Proposal of liquid immersion cooling with bubble-assisted natural convection for HPC-based cloud computing system

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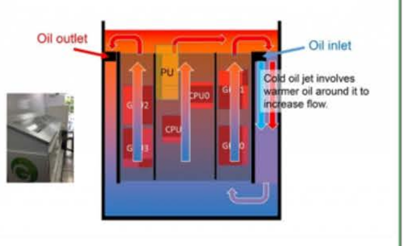
***Abstract*— A liquid immersion technique using a natural convection of a refrigerant is useful as a cooling method for high-heat generating High-Performance Computing (HPC) system, which has difficulty cooling by air alone. We proposed a natural convection method with bubble assistance in order to improve cooling efficiency, and eventually applied power limit. Perfluorocarbon structured refrigerants and Silicone oil were used as refrigerants. The bubble assistance technology exhibits high cooling performance under the wide operating conditions without depending on the type of the refrigerant and bathtub structure. As a result, an ideal convection was obtained even for commercially available HPC boards. The bubble assistance effect corresponded to a 5-10℃ CPU cooling without worsening the cooling efficiency. The power of creating bubble flow rate is negligible. Eventually, an average Power Usage Effectiveness (mPUE) of 1.02 was successfully demonstrated, and also allowable CPU input power limit reached above 320 W, corresponding to around 30kw for the entire system.**

TABLE I. Several liquid cooling technologies and their features.

Type	Single Phase			2 Phases
	Forced Convection	Natural Convection	Refrigerant Dripping	Boiling
Structure	 Forced convection of refrigerant by pump inside liquid tank	 Natural convection with the power of the CPU's heat as the driving force by merely immersing in refrigerant	 Refrigerant drip onto the CPU	 Boiling (vaporization) of refrigerant on the CPU surface and circulation of liquefaction on the surface of the cooling plate
Refrigerant	High Boiling Temp.(Fluorinert FC43/FC3283, Silicone Oil Si6/Si35)			Low Boiling Temp.(Novec)
Feature	Pump for refrigerant convection essential	Pump for refrigerant convection unnecessary	Small pump required for lifting refrigerant	Phase change due to boiling phenomenon
Ref.	Fujitsu Journal, 1P, Aug.15, 2016.	This Study Matsuoka, Matsuda and Kubo, IEEE 6th Intl. Conf. Cloudnet, 10-1109, 2017.	Matsuda, Matsuoka and Miyake, Ashrae 2018 Winter Conference	https://www.grcooling.com/carnotjet/

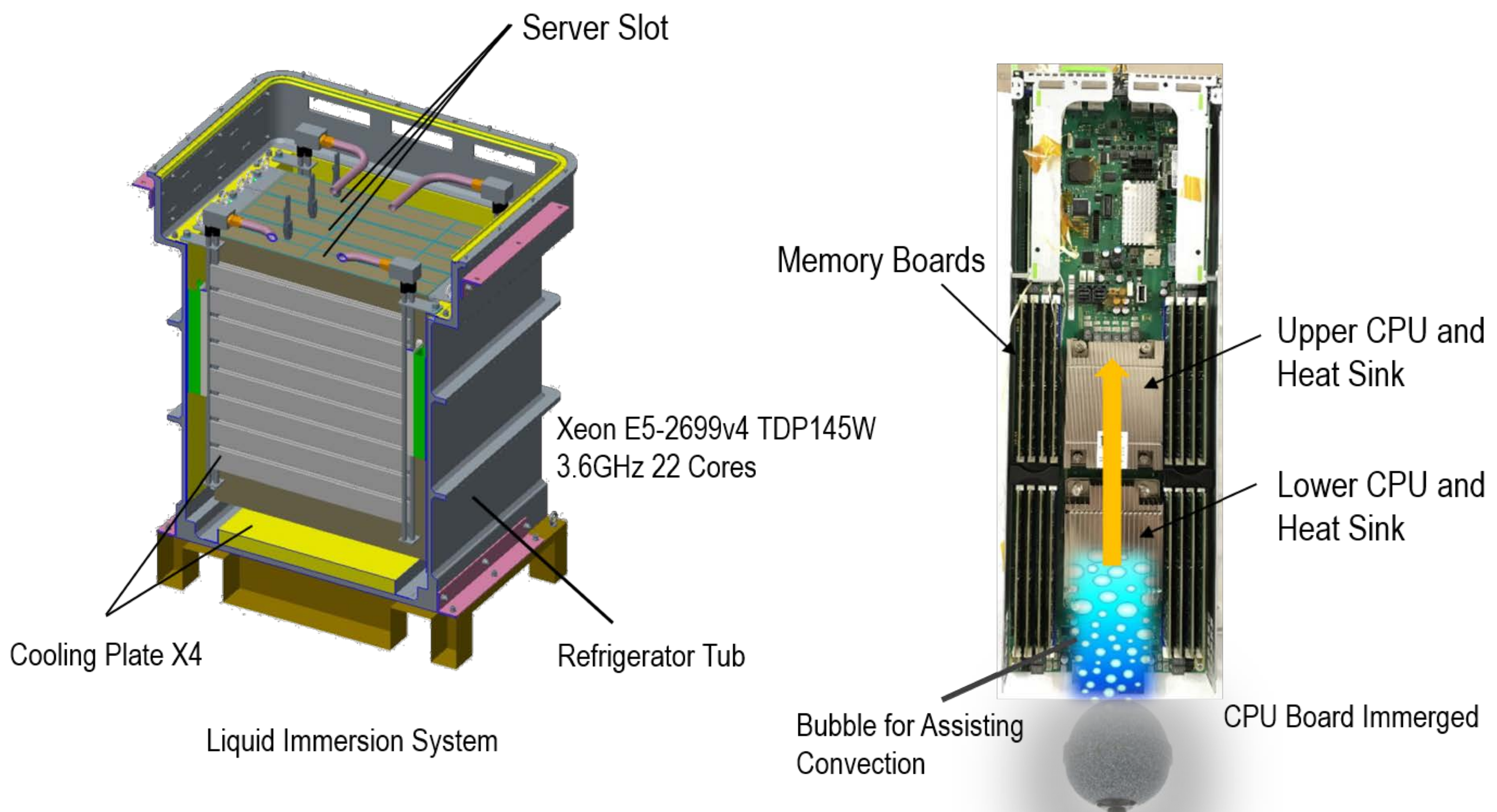


Fig.1 Experimental apparatus for liquid immersion cooling with bubble assisted natural convection and commercially available HPC board.

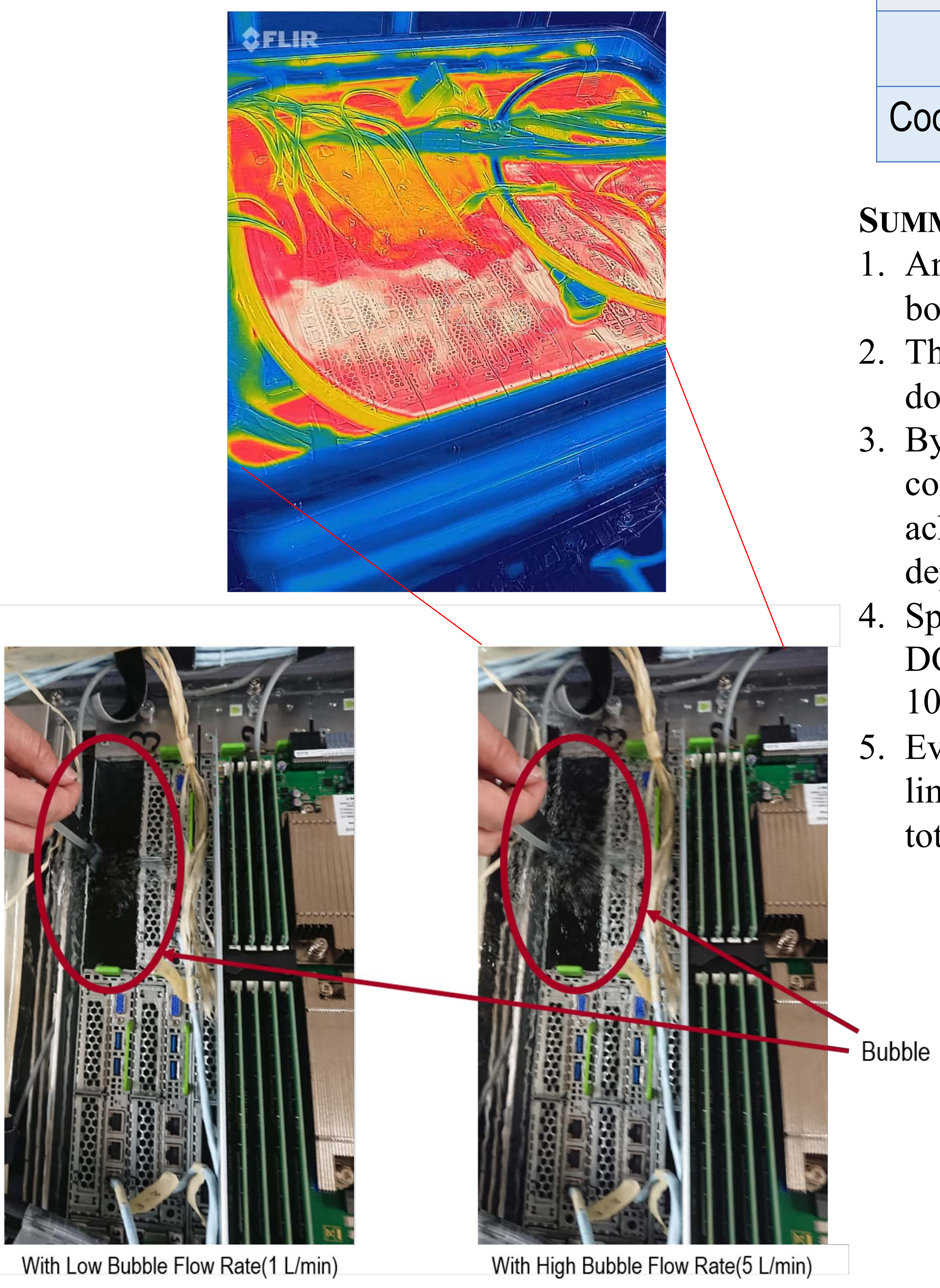


Fig.2 Snapshots of bubble flow on top of refrigerant.

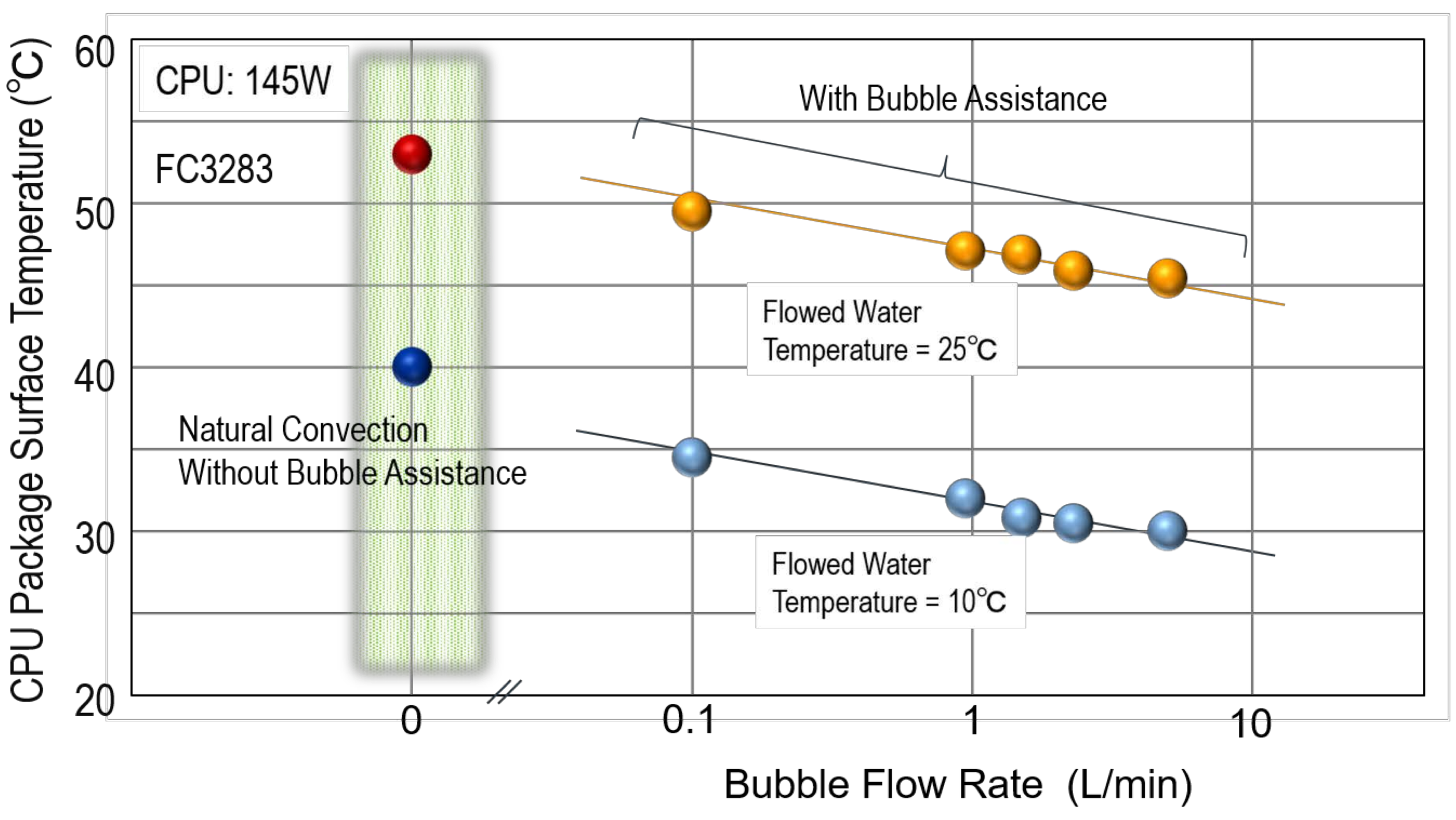


Fig.3 Typical relationship between bubble flow rate and CPU package surface temperature. Water temperatures flowed inside cooling plate are 10 and 25℃. Temperatures for natural convection are also shown. Here, Fluorocarbon (FC3283) was used as a refrigerant.

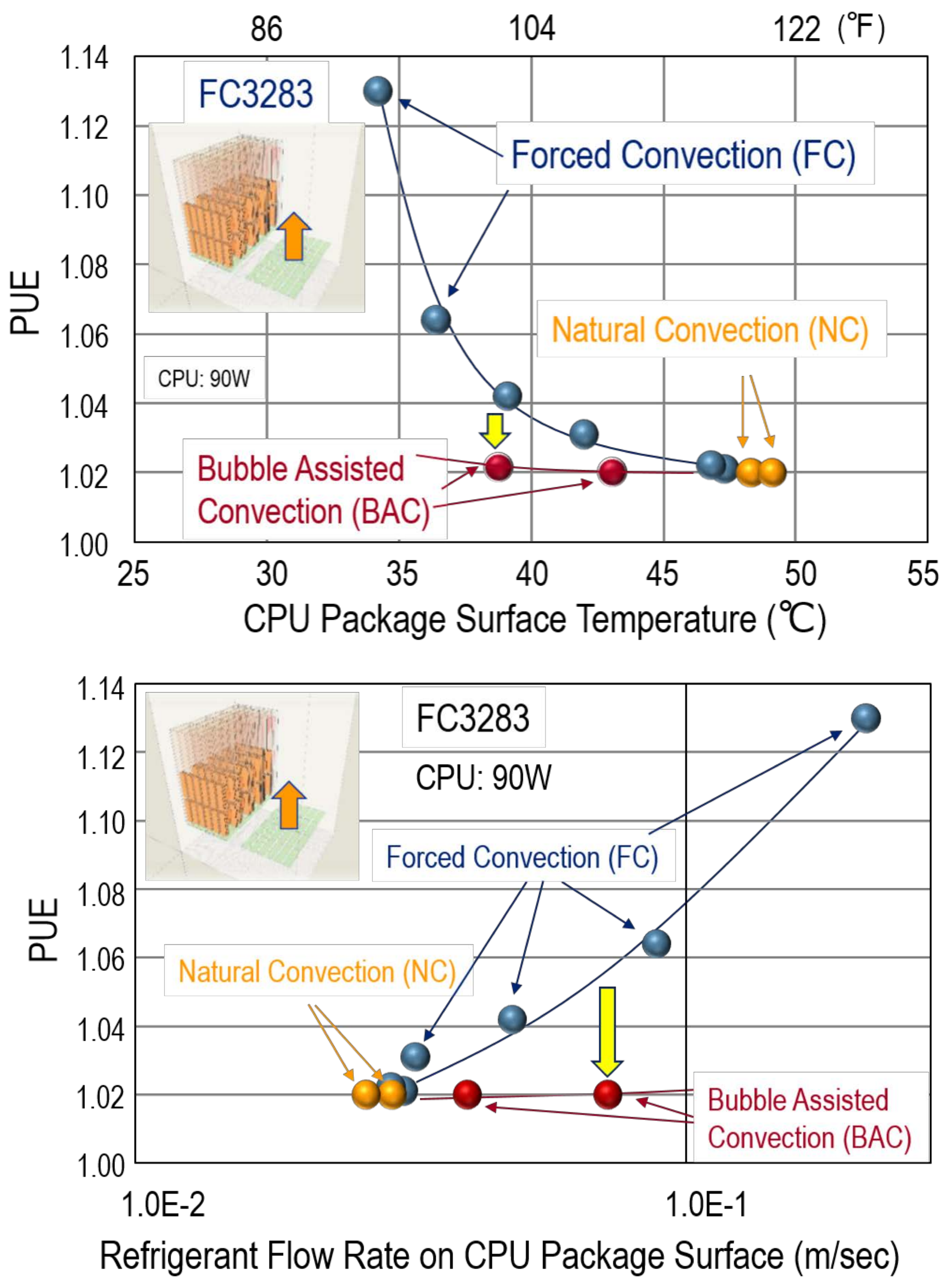


Fig.4 Relationships between refrigerant flow rate on CPU package surface and PUE (lower graph), and relationships between CPU package surface temperature and PUE (upper graph) for forced convection (FC) mode with fan, natural convection (NC) mode without fan, and bubble assisted convection (BAC). Here, Fluorocarbon (FC3283) was used as a refrigerant.

TABLE II. Cooling performances of several convection systems.

	Forced Convection	Natural Convection	Bubble-assisted Convection
PUE	Middle	Low	Low
Cooling Capacity	High	Middle	High

SUMMARY

1. An ideal convection was obtained even for commercially available HPC boards using natural convection with bubble assistance.
2. This cooling system does not require a strict connection path design that does not hinder it, as in the simple natural convection system.
3. By means of bubble assistance, the high cooling-effect as for forced convection and low PUE as for natural convection were simultaneously achieved at the same time, under the wide operating conditions without depending on the type of the refrigerant and bathtub structure.
4. Specifically, the bubble assistance of 0.1-5m/sec bubble flow rate with a DC motor power of only 0.4-10W demonstrated CPU cooling-effect of 5-10℃.
5. Eventually, an average PUE of 1.02 was successfully achieved. The upper limit of applied CPU power reached above 320W, corresponding to the total system power of 30kW.

ACKNOWLEDGEMENT

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