fins. The fluid flow calculation has been simulated using FLUENT software. The buoyancy driven flow in the system was assumed to be laminar based on previous studies. The boundary condition of model is defined the situation occur at the surface condition in term of friction. Meanwhile, defining the meshing is vital in order to discrete each part to certain section for more accuracy FLUENT's analysis. It is important to define model, meshing, and boundary conditions before running into FLUENT. The suitable boundary conditions are needed for a successful computational work. After creating a geometry which have one surface defined the specify boundary types of heat sink, the fin length such as the isothermal wall , while the entry and exit zones type is Inlet and Outlet-Pressure boundary and interruption length is symmetry as shown in **Fig.2**.The surface was meshed for the heat sink using a Quad element of Pave schema type in the space interval size (0.001) chosen as shown in **Fig.3**, the Gambit grid generator used approximately (0.5) million computational cells for different cases. No-slip condition is applied for velocity and temperature on the walls.

3-2 Simulation with FLUENT

FLUENT solves the governing integral equations for the conservation of mass, momentum, energy. There are two processors used to solve the flow and heat transfer equations. The first

preprocessor is the program structure which creates the geometry and grid by using GAMBIT. The second post processor is solving Navier-Stokes equations which include continuity, momentum and energy. **Bocu and Altac, 2011.**
The set of conservation equations are:
Mass conversion equation

$$\nabla . V = 0 \tag{1}$$

Momentum.

$$(V . \nabla) V = -\frac{1}{\rho} \nabla P + v \nabla^2 V + g\,\beta (T - T_o) j \tag{2}$$

Energy.

$$(V . \nabla) T = \alpha \nabla^2 \mathrm{T} \tag{3}$$

The analysis is carried using laminar flow. The effect of density variation with temperature estimated by Boussinesq approximation. In the current study there are different wall temperatures of (20 ,30 ,40 ,50 ,60 and 100 ºC) will be used. The interruption region used the symmetry boundary condition when there is no heat flux in the direction normal to the fin surfaces. The pressure inlet and outlet boundary condition are applied to the channel inlet and out let which define at inlet and outlet as static/gauge pressure boundary. ‘‘A no-slip isothermal solid surface is considered for the walls. **Fig. 2**, shows the numerical simulation of the domain considered, along with the chosen boundary conditions for continuous and interrupted fins’’. The initially condition for second order is used in this study.

4. SIMULATION RESULTS

4-1 Validation of the Present Work

The present numerical simulation results have been validated with **Mostafavi, G. 2012**. In **Fig.4,** it can be seen that there is a good agreement between our numerical simulation results with the correlation equation of it and the error is not more than 6%.

4-2 The Variation of Heat Sink on Temperature and Velocity Distribution.

A single channel has been chosen to show the effect of interrupted length on the temperature and velocity distribution. **Figs. 5. to 8.** show the temperature and velocity distribution contours. The effect of interruption length on the thermal boundary layer could be noticeably observed. The figures show also the effect of repeated interruption on temperature distribution and restore the thermal boundary layer in the channel. The repeated resetting is lead to delay the flow to get the fully-developed condition.

The development of flow in the channel can be seen through a largamente regions. The flow in the lower, middle and top regions is non uniform developing flow due to discontinuous of the thermal boundary layer. The velocity increases as the channel height increase due to the buoyancy effect.

4-3 The Variation of the Interruption Length

The effect of important parameters on heat transfer from interrupted rectangular fins has been investigated. The effect of the fin length *l* and fin interruption length G on Nusselt number is shown in **Figs. 9 to 14.** It is clear that the relation between ξ and the Nusselt number was directly proportion. Which is meaning the heat transfer coefficient improved. These Figures prevail if the fin length is constant, and G is variable, it can conclude that the Nusselt number increases. Another significant parameter the value of γ which is most advantageous when $\gamma \leq 25$ after that not any significant on the value of Nusselt number.

4-4 The Variation of Temperature Difference

The relation between Nusselt number and γ with different temperatures (different heat fluxes) can be seen in **Figs. 15. to 18.** The result shows the Nusselt number has increased when the γ and temperature of fins wall was increased. In another word when the heat flux increases the heat transfer coefficient enhanced. Therefore the increasing of fin interrupted length causes an increase in the heat flux due to butter interruption in the thermal boundary layer, as well as the number of interruption length.

4-5 The Effect of Different Temperature on Heat Flux and Heat Transfer Coefficient

The numerical simulation result of the heat flux from heat sink with interrupted fins as a function of different wall temperatures are shown in **Figs. 19. to 22**. As it was expected the heat flux improves as γ increases (i.e., as G increases). The increasing of heat flux due to enhance interruption in thermal boundary layer. It is clear from **Figs. 23. to 26** depict the relation between different temperature and heat transfer coefficient with different γ. This show that the heat transfer coefficient enhances as the different temperature and γ increase. Further the effect of different temperatures have not significant on the heat transfer coefficient when the temperature is greater than 70 ^{o}C in all cases. That means the interruption length leads to a higher thermal performance due to the fact that interrupted fins dissipation the thermal boundary layer growth, thus, leads to a higher natural heat transfer coefficient.

5- CONCLUSIONS

Numerical studies have been performed for free convective heat transfer from installed interrupted rectangular fins in order to find the relation between heat sink with different parameters (such as fin length and interrupted length) and heat transfer coefficient. The following conclusion can be considered as follows:

- The most significant component of the current study is the strength of character of the effect of interruption length in natural convection fin. The purpose of employment the fin interruption technique for resetting the boundary layer, which was causing reduced in thermal resistance.

- The increasing the fin interruption length and the number of interruptions cause an increasing in the heat flux which is a result of the frequent resets imposed on to the thermal boundary layer, in other word "better" interruption occurs in the thermal boundary layer.
- In this study the optimum ratio of interrupted length to fin length (γ_{opt}) is a function of surface temperature, for different length (12.5 mm<l<37.5 mm), as follows.

$$\gamma_{opt} = \left(\frac{G}{l}\right)_{opt} = C\left(\frac{T_w - T_{amb}}{T_{amb}}\right)^{n}$$

Where C = 11 and n = -2.18

- The heat flux, and the heat transfer coefficient are direct proportion with the temperature difference. Another significant parameter the value of γ which is most advantageous ≤ 25 after that there is not any significant on the value of Nusselt number.

REFERENCES

- Bejan A., 1984, *Convection Heat Transfer*, Wiley, New York.
- ANSYS Fluent (ver. 15) *Computational Fluid Dynamics Softrware, ANSYS*, Inc. Academic.

- Bar-Cohen and Rohsenow, *Thermally Optimum Spacing of Vertical, Natural Convection Cooled, Parallel Plates*,1984, J. Heat Transfer Vol. 106,pp-116-124.

- Mostafavi G., 2012, *Natural Convective Heat Transfer from Interrupted Rectangular Fins*, Thesis in Master of Applied Science, School of Engineering Science Faculty of Applied Sciences, Simon Fraser University Fall.

- Mostafavi Golnoosh, Mehran Ahmadi and Majid Bahrami,2013, *Effect of Fin Interruptions on Natural Convection Heat Transfer from A rectangular Interrupted Single-Wall*, International Technical Conference and Exhibition on Packaging and Integration of Electronic and Photonic Microsystems InterPACK2013 Burlingame, CA, USA.

- Pathak, M. K., Mer, K. K. S. and Pawan K. P., 2013, *Numerical Analysis of Natural Convection in Rectangular Enclosure with Heated Finned Base Plate*, IJRMET Vol. 3, Issue 2,pp-64-67.

- Edlabadkar, R. L., N. K. Sane and Parishwad, G.V., 2008, *Computational Analysis of Natural Convection with single V-Type Partition Plate*, 5th European Thermal-Sciences Conference, The Netherlands.

- Tamayol, F. McGregor, E. Demian, E. Trandafir, P. Bowler and M. Bahrami, 2011, *Assessment of Thermal Performance of Electronic Enclosures with Rectangular Fins: A passive thermal solution*," in ASME pacific rim technical conference and exhibition on packaging and Integration of electronic and photonic systems, Portland, Oregon, USA,.

- Sukumar, R. Sam, G. Sriharsha, S. Bala Arun, P. Dilip kumar, Ch. Sanyasi Naidu,2013 ,*Modelling And Analysis of Heat Sink with Rectangular Fins Having Through Holes*,International Journal of Engineering Research and Applications (IJERA) ISSN: 2248-9622 www.ijera.com, Vol. 3, Issue 2, March -April 2013, pp.1557-1561.

- Vinod M. Wankar and S.G. Taji, 2012, *Experimental Investigation of Flow Pattern on Rectangular Fin Arrays under Natural Convection*, International Journal of Modern Engineering Research (IJMER), Vol.2, Issue.6, pp-4572-4576.

- Z. Bocu, Z. Altac, 2011, *Laminar Natural Convection Heat Transfer and Air Flow in Three-Dimensional Rectangular Enclosures with Pin Arrays Attached to Hot Wall*", Applied Thermal Engineering, 31, , pp. 3189-3195.

NOMENCLUTER

Symbol	Description	Unit
G	interrupted length	m
g	gravitational acceleration,	m/s^2
h	heat transfer coefficient	W/m^2k
j	unit vector in y-direction	
L	total length	m
l	fin length	m
Nu	nusselt number	
P	pressure	N/m^2
S	fin spacing	m
T	temperature	C°
V	velocity	m/s
α	thermal diffusivity	

β	thermal expansion coefficient	K^{-1}
∇	divergence	
γ	ratio of the interrupted length, G to the fin length, *l*	
ζ	the ratio of the fin length *l*, to the fin thickness t	
ν	kinematic viscosity	m^2/s
ρ	fluid density	kg/m3
C , n	constant	

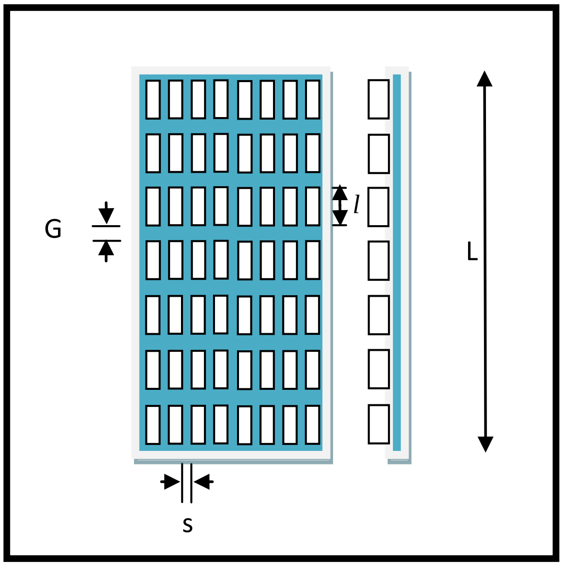

Figure 1. Schematic of the considered heatsink geometry interrupted rectangular.

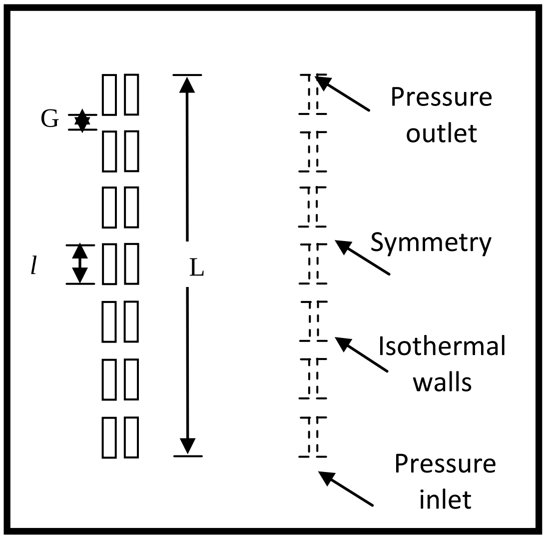

Figure 2. Schematic of the numerical domain of interrupted fins and boundary conditions.

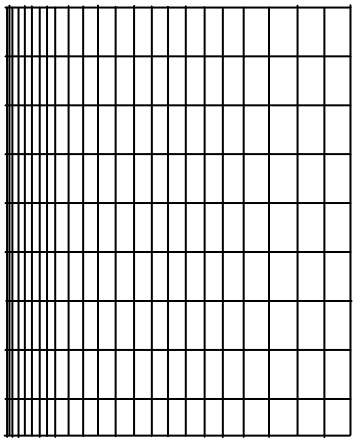

Figure 3. Grid used in the model .

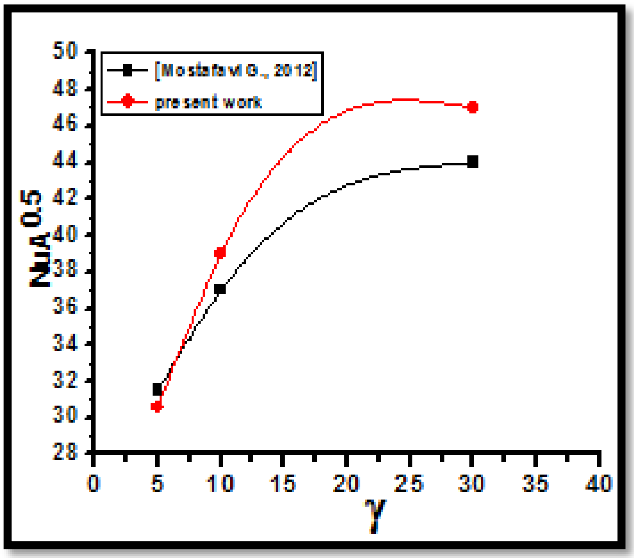

Figure 4. Validation of computational analysis graph.

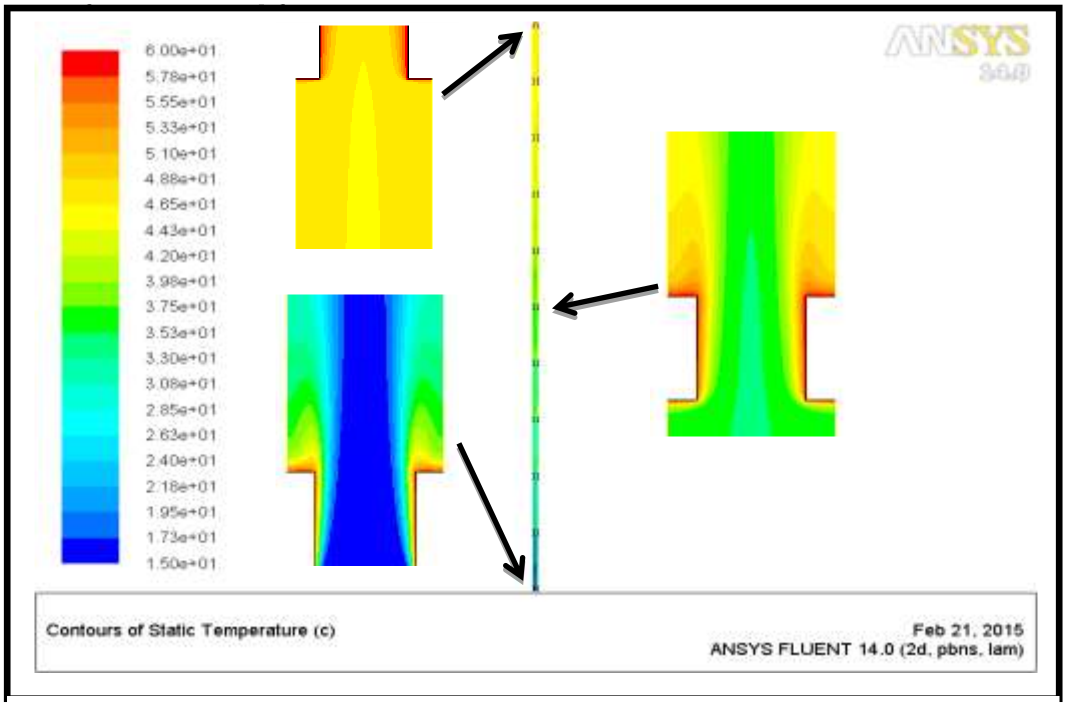

Figure 5. Temperature distribution contours of the interrupted fins for ζ=5 and γ=10 with isothermal temperature = 60 ^{o}C.

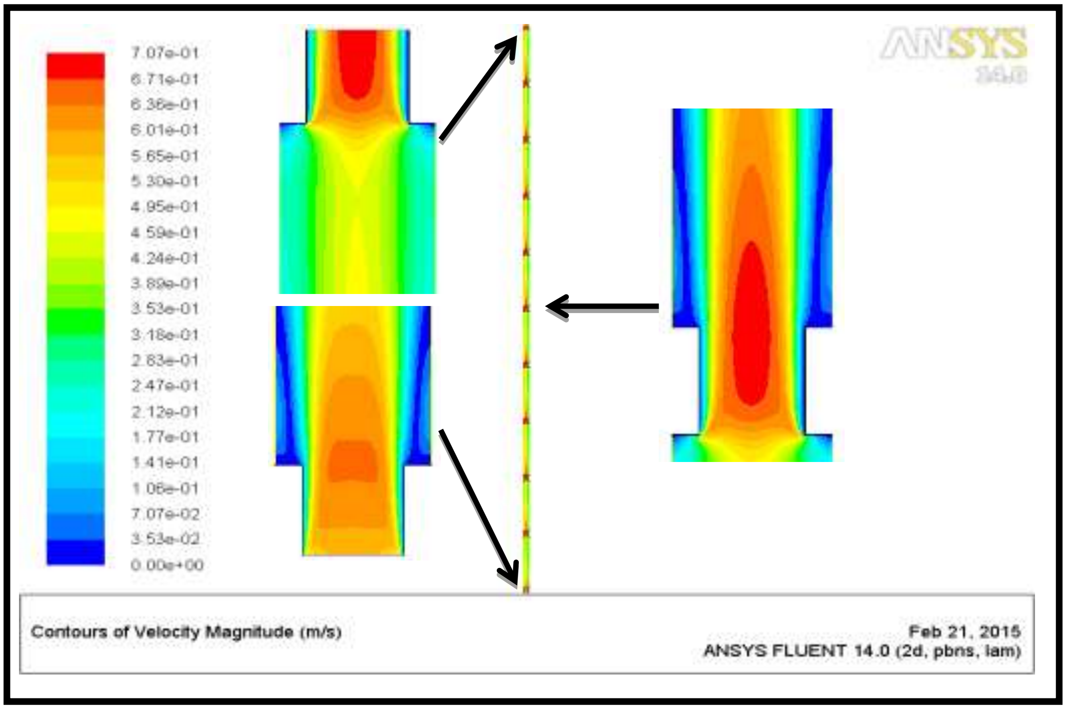

Figure 6. Velocity distribution contours of the interrupted fins for ζ=5 and γ=10 with isothermal temperature = 60 °C.

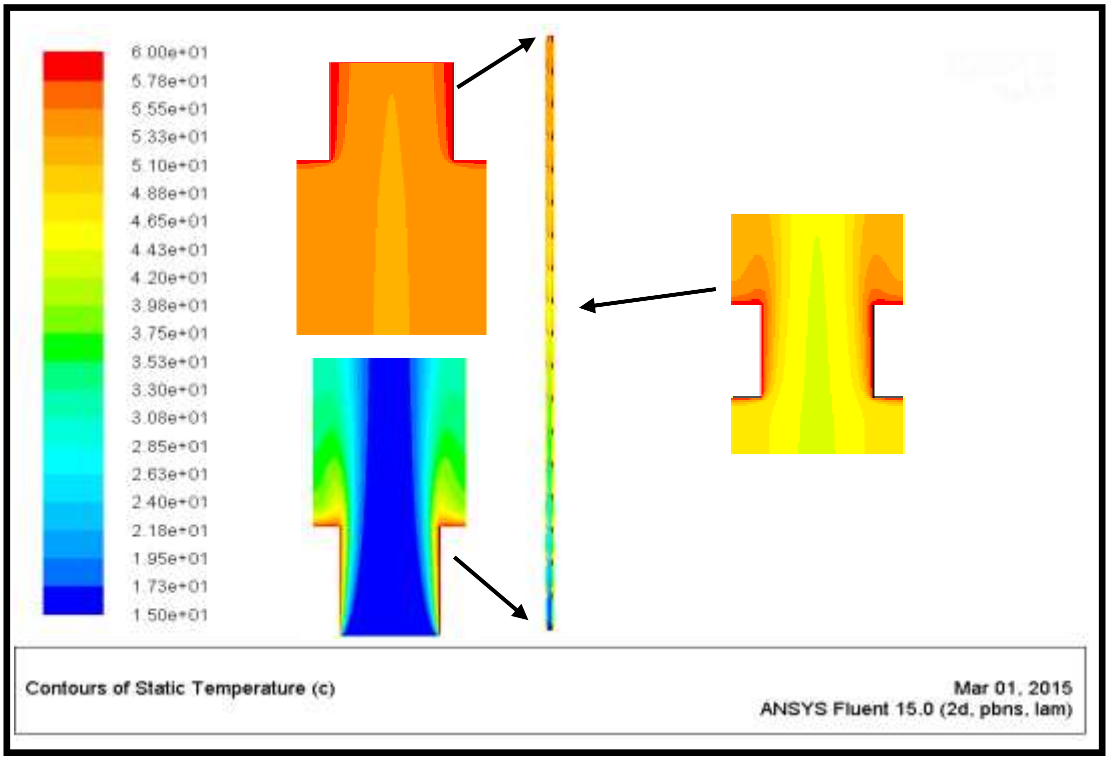

Figure 7. Temperature distribution contours of the interrupted fins for ζ=5 and γ=5 with isothermal temperature = 60 °C.

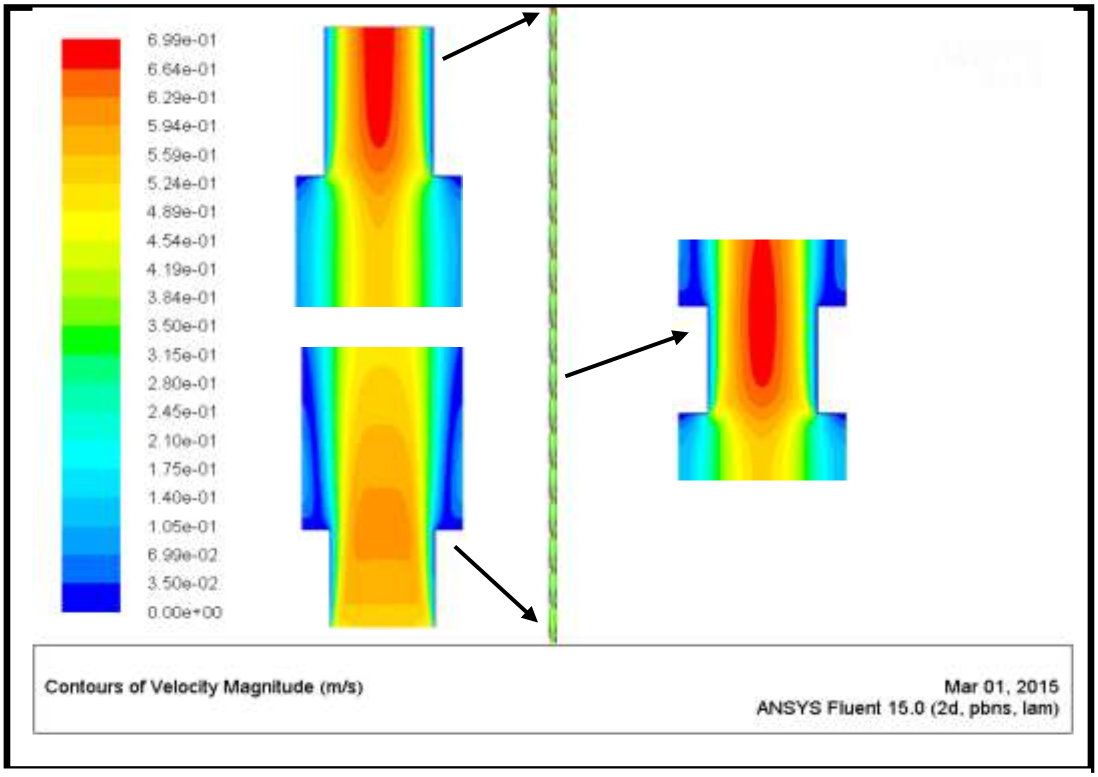

Figure 8. Velocity distribution contours of the interrupted fins for ζ=5 and γ=10 with isothermal temperature = 60 ^{o}C

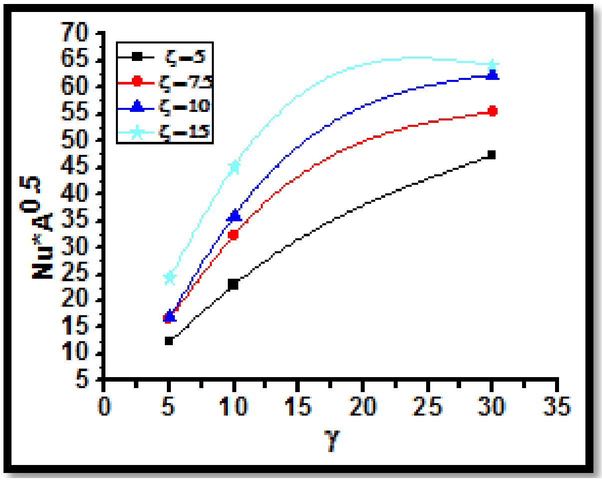

Figure 9. The effect of interruption length on Nu. With different ζ = *l*/t at T=20 ^{o}C.

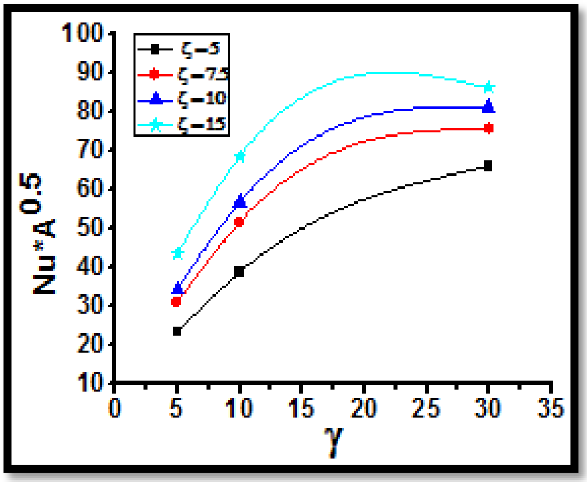

Figure 10. The effect of interruption length on Nu. With different ζ = *l*/t at T=30 ^{o}C.

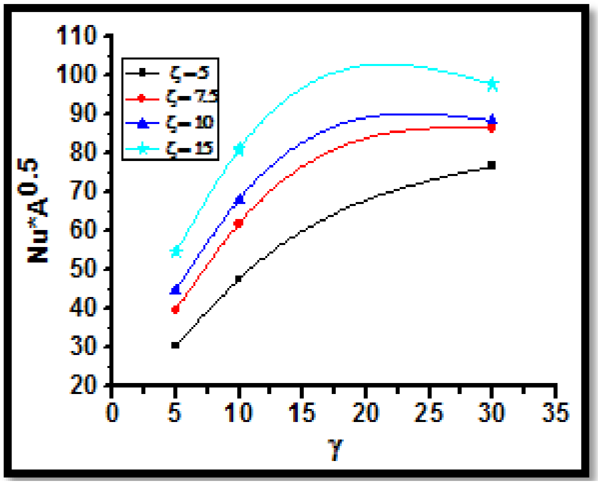

Figure 11. The effect of interruption length on Nu. With different ζ = *l*/t at T=40 ^{o}C.

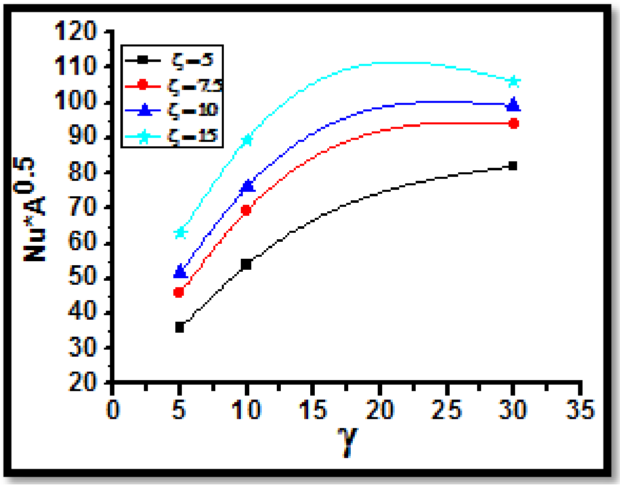

Figure 12. The effect of interruption length on Nu. With different ζ = *l*/t at T=50 ^{o}C.

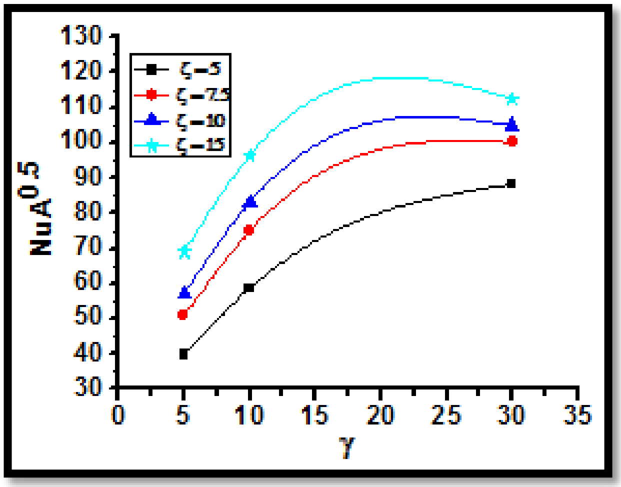

Figure 13. The effect of interruption length on Nu. With different ζ = *l*/t at T=60 ^{o}C.

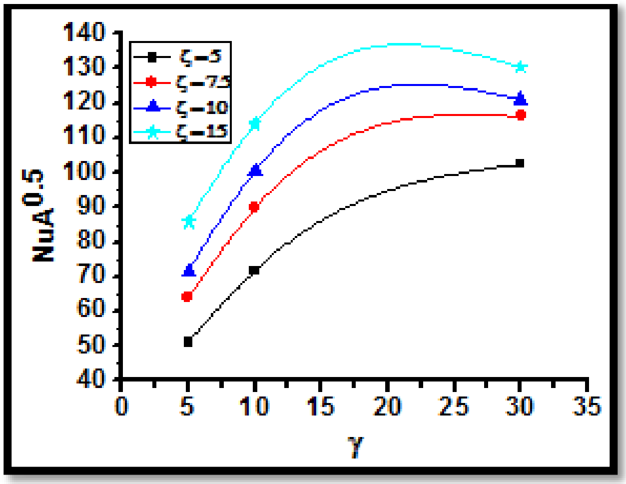

Figure 14. The effect of interruption length on Nu. With different ζ = *l*/t at T=100 ^{o}C.

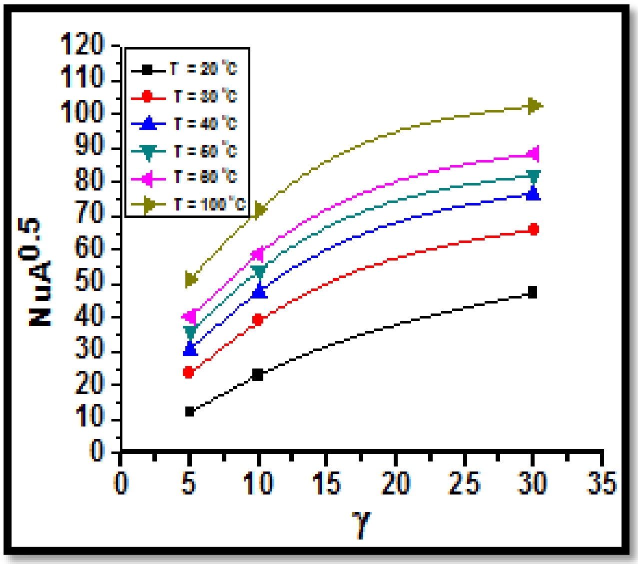

Figure 15. The effect of interruption length on Nu. With different temperature at ζ = 5.

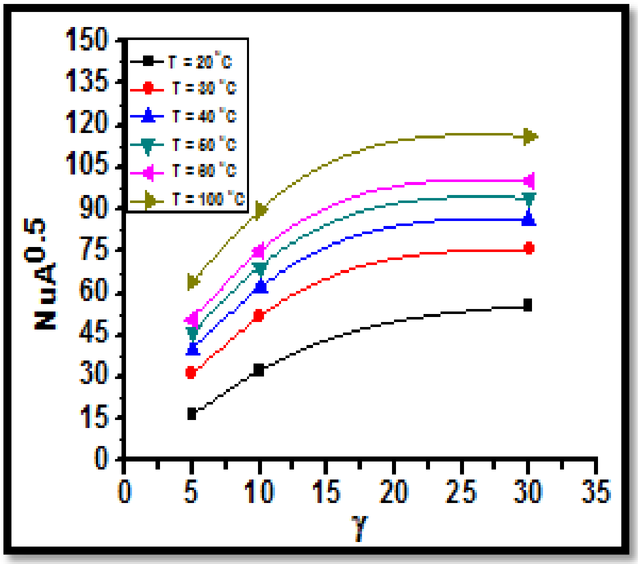

Figure 16. The effect of interruption length on Nu. With different temperature at ζ = 7.5.

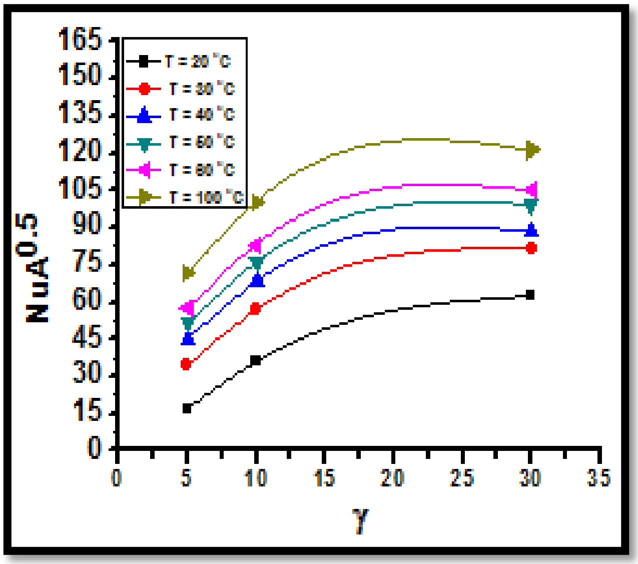

Figure 17. The effect of interruption length on Nu. With different temperature at ζ = 10.

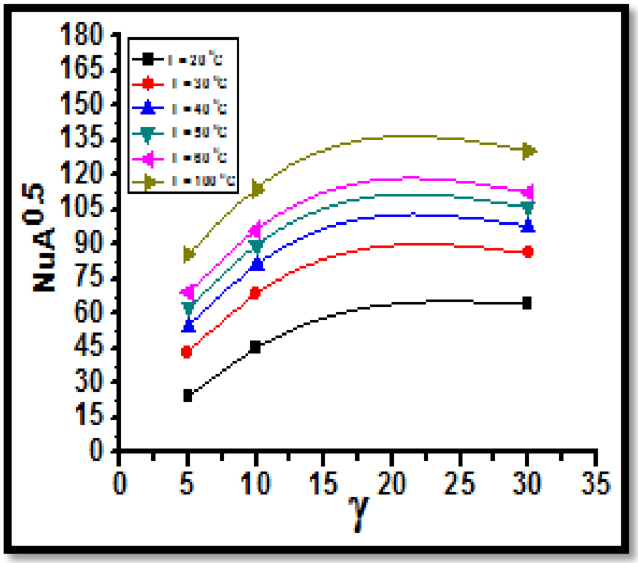

Figure 18. The effect of interruption length on Nu. With different temperature at ζ = 15.

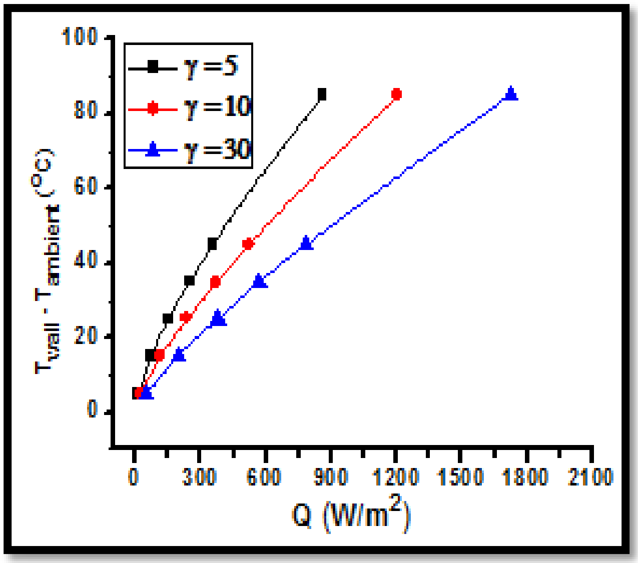

Figure 19. The effect of heat sink on heat flux with different γ at ξ =5.

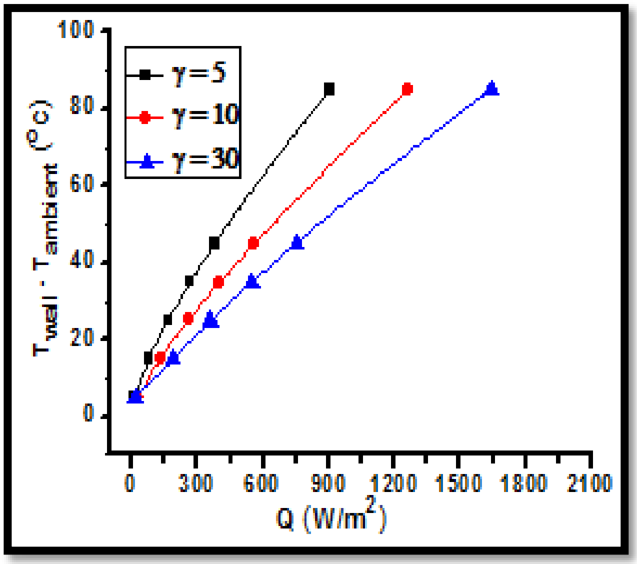

Figure 20. The effect of heat sink on heat flux with different γ at ξ =7.5.

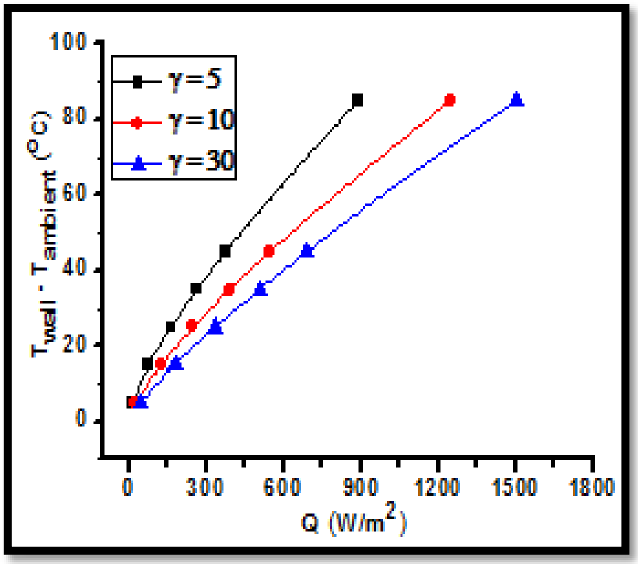

Figure 21. The effect of heat sink on heat flux with different γ at ξ =10.

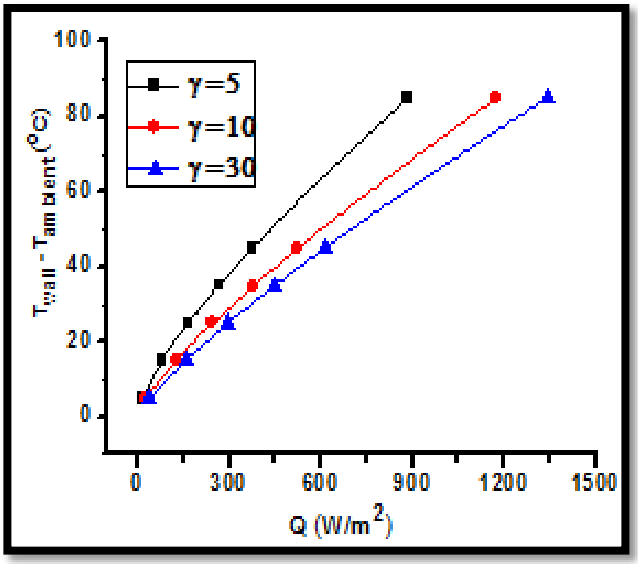

Figure 22. The effect of heat sink on heat flux with different γ at ξ =15.

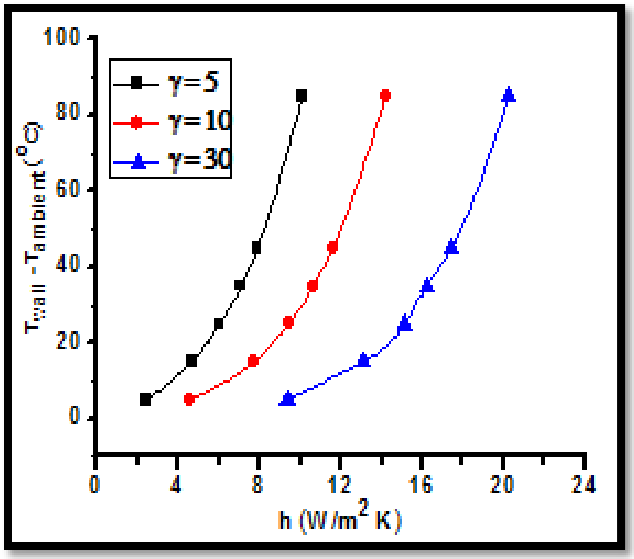

Figure 23. The effect of heat sink on heat transfer coefficient with different γ at ξ=5

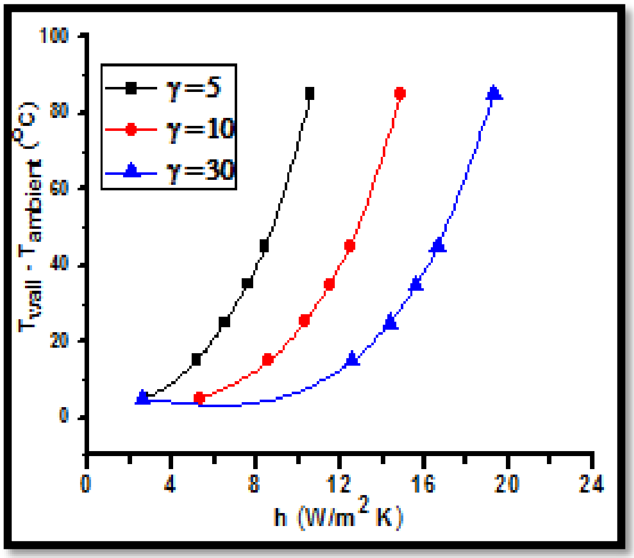

Figure 24. The effect of heat sink on heat transfer coefficient with different γ at ξ =7.5.

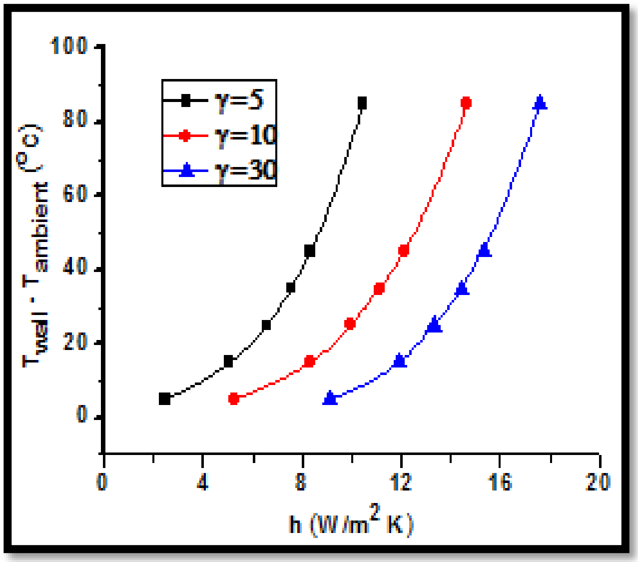

Figure 25. The effect of heat sink on heat transfer coefficient with different γ at ξ = 5

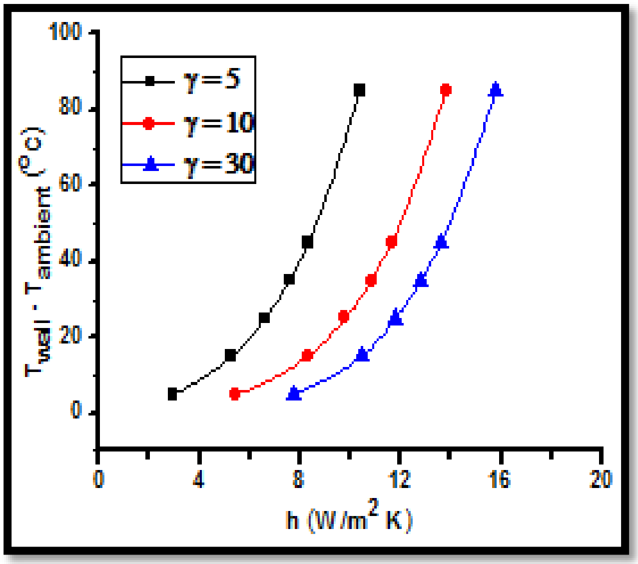

Figure 26. The effect of heat sink on heat transfer coefficient with differentγat ξ =7.5.