

# Experimental Study on Impact of Installation Angle on Heat Transfer Performance of Spray Cooling

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**Abstract**—The spray cooling technology has great advantage in high heat flux removal. Because the heat transfer of spray cooling has much to do with the heater surface temperature, it is important to ensure that the entire heating surface temperature is in an effective operating range. Otherwise, excessive local temperature may threaten the normal operation of spray cooling. In this paper, experimental method was used to investigate the effect of installation angle of spray cooling on the heat transfer performance. The five installation angles tested in this study were 0°, 45°, 90°, 135° and 180°. Other experimental parameters remain constant, such as the flow rate, the spray height and the spray pressure. The results show the heat flux as a function of surface temperature with various installation angles in a graphical format.

**Keywords**—*spray cooling; electronic structure design; experimental study; heat exchange design*

## I. INTRODUCTION

With the development of industrial technology, the energy consumption and heat dissipation problems become increasingly serious for the electronic equipment used in the aerospace field. For instance, the heat flux of new generation electronic equipment is up to 106~107 W/cm<sup>2</sup> and the heat output of the most advanced processor is more than 250 W/cm<sup>2</sup> [1]. Consequently, the

heat radiation problem has become a serious restriction for the development of airborne electronic devices and the thermal management techniques are critical to their working performance [2].

Nowadays, thermal management techniques such as micro-channel cooling, jet impingement cooling, heat pipe cooling are proposed. Because of the high thermal conductivity, diamond can be used in laser crystal cooling to improve the distribution uniformity of temperature as well as thermal stress. Heat can be removed quickly and finally escapes into the surrounding air by other means. Micro-channel liquid convection cooling has been widely used but the system still need to be optimized to reduce channel flow resistance, improve system stability and avoid channel blockage. Compared with other cooling methods, spray cooling has a lot of advantages such as high heat transfer coefficient and critical heat flux (CHF), low superheat and reduced coolant flow rate [3~5]. Liquid can be atomized into small droplets (20~100μm in diameter) under the action of high pressure gas or its own pressure [6~9]. The former is called the air-assisted spray, and the latter is the pressure spray. The small liquid droplets are sprayed onto the heater surface to achieve efficient heat transfer. Spray cooling has been compared to jet impingement and pool boiling, obtaining higher heat flux at low superheat, which makes it one of the most appealing cooling methods for the thermal management needs of high heat flux systems [10~11].

The objective of this investigation is to study the effect of spray cooling installation angle on the heat transfer performance. The heater surface temperature and heat flux are collected and calculated during the tests. The experimental results are shown in a graphical format.

## II. EXPERIMENTAL STUDY OF SPRAY COOLING METHOD

### A. Experimental device

The spray cooling experimental system established in this study is shown in Fig. 1. The system is mainly made up by the liquid pump, filters, nozzle, valves, heated surface and water reservoir. The core components are the heated surface and the guiding surface. The working fluid (water) is pumped by a liquid pump from the water reservoir through a filter and then into the piping. The pipeline is divided into two branches. One branch leads the excess coolant through the safety valve and then makes it flow back into the water reservoir for cycling. The other branch guides the coolant through the pressure buffer, the pressure gauge, the filter, the check valve, the flow meter, the temperature sensor and the pressure sensor. Finally, the working fluid is sprayed onto the heater surface through a nozzle for heat exchange.

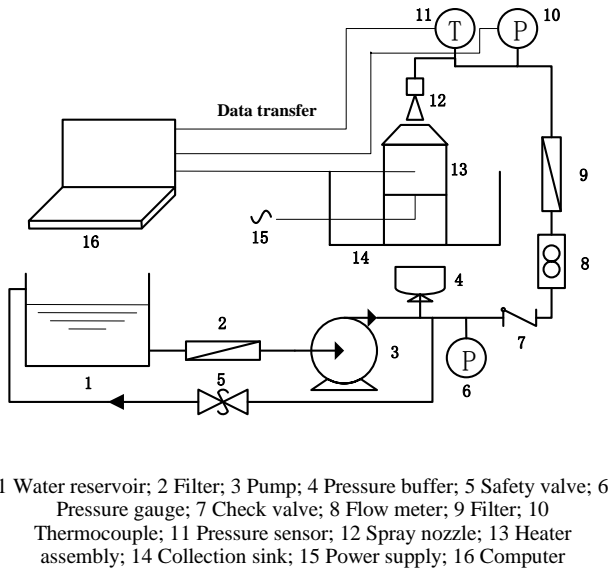


Figure 1. Spray cooling system

The system uses Advantech data acquisition module to collect the temperature and pressure data of the measured points and controls heating power by the power regulation module.

### B. Simulation of the heat dissipation from high power electronic equipment

The system uses the heated copper top surface to simulate the heat dissipation from the high power electronic equipment and the surface can be called the spray cooling surface. The structure of the heater is shown in Fig. 2.

Three heating rods with a maximum capacity of 120W are placed on the bottom of the heated copper, which are used as the power input. Six thermocouples are inserted into the six small holes drilled on the neck of the heated

cooper and they all are used to measure the temperatures and calculate the heat flux.

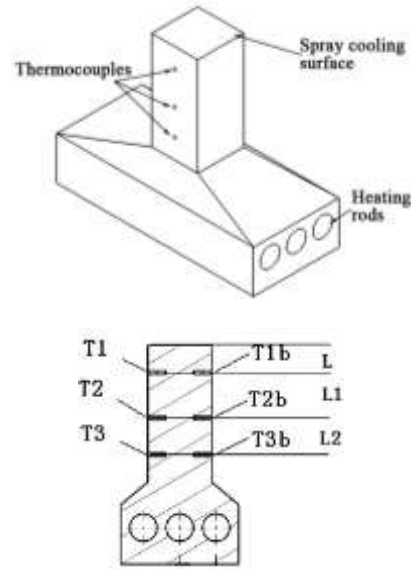


Figure 2. Simulation of high power electronic equipment

### C. Green laser flow visualization technology

In this study, the green laser flow visualization devices like the semiconductor laser and HD video camera are used to observe the spray pattern. The semiconductor laser is a double lumen Nd: YAG pulse laser, which has a maximum energy of 5 W, laser wavelength of 532 nm, and a repetition frequency of 1-15 Hz.

After the green laser is produced, the cylindrical len expands the original laser beam into a green light sheet which has a certain angle. Then the liquid flow characteristics on the spray cooling surface can be investigated qualitatively. The transient flow process displayed by the green laser will be recorded by the HD video camera so that the whole evolution process about the liquid flow can be obtained.

## III. ANALYSIS ABOUT HEAT TRANSFER PERFORMANCE IN DIFFERENT INSTALLATION ANGLES

### A. Experimental conditions

With a flat heater surface and a conical flow guiding face, experiments are conducted to study the heat transfer performance of spray cooling under different installation angles.

During the experiment, the spray nozzle keeps perpendicular to the heater surface. The spray cooling installation angle means the angle (marked with  $\alpha$ ) between the centerline of nozzle and the opposite direction of gravity as shown in Fig. 3.

The installation angle  $\alpha$  tested in this experiment was 0, 45, 90, 135, 165 and 180 degrees. For a given installation angle, the power input for the copper heater varied from 32 W/cm<sup>2</sup> to 162 W/cm<sup>2</sup>. Other experimental conditions remained constant. The spray pressure before the nozzle outlet was 1.0 MPa, and the spray height was 28 mm. The mass flow rate was 1.91 kg/h and the coolant temperature was 23 oC.



Figure 3. Spray cooling installation angle  $\alpha$

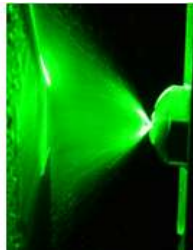
#### B. Analysis about green laser flow visualization results

Figure 4 shows the spray cooling flow regimes in different installation angles obtained by the green laser and HD video camera.

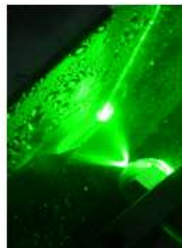
According to figure 4, we can find that when the installation angles are 0 degree, 90 degrees and 135 degrees, the condensed water after spray cooling is able to flow away through the conical guiding surface and the liquid will not accumulate on the heater surface. However, when the installation angles are 165 degrees and 180 degrees, the condensed water will come into being large droplets and then stay on the spray cooling surface for a while.



(a) 0 degree



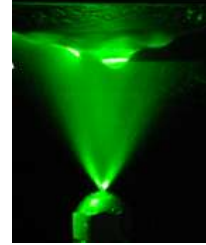
(b) 90 degrees



(c) 135 degrees



(d) 165 degrees



(e) 180 degrees

Figure 4. Spray cooling flow regimes in different installation angles

#### C. Analysis about the heat transfer performance in different spray cooling installation angles

Figure 5 shows the heat flux as a function of heater surface temperature with various installation angles.

It can be concluded that:

Firstly, when the heat flux is lower (relative to  $110 \text{ W/cm}^2$ ), the heat transfer performance curves obtained under 0 degree, 45 degrees, 90 degrees and 180 degrees are almost overlapped, which show similar cooling capability. While the curve obtained under 135 degrees is obviously below others and the spray cooling performance is the worst.

Secondly, when the heat flux is higher (relative to  $110 \text{ W/cm}^2$ ), 0 degrees spray cooling installation angle has the best heat transfer performance, followed by 45 degrees. But when the installation angles are 90 degrees, 135 degrees and 180 degrees, the heat transfer performance is close and worse.

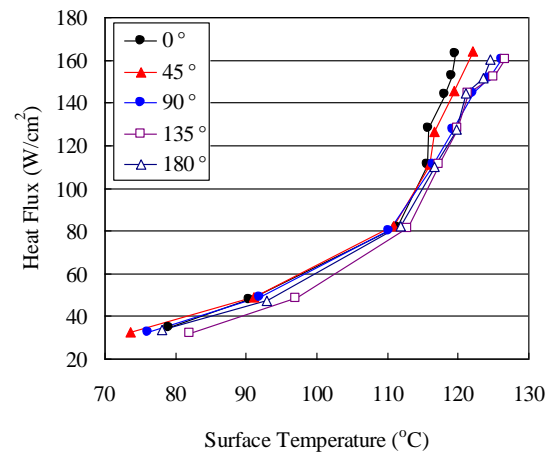


Figure 5. Heat flux vs. surface temperature as a function of spraying cooling installation angle

#### IV. CONCLUSION

With the increase of heat consumption, more fast and efficient cooling technology is required. Because of the better heat transfer capability, spray cooling has become one of the most attractive and promising cooling methods.

In this paper, experimental method is used to research the heat transfer performance of spray cooling. A spray cooling system is set up to investigate the effect of installation angle on the cooling performance and green laser flow visualization technology is used to observe the liquid flow on the heater surface. The five installation angles tested in the experiment are 0°, 45°, 90°, 135° and 180°. Other experimental parameters remain constant, such as the flow rate, the spraying height, the spray pressure and so on. The experimental results can be concluded as follows.

Firstly, when the heat flux is lower than 110 W/cm<sup>2</sup>, the heat transfer performance of spray cooling in installation angles of 0 degrees, 45 degrees, 90 degrees and 180 degrees is similar and higher than that obtained in an installation angle of 135 degrees.

Secondly, when the heat flux density is higher than 110 W/cm<sup>2</sup>, 0 degree spray cooling installation angle has the best heat transfer performance, followed by 45 degrees. But when the installation angles are 90 degrees, 135 degrees and 180 degrees, the heat performance become worse.

#### ACKNOWLEDGMENT

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