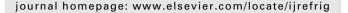




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Experimental evaluation of a controlled hybrid two-phase multi-microchannel cooling and heat recovery system driven by liquid pump and vapor compressor

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ARTICLE INFO

Article history:
Received 6 August 2012
Received in revised form
6 November 2012
Accepted 8 November 2012
Available online 23 November 2012

Keywords:
Data center
Chip
Cooling
Heat recovery
Two-phase flow
Controller

ABSTRACT

The energy use in data centers is on an accelerating rise due to both demand and technological limitations. Today, the most widely used cooling strategy for data centers is refrigerated air-cooling. Unfortunately, air-cooling presents phenomenally low efficiencies. Therefore green computing paradigms are needed to improve energy efficiency by several orders of magnitude and allow a continued chip scaling for tackling the energy crisis in future-generation data centers. A promising solution would be implementing direct on-chip two-phase cooling technology, which not only improves the heat removal efficiency but also permits the reuse of waste heat since the two-phase coolant can cool CPUs effectively at 60 °C. In the present work a specific cooling cycle using micro-evaporation technology has been experimentally evaluated considering different aspects such as cooling cycle and energy recovery efficiencies and controllability. In resume, this novel cycle shows strong competence in energy usage, heat recovery and controllability towards green data center.

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Evaluation expérimentale d'un système hybride et régulé de refroidissement diphasique à microcanaux et de récupération de chaleur entraîné par une pompe et un compresseur de vapeur

Mots clés : centre de données ; puce ; refroidissement ; récupération de chaleur ; écoulement diphasique ; régulateur

Nomenclature			
		ΔT	temperature difference [°C]
Roman		$\varepsilon_{ ext{cond}}$	condenser's effectiveness [–]
A_{SMV}	stepper motor valve aperture [%]	$\eta_{ m c}$	cooling cycle efficiency [–]
С	transfer function of the controller or empirically	$\eta_{ m hr}$	heat recovery efficiency [–]
	adjusted parameter	θ	transport delay, s
COP	coefficient of performance [-]	τ	time constant, s
G	transfer function of the system	$ au_{ m D}$	desired closed-loop time constant, s
h	specific enthalpy [kJ kg ⁻¹]	Subscripts	
Н	closed-loop transfer function	cond	condenser
HL_{MMEs}	overall heat load on the MMEs [W]	i	inlet junction of the two MMEs
K_C	PI proportional gain	0	outlet junction of the two MMEs
K_I	PI integral gain	S	speed
K_P	static gain of the system		set point
ṁ	working fluid mass flow rate [kg $ m s^{-1}$]	sp	set point
р	position of the pole in the complex plan	Acronyms	
P	pressure [bar] or scheduling parameter	CHF	critical heat flux [W cm ⁻²]
Q	heat transfer rate [W]	CPU	central processing unit
Q_{input}	total input power applied on pseudo-chips and	EEV	electric expansion valve
	post heater [W]	iHEx	internal heat exchanger
T	temperature [°C]	LA	liquid accumulator
T_I	PI integral time	LPC	liquid pump of cooling loop
и	system input	LPW	liquid pump of water loop
UA	overall conductance [W K ⁻¹]	LS	liquid separator
W_{input}	total input power applied on drivers and actuators	MIMO	multiple input multiple output
	[W]	MME	multi-microchannel evaporator
$\dot{W}_{ m input}$	total input power of the two pseudo-chips [W]	SIMO	single input multiple output
W_{vsc}	compressor input power	SISO	single input single output
Xo	outlet vapor quality [–]	SMV	stepper motor valve
у	system output	VSC	oil-free mini-compressor
Z	position of the pole in the complex plan		

1. Introduction

The energy consumption of data centers in the US was estimated to be about 80 billion kWh by 2010, which represents an annual energy cost of approximately \$5.9 billion and 2% of total electricity use (EPA, 2007; Joshi and Kumar, 2012, Koomey, 2011). With the US having an annual increase of total electrical generation of approximately only 1.5% combined with the current growth rate of electrical energy by data centers being between 10% and 20% per annum (driven now even more by smart phones), data centers potentially will use all of the electrical energy produced by 2030 (Utsler, 2010) if current growth rates continue! With air cooling of the servers in data centers accounting for most of the non-IT energy usage (up to 45% of the total energy consumption (Joshi and Kumar, 2012, Koomey, 2007)), this is the logical energy user that needs to be earmarked to reduce its wasteful use.

Nowadays, the most widely used cooling strategy is refrigerated air cooling of the data centers' numerous servers. When using this solution, nevertheless, 40% or more of the refrigerated air flow can by-pass the racks of servers in data centers all together (Joshi and Kumar, 2012, Marcinichen et al., 2010) while also "cooling" thousands of servers that are not

even in operation. This massive waste of energy motivates the search for a new "green" cooling solution for the future generation of higher performance servers that use much less energy for their cooling. One promising solution is the application of on-chip two-phase cooling to dissipate the high heat flux densities of server CPU's. The most promising working fluids for these applications appear to be conventional refrigerants, for instance HFC134a, as opposed to low pressure dielectric coolants (such as FC-72) or water-cooling.

Hannemann et al. (2004) proposed and experimentally evaluated a pumped liquid multiphase cooling system (PLMC) to cool microprocessors and microcontrollers of high-end devices such as computers, telecommunications switches, high-energy laser arrays and high-power radars. They emphasized the significant benefits of reduced pumping energy consumption, size and weight that were provided with the PLMC solution.

Mongia et al. (2006) designed and built a small-scale refrigeration system applicable to a notebook computer, which included a mini-compressor, a microchannel condenser, a microchannel evaporator and a capillary tube as the throttling device. COP's on the order of 3.7 were obtained, comparable with those obtained in modern household refrigerators.

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