Experimental Investigation of Cooling of Electronic Equipment

Ece AYLI, Caner TURK and Selin ARADAG
TOBB University of Economics and Technology, Department of Mechanical Engineering

***Abstract*— Electronic systems cooling is an attractive research area in engineering. The aim of this research is to design vortex promoters for cooling of electronic equipment. Different shapes of vortex promoters are used in the experimental study for turbulent flow and the results are used to validate the results of a previous computational work performed by the authors. Another aim is to choose an appropriate promoter and promoter location which provides best turbulence effects and most effective cooling. Temperature values are measured with thermocouples at several monitoring locations. The results show that the most effective vortex promoter for cooling is triangular type of promoter for the flow conditions tested.**

***Index Terms*—Electronic cooling, Experimental Study, Turbulent Flow, Vortex Promoter.**

I. INTRODUCTION

Electronic systems cooling has been extensively examined recently because of the interest from both scientific and technological points of view. On the technological part, with the improvements of the electronics systems, higher processing speeds, more power, smaller systems become more of a necessity than ever before. One of the most important results of these necessities is the need to handle more complex geometries. Therefore one of the biggest issues in the electronics systems is the cooling of these complex geometries. Especially in military, healthcare and aerospace applications, effective cooling is crucial. With an efficient cooling, electronics systems become more reliable and durable [1].

On the scientific part, heat that is generated in electronic systems is proportional to the square of voltage and the frequency of the system. So, engineers try to increase the frequency and decrease the voltage to be able to decrease heat generation. Developing effective cooling techniques of electronic systems is a major challenge. Therefore different cooling techniques have been developed to remove the heat from electronic components [2-4]. Two main types of cooling are air and liquid cooling [2, 5, 6].

E.Ayli is a PhD student at TOBB University of Economics and Technology, Ankara, 06560, Turkey (e-mail: ueayli@etu.edu.tr).
C.Turk is a MSc student at TOBB University of Economics and Technology, Ankara, 06560, Turkey (e-mail: cturk@etu.edu.tr).
S. Aradag is an Associate Professor at TOBB University of Economics and Technology, Ankara, 06560, Turkey (e-mail: saradag@etu.edu.tr)

Air cooling is an inexpensive but reliable way of cooling. It is easy to find air; design and maintenance are also easy with air. Therefore, air cooling is used widely in electronic systems cooling. Heat transfer can occur in three different ways: conduction, convection and radiation.

Convection is a widely used cooling technique. Forced convection is a better choice when it is compared with natural convection as it provides higher heat transfer rates and higher Prandtl numbers. In forced convection, adding a fan to the system is one of the methods. Air is forced to move with the help of a fan. To decrease system temperature, fan speed, which is one of the important parameters in efficient cooling, should satisfy turbulent flow conditions [1, 7].

Aradag et al. [7] used vortex promoters for effective cooling. They performed their computational analyses in two parts. In the first part, heat convection coefficients and maximum temperatures are obtained in a single circuit system for laminar flow. In the second part of the study, the effects of the distance between two heat sources are examined. Two different types of vortex promoters are utilized to decrease maximum temperature values in the system. When the results are examined, it is seen that the systems that include vortex promoters, regardless of the geometry and the location of the promoters, have smaller maximum temperature when compared with the case without a vortex promoter. Triangular vortex promoters are shown to be able to decrease maximum temperatures in the system more than rectangular promoters. Their study emphasizes with the help of CFD results that the heat sources should be placed as far away from each other as possible.

In the study of Etemoglu et al [8], some possible solutions are given to decrease heat generation in electronics systems. According to their study, increasing the frequency and decreasing the voltage can decrease heat generation. Adding a fan to the systems for cooler air is another possible solution which is provided in this article. Heat transfer rates are increased in forced convection. Spreading heat with a copper sheet to achieve turbulent flow is also suggested to decrease the temperature of the system.

Gomes [1], analyzed the effects of the size, shape of the promoter and the location of heat sources on cooling, experimentally. According to this study, as shaped corners provide stronger vortices, hexagon promoter is the most effective promoter which creates the biggest disturbance in the flow. Second effective promoter geometry is the square one. Circle promoter has no cooling effect in the system. Better heat transfer occurs when separation between the heat sources are farther.

Icoz and Jaluria [9] investigated natural convection heat transfer in a horizontal channel with two heat sources. Most appropriate boundary conditions to accurately model the transport processes are investigated. The effect of Grashof number, cavity dimensions, distance between the heat sources, heat transfer characteristics and their effects on the flow are also investigated. When the channel height and the separation distance are increased, instability is observed.

Ayli et al. [11] examined the effects of promoter geometries, promoter locations and number of heat sources for laminar and turbulent Reynolds numbers, numerically. According to their analysis, the temperatures attained in double circuit systems are higher than single circuit systems. In laminar flow, triangular and rhombus promoters are able to decrease maximum temperature values. In turbulent flow, rhombus promoter causes heating instead of cooling.

II. OBJECTIVE OF THE STUDY

The objective of the present study is to design effective vortex promoters for cooling of electronic equipment. The effects of the geometry of promoters are examined in detail for turbulent Reynolds numbers in 2D, experimentally. Previous computational results are used for comparison purposes [11] and additional transient computations are also performed.

III. EXPERIMENTS

Based on the study of Icoz [5, 9, 10] and Gomes [1], an experimental set-up is constructed as shown in Figure 1. Main components of the set up are; small scale wind tunnel which consist of a converging inlet, a rectangular channel and a test section. Other components are heaters, thermocouples, data taker and anemometer.

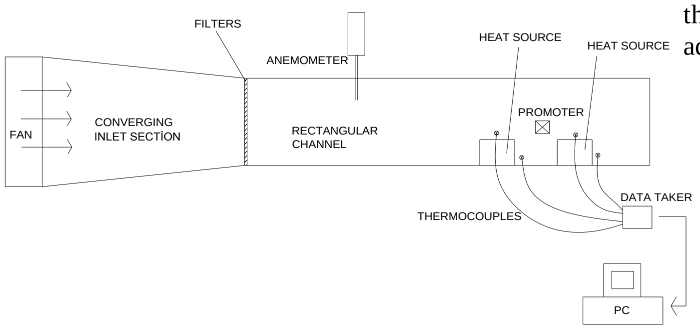

Figure 1. Schematic view of the experimental set-up

A. Rectangular Channel

The rectangular channel is made up of ceraboard. Using ceraboard is a good choice because perfect shaping is possible with it, it has good insulation properties and it also has a good tolerance to thermal shocks. As it is known from Icoz's [9] study, in order to assume two dimensional flow, width to height aspect ratio should be equal to or greater than 5. Therefore, width and height are 300 mm×60 mm, respectively. The length of the channel is 1000 mm. In order to observe uniform flow in the inlet, filters are placed at the entrance of the channel and a converging nozzle is used. For the top part of the rectangular channel, flexi glass is utilized. As flexi glass is transparent it is possible to see the phases of the experiment in every stage [9].

B. Heaters

Two similar heat sources are placed in the test section as it is seen in Figure 1. Based on the study of Icoz [5], heat source components are heating strip and copper block. Copper block is used as a heat spreader. Above and under the heaters, resistive elements mica and chrome are placed All these components are pressed together. The width and height of the copper blocks are 300 mm×20 mm, respectively. Length of the copper block is 30 mm. The dimensions of the heaters are chosen to be 300 mm×16mm. In Figure 2, schematic view of heat sources can be seen.

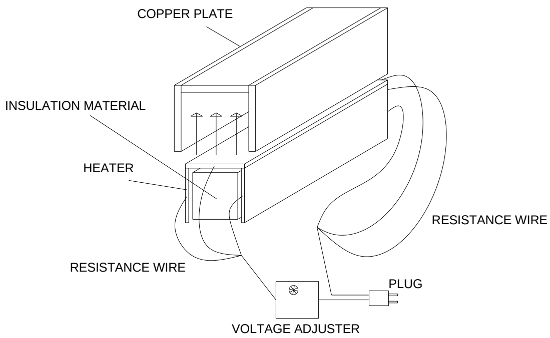

Figure 2. Schematic view of the heat sources

Copper plates are used as heat sources. Three plates are assembled as a U profile. Electrical resistance is used as a heater. This resistance exists in a material called mica. Mica has low thermal resistance and high dielectric strength. Heater is formed by pressing mica and the resistance by chrome thin plate. Heat transfer occurs between the heater and copper plate. Therefore copper behaves like a heat source. Insulation material is used to maintain the heat. The heater is linked to electricity. There is a voltage adjuster between the heater and the plug. Figure 3 is the view of heat sources and voltage adjuster respectively.

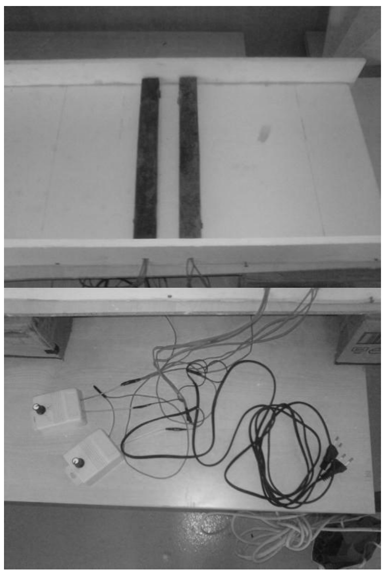

Figure 3. Heat Sources and Voltage Adjuster

C. Thermocouples and Data taker

Thermocouples are used for accurate temperature measurements. The type of the thermocouple used is a J-type which is made up of Fe-CuNi. Its sensitivity is about 55 µV/°C and it can measure temperatures between −40 to +750 °C which is appropriate for this experiment. As it is seen in Figure 4, four thermocouples are located on the test section. First thermocouple (point 1) is above the first heat source. Second one (point two) is located between the heat sources. Third one (point three) is above the second heat source and last one (point four) is near to the second heat source. Coordinates of the thermocouples are given in Table 1. Tips of the thermocouples are connected to the data taker to collect temperatures.

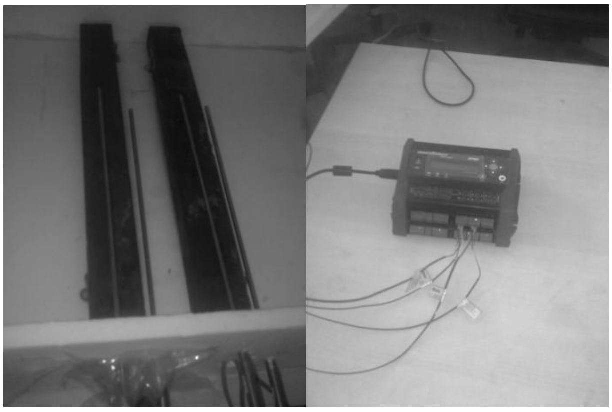

Figure 4. (a) Thermocouple Locations (b) Data Taker

Table 1. Thermocouples locations

	x-coordinate (mm)	y-coordinate (mm)
Thermocouple 1	621,5	40
Thermocouple 2	641,5	6,5
Thermocouple 3	685	40
Thermocouple 4	700	14

D. Vortex Promoters

Three different vortex promoters are used in the system which are square, triangular and rhomb promoters. The promoters are made from ceraboard because of its good insulating and easy shaping properties. Promoter dimensions are 0.01 m x 0.01 m for height and length. The width of the promoter is 300 mm.

E. Anemometer

An anemometer is used for free stream velocity measurement. As seen in Figure 5, an anemometer hole is opened in the flexi glass for measuring the fan velocity.

Figure 5. (a)Anemometer (b) Anemometer Hole

After closing the test section securely and joining the fan properly to the system with isolation; firstly, data taker is connected with the thermocouples and the computer. After successful connection, the thermocouples start to take temperature data. Heat sources get warmer with voltage calibration. After setting the desired turbulent Reynolds number (Re= 8850) with the help of the anemometer, the system is waited to reach steady state. 168°C is the steady state temperature. The experiments are performed and after the data collection, heat sources are unplugged and the system is cooled with the help of the fan. This process is repeated for all the cases with different kinds of promoters.

Experiments are performed for a Reynolds number of 8850. Temperature values are measured at four different points. Four different cases are performed which are no promoter, square promoter, triangle promoter and rhomb promoter cases. As it is known from Ayli et al.'s previous computational work, [11] when the vortex promoter is placed between and close to the heat sources, incoming air mixes with hot air. As a result of this mixing, maximum temperature value decreases. Therefore promoters are located between the heat sources.

IV. COMPUTATIONAL METHODOLOGY

2D, unsteady, incompressible turbulent flow in a channel with two heat sources is considered. Vortex promoters are placed between the heat sources which are able to decrease maximum temperature values in the channel. Three types of vortex promoters are tested: triangular, square and rhombus shaped and their locations are same with the promoters which are used in experiment. The grid is generated using Gambit. Unstructured meshes are employed for all computations. The computations are performed with Fluent CFD software [13]. Four monitoring points are used. Monitoring point locations are same with the thermocouple locations. Details of the computations are given in the work of Ayli et al [11].

V. RESULTS

As it is known from Ayli et al.'s [11] previous work, after performing steady state simulations, it was understood that the nature of turbulent flow with vortex promoters is transient. Therefore transient analyses at Reynolds 8850 are performed both experimentally and numerically in this study. Transient behavior of the flow with square, triangle and rhomb vortex promoter is investigated in a double circuit system. Results will be given in several parts as it is given below.

Double Circuit System without Vortex Promoter Case

Measurement results for the maximum temperature are shown in Table 2 and in Figure 6 for the four measurement points. As there are no obstacles in the system, convergence occurs easily, as it is expected maximum temperature value obtained, is between the heat sources (Point 2). Point two is exposed to more heat as it is located between the heat sources. For point 2, the difference between experimental and numerical temperatures is % 0.3. Most effective cooling is necessary for point 2. Point 1 gets cold easily as cool air comes directly to this point. Point 4 also needs effective cooling.

Table 2. Temperature values at the monitoring points in double circuit system without vortex promoter case

	Numerical Temperature Values(K)	Experimental Temperature Values(K)	Difference Between Values
Point 1	294	293	%0.3
Point 2	330	331	%0.3
Point 3	297	305.6	%2.8
Point 4	325	326	%0.3

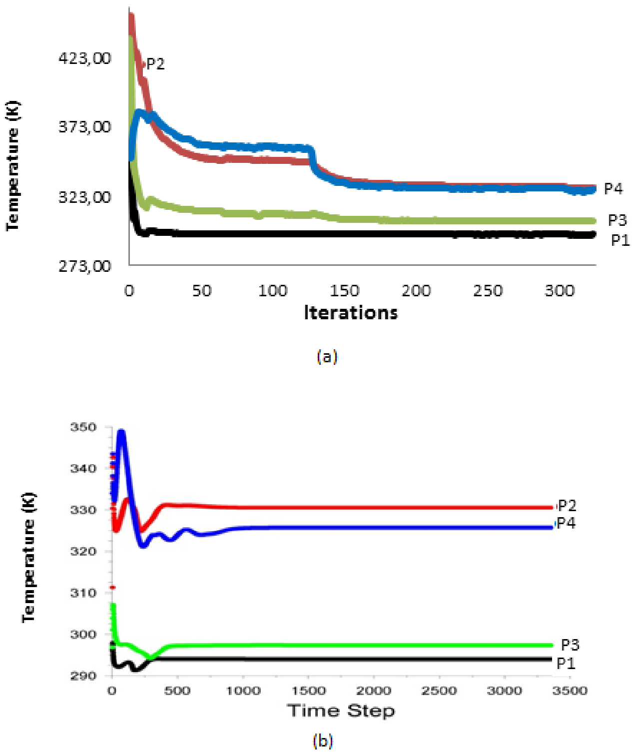

Figure 6(a) Experimental temperature convergence history of four points without vortex promoter at Re=8850 (b)Converged temperature values of four monitoring points without vortex promoter at Re=8850 (Simulation)

F. *Double Circuit System with Square Promoter Case*

Square vortex promoter is located between the heat sources. The temperature values for simulation and experiment is given in Table 3. Not all of the promoters are able to decrease maximum temperature values. Square promoter cannot focus air between the heat sources effectively; therefore at some points maximum temperature value increases instead of decreasing.

Table 3 .Temperatures at the monitoring points in double circuit system with square promoter case

	Numerical Values(K)	Exp. Temperature Values(K)	Difference Between Values
Point 1	294.5	303.4	%3
Point 2	330	310	%8.6
Point 3	296	300	%1.3
Point 4	325	343	%5.2

As experiment total time is much longer than the simulation time, the system is cooled more in the experiments. The difference in the temperature value of point 2 between experiment and simulation may be caused by this situation. Thermal boundary layer develops on the top surface of the first heat source and thermal wake occurs between the heat sources. Also it is seen from the contours that right in the corner of the heat sources, maximum temperature value occur [11].

Double Circuit System with Rhomb Promoter Case

Second promoter type is rhombus shaped. Rhomb vortex promoter in this location is not a good choice for both experiment and simulation as it is seen from Table 4. For simulations, the temperature of point 1 decreases only 1 K, nothing changes at point 3 and the temperatures of the other two points increase instead of decreasing.

Table 4.Temperatures at monitoring points in double circuit system with rhomb promoter case

	Numerical Approximation Values	Experimental Temperature Values(K)	Difference Between Values
Point 1	293	297	%1.7
Point 2	342	322	%6.2
Point 3	299	308	%3
Point 4	336.5	302	%11.4

Double Circuit System with Triangle Promoter Case

Heat sources provide heat and energy to the ambient. Maximum temperatures occur between the heat sources. When a promoter is placed at an effective location, incoming air is forced to enter the area between the heat sources. In other words, the promoter separates the air and increases the amount of air entering between the heat sources. In this situation, hot air and incoming air are mixed and velocity increases in this section and stronger vortices are formed; therefore effective cooling occurs. The triangular promoter has some cooling effect if it is placed at an effective location. As it is observed, triangular promoter causes a disturbance in the flow. Depending on time, near the second heat source, cooled area is increased.

When numerical values are considered which are given in Table 5, it is seen that, this cooling amount is not enough for efficient cooling. With better locations and better promoter sizes, rectangular promoter can be a more effective promoter. Although, experimental values are lower than numerical values, the temperature of point 2 decreases 21 K with a triangle promoter in experiment. It can be said that, triangular promoter causes a disturbance in the flow and it directs the flow above the heat sources and between the heat sources. The incoming air and warm ambient air mixes; so maximum temperature value decreases.

Table 5.Temperatures at monitoring points in double circuit system with triangle promoter case

	Numerical Approximation Values	Experimental Temperature Values(K)	Difference Between Values
Point 1	294.5	303.4	%3
Point 2	330	310	%6.1
Point 3	296	292	%1.3
Point 4	325	343	%5.2

VI. CONCLUSION AND FUTURE WORK

This work is related to experimental and computational analysis of heat transfer in electronics systems. Three different vortex promoters are tested for double-circuit systems in order to decrease the maximum temperature values attained in the systems. Summary of all temperature values are given in Table 6. When this table is examined, it is seen that rectangular and rhombus vortex promoters are not very effective.

The triangular promoter can be an efficient promoter if it is located near the heat sources. According to the experimental results, triangle vortex promoter works efficiently at this location. In addition, when simulation results are examined, this promoter geometry can direct the incoming air to the area between heat sources and the maximum temperatures seen is reduced by this promoter.

The biggest problem in computational analysis is cost. Simulations are performed for only 45 seconds of flow. On the other hand, experimental time is 180 minutes. If the total run times were the same, computational values might have been closer to the experimental values.

As a future study, other locations and different vortex promoter geometries can be tested both computationally and experimentally.

Table 6. Temperature Comparisons for experiment and Simulation (E denotes the experiment, S denotes the simulation)

	No Promoter		**Square Promoter**		**Rhomb Promoter**		**Triangle Promoter**	
	E	**S**	**E**	**S**	**E**	**S**	**E**	**S**
Point 1	294	293	303.4	294.5	297	293	303.4	294.5
Point 2	331	330	310	330	322	342	310	330
Point 3	305.6	297	300	296	308	299	292	296
Point 4	326	325	343	325	302	336.5	343	325

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Ece Aylı was born in Ankara in 1989. She graduated from TED Ankara College in 2006. She received her BS and MS degrees from TOBB University of Economics and Technology, Department of Mechanical Engineering in 2010 and 2012, respectively. She is currently a Ph.D. student and a graduate research assistant at the same department.