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Numerical Study of Heat Release of the Symmetrically Arranged Extruded-Type Heat Sinks

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***Abstract*—**In this numerical study, we want to present the design of highly efficient extruded-type heat sink. The symmetrically arranged extruded-type heat sinks are used instead of a single extruded or swaged-type heat sink. In this parametric study, the maximum temperatures, the base temperatures between heaters, and the heat release rates were investigated with respect to the arrangements of heat sources, air flow rates, and amounts of heat input. Based on the results we believe that the use of both side of heat sink is to be much better for release the heat than the use of single side. Also from the results, it is believed that the symmetric arrangement of heat sources is recommended to achieve a higher heat transfer from the heat sink.

***Keywords*—**Heat Sink, Forced Convection, Heat Transfer, Performance Evaluation, Symmetrically Arranged.

I. Introduction

A SOLAR inverter is a power-electronic device that transforms dc voltage from a solar array panel to ac voltage that can be used to power loads such as home appliances, lighting and power tools [1]. The inverter consists of insulated-gate bipolar transistors (IGBTs), several electronic parts and controllers, and a heat release system. The IGBTs are high converting speed power semiconductors and are essential element in the inverter. The power loss from the IGBT turns into heat and increases the junction temperature inside the device. This heat degrades the characteristics of the device and shortens its life. So, it is important to allow the heat produced from the chip junction to be released outside to lower the junction temperature [2], [3]. That is why the IGBTs are packed with the heat release system like heat sink in the inverter. Generally, a heat release system in a solar inverter has heat sinks, induction fans and flow ducts for the forced convection, and some sensors to control the system.

Numerous research works related with various heat sinks have been carried out. In 2004, Lee [4] reported the design process with using both experiment and simulation results. He showed that the differences between them were less than 10% for the 400 kW IGBT inverter. Similarly, Jeon et al. [5] examined the effects of temperature increment of the serially aligned heat sources on the heat release performance of the tunnel-type air-cooled heat sink. Also, they presented the example design of heat release system by using the empirical relation came from the experiment. While, Kim et al. [6] developed the heat release system for the deep-focused solar cell modules having heat spreaders and heat sinks. They also reported the empirical relation can be used for the estimation of heat release performance of the natural convection heat sink. In 1996, Shaukatullah et al. [7] reported an optimized design of pin-fin heat sink for use in low velocity applications where there is plenty of open space around for the air to bypass the heat sink. While, in 2002, Kim et al. [8] investigated the thermal performance of several heat sinks such as extruded, aluminum foam, and layered one. Lee [9] reported the optimization of heat sink with pressure drop and heat transfer area. The pressure drops and heat transfer were varied by changing the number of fins. Riu et al. [10] evaluated the performance of a heat sink with strip-shaped fin, and tried to determine the optimal geometry.

The extrude-type heat sinks are used widely in the several fields of heat release systems. Compared with a swaged-type heat sink which might be assembled together with base plates and fins an extruded-type heat sink has much better heat transfer property. While in the cases of large-scaled heat release systems, swaged-type heat sinks are used instead of the extruded-type heat sinks due to their fabrication limit related with the extrusion pressure.

Because the solar power generation is one of the promising alternative energy sources, the intensification and large-scale power generation are inevitable. Following the large-scaled generation, which means the more heat can be lost and should be released to outside the inverter, the heat release system need to be scaled-up or high efficiency operated. The heat release thru heat sinks used in the conventional system depends on the heat transfer area and mass flow rate of the heat sink. The heat transfer area is determined by the number and size of fins inside of the heat sink. With the same heat release efficiency, the bigger heat sink which has lager heat transfer area is essential to release more heat to outside the inverter. While, because most of the large capacity inverters are big enough, the enlarged heat sink is not a good solution for the large capacity. So, to release more heat with the same dimension of the heat sink the more efficient heat sink is needed.

In this numerical simulation, we want to present the design of highly efficient extruded-type heat sink. The series of symmetrically arranged extruded-type heat sinks are used instead of a single extruded or swaged-type heat sink. Heat release performances, temperatures of bases and heat sources of the heat sinks are compared with respect to the arrangements and mass flow rates of the heat sinks.

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II. Experimental Method and Simulation

A. Problem Description

Schematics in Fig. 1 show the shape and dimension of the conventional aluminum (Al-6061) heat sink facing three power semiconductors (IGBTs) on the upper base. The unit of the length in Fig. 1 is millimeter. All the large-scaled heat sinks used in industrial and solar inverters have been used as such. The heat sink in Fig. 1 has dimensions of 410 mm in width, 325 mm in length and 100 mm in height. The thickness of base plate, and height and thickness of the fin, and spacing between fins are 15, 70, 1.5, 5.3 mm, respectively. The complexity of electric wiring in inverter and the possibility of poor thermal conduction between bases and fins of the swaged-type heat sink make it difficult to use both side of bases, upper and lower sides, of the heat sink. For a swaged-type heat sink, the three parts, fins, upper, and lower base, were manufactured separately, and then fins were inserted between the bases. A braising process between one base and fins can be done to get a better heat conduction, but for the other base due to the small space it is impossible to do the hand-worked braising between them. This is why the single-sided use and the poor thermal conduction of the conventional swaged-type heat sink.

To overcome the above drawbacks of the conventional aluminum-made swaged-type heat sink, a system of symmetrically arranged extruded-type heat sinks is proposed in this study as seen in Fig. 2. It is well known that the extruded-type heat sink has a better heat transfer characteristics and lower production cost than the swaged-type one, but it has a weakness of scale-up. Due to the large pressure drop in the extrusion process of the aluminum it is not easy to produce heat sinks bigger than 300 mm in width with reasonable cost. So, we are proposing the heat sink system consists of two extruded-type heat sinks as seen in Fig. 2. In this configuration the heat sources (IGBTs) are able to attach both on upper and lower bases, and the heat transfer area including finned surfaces might be used more effectively than the case of single arranged IGBTs as shown in Fig. 1. A sufficiently fast forced convection flow through the heat sink makes the buoyancy effect inside the finned channel useless.

Using a simple heat transfer equation as below [11], the calculation for the amount of heat transfer thru the heat sink was done. Here, $\dot{Q}$, $\dot{m}_{air}$, C_p, and ΔT denote heat transfer rate (W), mass flow rate of air (kg/s), specific heat at constant pressure (J/kg·K), and temperature difference between inlet and exit air thru the heat sink (K), respectively.

$$\dot{Q} = \dot{m}_{air} \times C_p \times \Delta T \qquad (1)$$

B. Numerical Simulation

A numerical simulation was done using a commercial flow simulation program (Fluent ver. 6). Steady solutions were obtained using an incompressible air flow and a standard *k-ε* turbulence flow model. Ambient air temperature was maintained at 20°C throughout the simulation, and air flow rates through the heat sink were specified as 0.11, 0.22 and 0.44 kg/s. The total input heat flows from the heat sources (IGBTs) were 1950, 3250, and 3900 Watt. The IGBT shown in Fig. 1 has dimension of 60(W) x 120(L) x 20(H) mm^3.

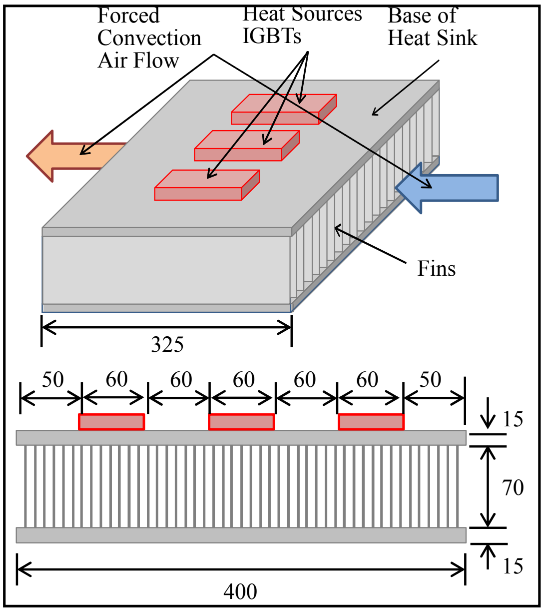

Fig. 1 Schematics of a conventional heat sink

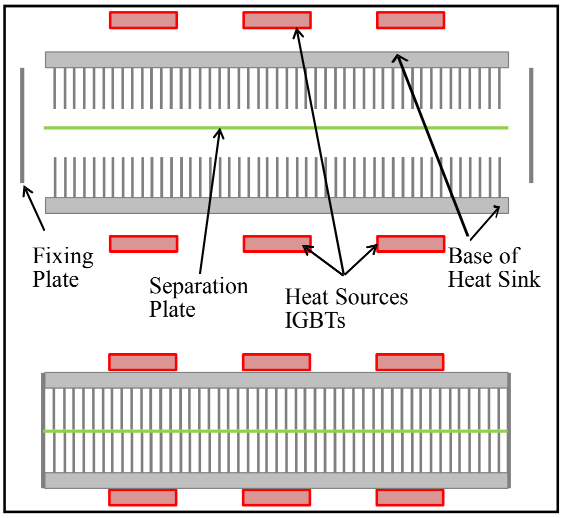

Fig. 2 Schematics of a symmetrically arranged heat sink

III. Results and Discussion

A. Validation of the Simulation

At first, to confirm the well-defined boundary conditions and several parameters the simulation results were compared with the experimental data [12]. The base temperature between heaters and the percentile heat release performances from experiments and numerical simulations for the 38- and 47-finned extruded-type heat sinks are presented in Figs. 3 and 4. In these validation results the total heat input from the three heat sources on the upper base was 1905 Watt. From the two figures it is believed that due to the increased heat transfer area the base temperature and the heat release of the 47-finned heat sink has the better performances than those of the 38-finned heat sink. In spite of the small loss in the mass flow rate caused by the increased pressure drop, as the heat transfer area increased from 38 fins to 47 fins in the experimental data, the percentile heat release performances are increased from 83.5% to 85.8%, while the base temperature between heat sources are decreased from 54.5 to 51.4°C. On the basis of the small differences and consistent results between the experiment and the simulation in Figs. 3 and 4 we believed that the validation of the boundary conditions and parameters of this simulation has been accomplished.

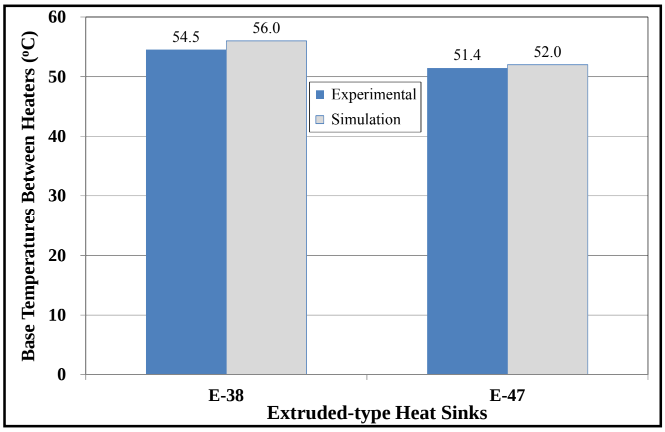

Fig. 3 Base temperatures of E-38 and E-47 heat sinks for validation

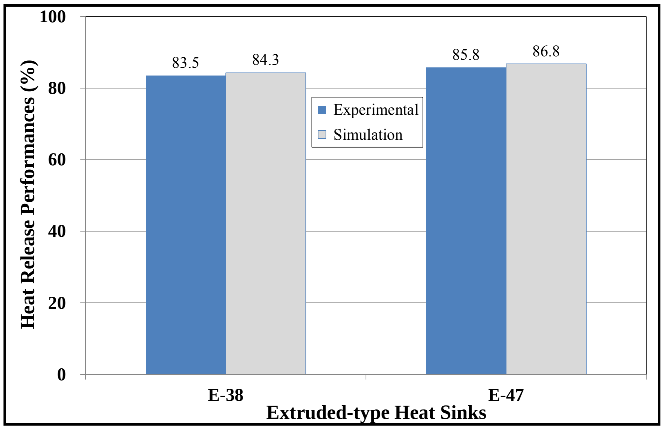

Fig. 4 Percentile heat release of E-38 and E-47 heat sinks for validation

B. Effect of Heat Source Arrangement on the Heat Release Performance

To know the effect of dispersed heat sources on the heat release performance the comparison of the case of the single-side arranged heaters (as seen in Fig. 1) with that of the dual-side arranged heaters (as seen in Fig. 2) was done. Figs. 5-7 are showing the maximum temperatures of heater, base temperatures between heaters and percentile heat release performances, respectively, with flow rates of cooling air through the heat sink. Despite the same heat input of 1950 W, the case using both side of the heat sink shows lower maximum temperatures and base temperatures than those of the case using one side of the heat sink as seen in Figs. 5 and 6. From these it is believed that the use of both side of the heat sink is more effective than the use of single side. Dissimilar with the temperature results in Figs. 5 and 6, the heat release performances of the two cases, the single side and both side, as seen in Fig. 7 are almost same. The reason of this discrepancy between the results seen in Figs. 5 and 6 and those seen in Fig. 7

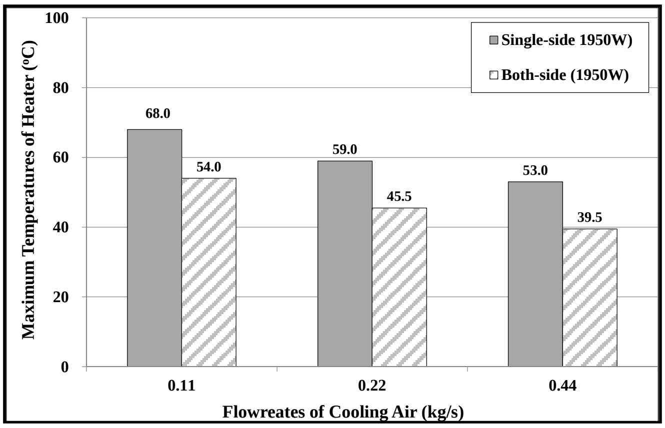

Fig. 5 Maximum temperatures of heat sinks with cooling air flow rates

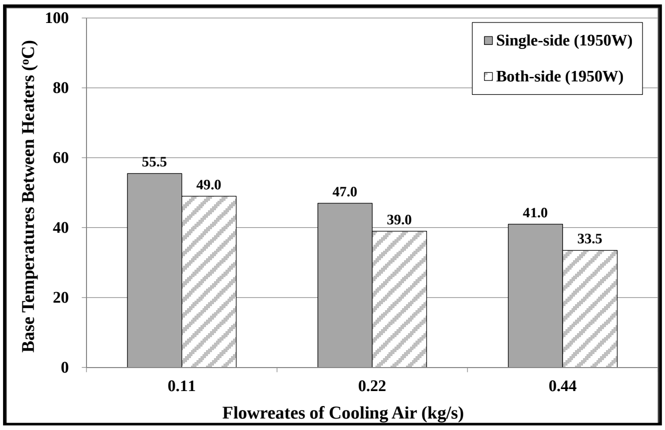

Fig. 6 Base temperatures of heat sinks with cooling air flow rates

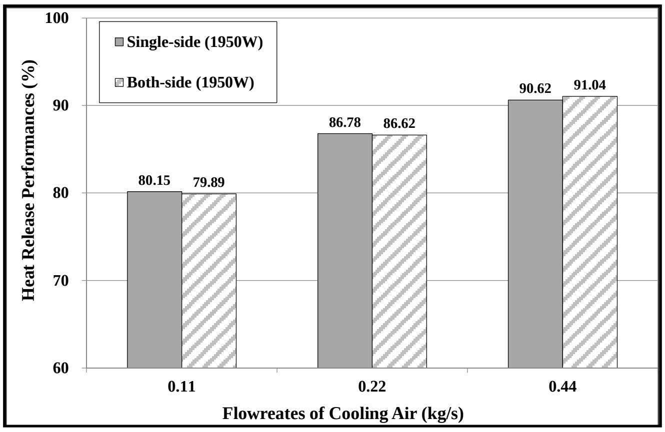

Fig. 7 Heat release rates of heat sinks with cooling air flow rates

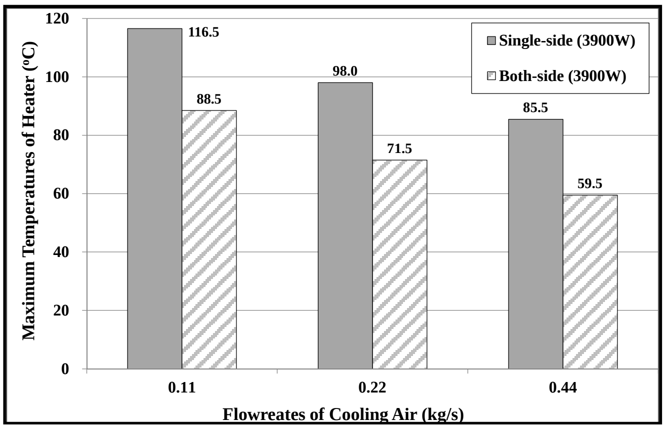

Fig. 8 Maximum temperatures of heat sinks with cooling air flow rates

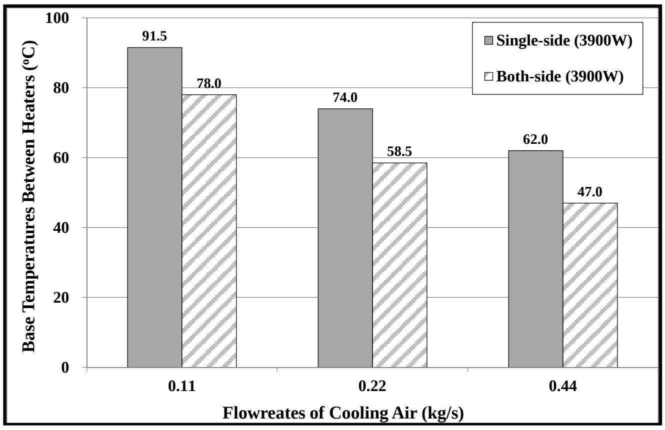

Fig. 9 Base temperatures of heat sinks with cooling air flow rates

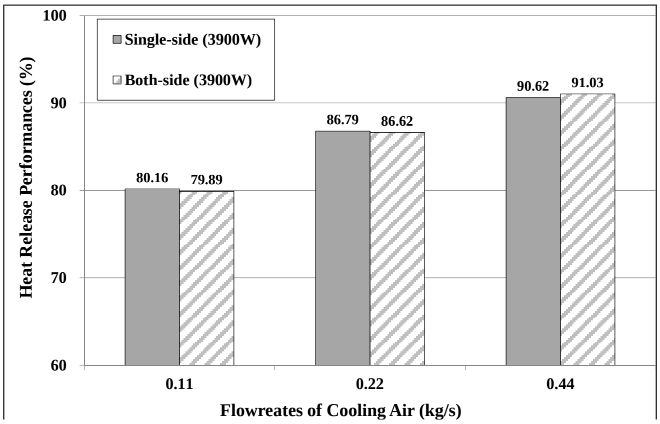

Fig. 10 Heat release rates of heat sinks with cooling air flow rates

To assess the merit of the dual-sided heat sink used in the high capacity inverter the doubled heat input, from 1950 W to 3900 W, was applied, and the results were presented in Figs. 8-10. Same as the Figs. 5 to 7, the maximum (heat source) temperatures, base temperatures between heaters, and percentile heat releases thru heat sink for the cases of 3900 W heat input were presented in Figs. 8, 9, and 10, respectively. The results show similar tendencies to those of the case of 1950 W heat input, but the temperature differences between the cases of the single and dual arrangement of the heaters are much larger than those of the smaller heat input. The amounts of heat release thru the heat sink are approximately twice as much as those of the smaller heat input. While, due to the enlarged hot heater area the heat release rates are almost same as those of the case of 1950 W heat input.

In the above parametric study, the maximum temperatures, the base temperatures between heaters, and the heat release rates were investigated with respect to the arrangements of heat sources, air flow rates, and amounts of heat input. Based on the above results we believe that the use of both side of heat sink is to be much better for release the heat than the use of single side.

C. Effect of Heat Source Symmetry on the Heat Release Performance

To find out the better position of heat sources for the higher heat release from the heat sink the comparison of an asymmetric and a symmetric arrangement of IGBTs has been investigated. The asymmetric arrangement of five 650 W IGBTs and the symmetric position of six 542 W IGBTs are seen in Fig. 11. Figs. 12-14 are showing the maximum temperatures of heater, base temperatures between heaters and percentile heat release performances, respectively, with flow rates of cooling air through the heat sink. Though the two arrangements have the same total heat input, 3250 W, the case of symmetric arrangement is showing lower temperatures and better heat spread thru the entire heat sink. While, due to the enlarged hot IGBTs surface, that is to say the number of IGBT is increased from 5 to 6, the heat loss from the heat sink to the ambient was increased, and the heat release thru the heat sink was slightly decreased as seen in Fig. 14. From the results from Figs. 12 to 14, it is believed that the symmetric arrangement of heat sources is recommended to achieve a higher heat transfer from the heat sink.

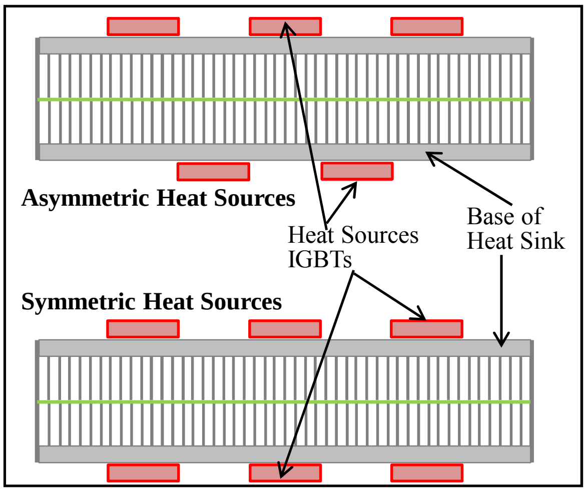

Fig. 11 Schematics of an asymmetric and a symmetric heat sink

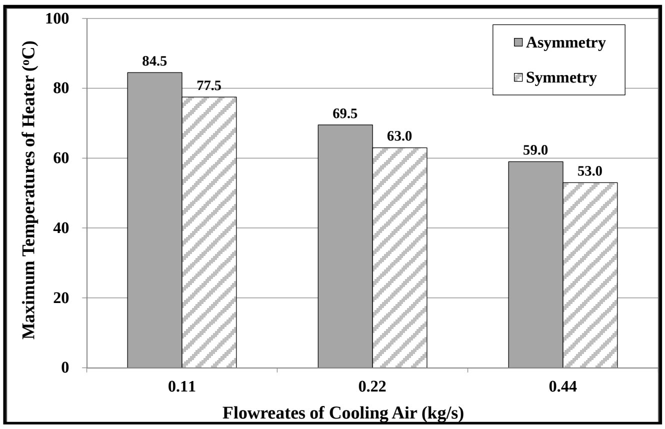

Fig. 12 Maximum temperatures of heat sinks with air flow rates

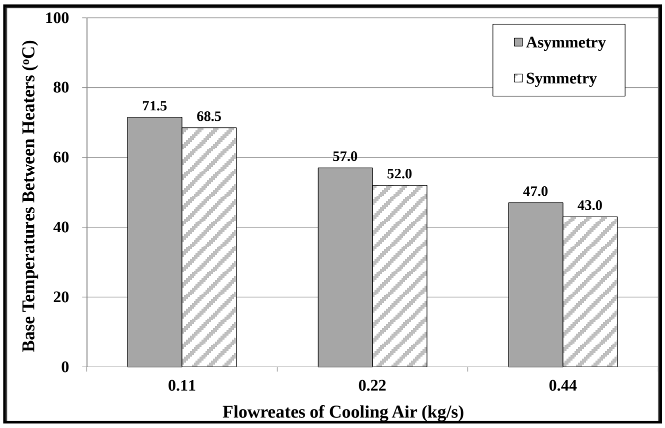

Fig. 13 Base temperatures of heat sinks with cooling air flow rates

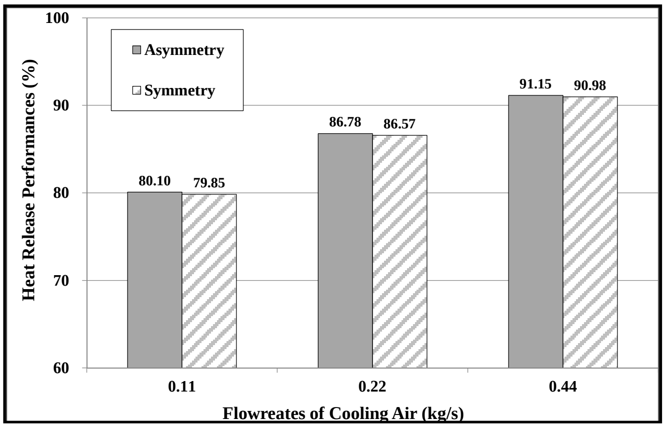

Fig. 14 Heat release rates of heat sinks with cooling air flow rates

IV. Conclusion

In this numerical study, the arrangement of highly efficient extruded-type heat sink system has been presented. The symmetrically arranged extruded-type heat sinks were used instead of a single extruded or swaged-type heat sink. In this parametric investigation, the maximum temperatures, the base temperatures between heaters, and the heat release rates were investigated with respect to the arrangements of heat sources, air flow rates, and amounts of heat input.

Based on the results we believe that the use of both side of heat sink is to be much better for release the heat than the use of single side. Also from the results, it is believed that the symmetric arrangement of heat sources is recommended to achieve a higher heat transfer from the heat sink.

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