VISUALIZATION OF FLOW AND HEAT TRANSFER AUGMENTATION ON OBLIQUE IMPINGEMENT JETS

Hideo Kimoto*, Chayut Nuntadusit* and Kenji Hamabe**

**Graduate School of Engineering Science, Osaka University, Osaka, 560-8531, Japan*
***Akashi R & D Center, Kawasaki Heavy Industry Ltd, Akashi, 673-8666, Japan*

Impingement jet cooling techniques have been investigated[1-2] in the past. Recently, various nozzle geometries for impingement cooling jet have been devised and some favorable effects for cooling effectiveness have been reported[3-4]. However, these nozzles have not necessarily been used to cool the real blade wall, and impinging flow and the characteristics of impingement cooling are not clear enough. The impingement cooling characteristics by oblique jets through a rectangular nozzle have been investigated experimentally in the present study.

EXPERIMENTAL

A rectangular jet nozzle (1.4mm wide, 13.9mm high and 140.0mm long) was used in the experiments and the attack angle to the electrically heated target plate was changed. The distance between the nozzle and target plate, Reynolds number of the jet and the heat flux of the target plate were changed. The velocity distribution and the turbulence of the impinging jet from the rectangular nozzle were measured by a Pitot tube and a hot wire anemometer. The pressure distribution on the target plate was also measured through a small hole on the target plate by Pitot tube method and the stagnation point of the jet impingement on the target plate was determined.

Flow pattern of wall jet on the target plate

Flow pattern of the wall jet generated by the impinging jet was visualized by the oil-film visualization technique. For the oil film the mixture of liquid paraffin and titanium dioxide was used. Under the non-heat flux condition of the target plate, the change of oil film pattern on the transparent acrylic plate was recorded in every 30 seconds by a camera during 120 seconds.
Typical result is shown in Fig.1, as a parameter of target to jet nozzle distance normalized by the jet nozzle width (L).

Heat transfer pattern on the target plate

Changing the heat flux of the target plate, the attack angle of the impinging jet and the impinging jet velocity, the experiment has been carried out. In the present experiment the target plate was made of stainless steel foil whose sizes were 160mmx100mm and 0.01mm thick. A liquid crystal sheet was attached with binder film onto the rear side of the impingement surface of stainless steel foil. The liquid crystal sheet used in this study changes the color systematically (from red to blue) two times between 20-50 C.
Direct current was supplied to the stainless steel foil from an electric power supply unit via copper bus bars. Changing the electric current to the foil, i.e. heat flux of the target plate, the color patterns of the liquid crystal sheet were recorded by a camera and the distribution of heat transfer was measured. The color pattern indicated on the liquid crystal sheet was analyzed by LED sensor method, which was developed in our laboratory. Typical result of the heat transfer patterns is shown in Fig.2, as a parameter of heat flux (q).

RESULTS AND CONCLUSIONS

The main results obtained in these experiment are as follows:

(1) In general, the jet used for impingement cooling through a rectangular nozzle did not spread over the target plate along the long axis of the nozzle. Thus, the cooling effectiveness of the impingement cooling jet through a rectangular nozzle is distributed over the target plate along the short axis of the nozzle

(2) The wall jets generated by oblique jets for impingement cooling through the rectangular nozzle are inclined toward the downstream plate and the stagnation point of the impinging jet moves upstream along the target plate.

(3) The wall jet generated by the impinging jet flows faster at the edges than that the middle part of the impinging jet and the heat transfer at the edge is promoted by the wall jet.

REFERENCES

1. Martin, M., "Heat and Mass Transfer between Impinging Gas Jet and Solid Surfaces" *Advances in Heat Transfer, Vol.13, Academic Press, New York*, pp. 1-60, 1977.
2. Goldstein, R.J. and Franchett, M.E., Heat Transfer from a Flat Surface to an Oblique impinging Jet, *Trans.ASME, J. Heat Transfer*, Vol.110, pp. 84-90, 1988.
3. Kimoto, H., Iizuka, K. and Hamabe, K., Precise and Convenient Measurement of the Temperature Profile Appearing on the Temperature-sensitive Liquid Crystal, *HEAT TRANSFER Japanese Research*, Vol.21, No.1, pp.77-90, 1992.
4. Nuntadusit, C., Kimoto, H., Ishida, H and Hamabe, K., Flow and Heat Transfer Characteristics of Some Impinging Jets, *Proc. 9th Int. Symp. on Flow Visualization*, Edinburgh 2000, 165, 1-15

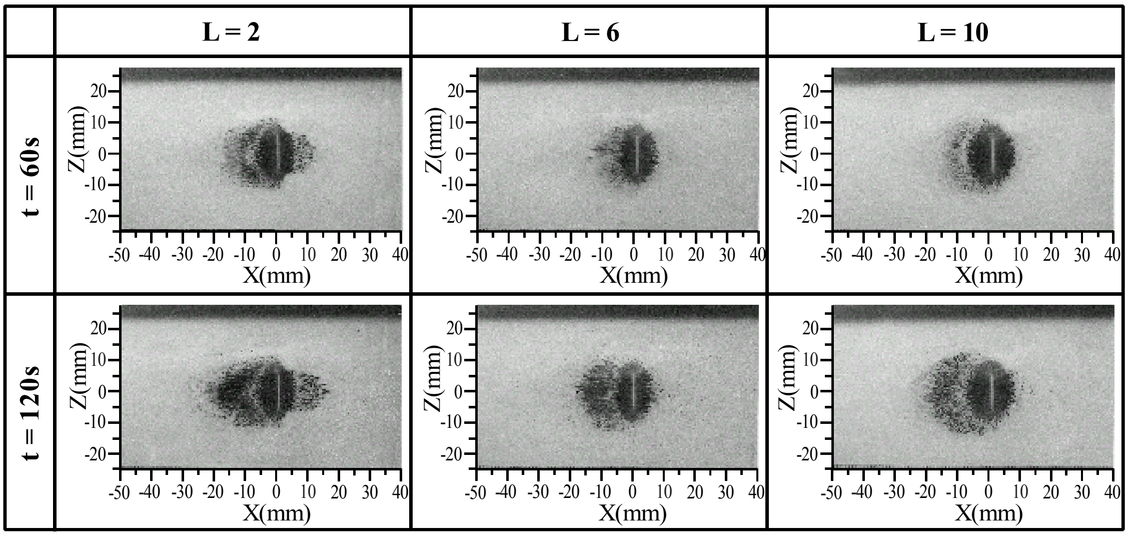

Figure.1 Typical flow pattern of wall flow by the oblique impinging jet. X=0 corresponds to the geometrical impingement point on the target plate through the center of jet nozzle. Attack angle from target plate to jet nozzle is 60 degrees.

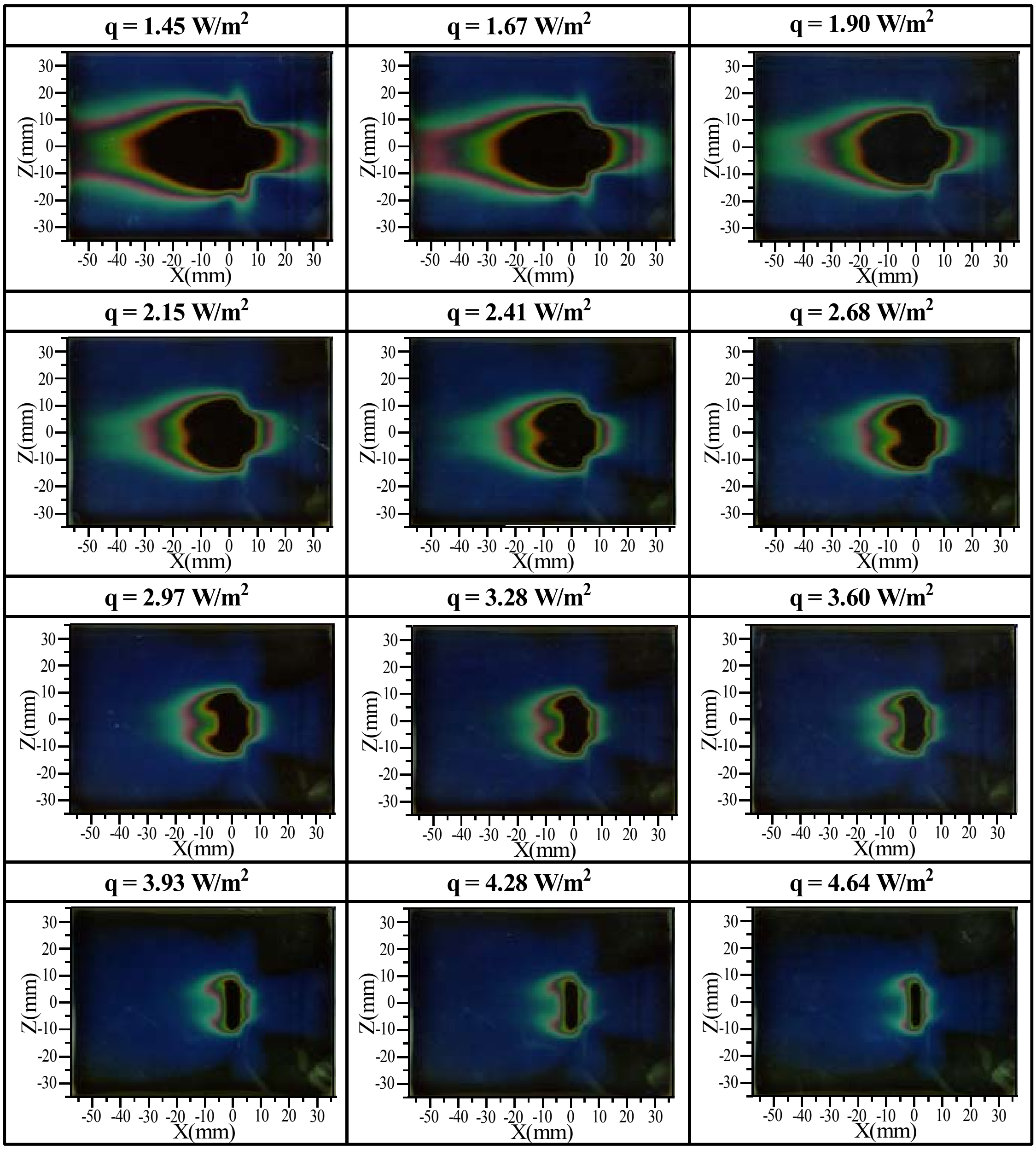

Figure 2. Typical color pattern of the liquid crystal sheet. X=0 corresponds to the geometrical impingement point on the target plate through the center of jet nozzle. Attack angle from target plate to jet nozzle is 60 degrees. Normalized distance from target plate to jet nozzle (L) is 2. Volume flow rate is 40 liters per minute.