STUDY OF CONJUGATE HEAT TRANSFER IN MICROCHANNEL HEAT SINK USING NANOFLUID AS CONVECTION WORKING FLUID

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by

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Submitted

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to the

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CERTIFICATE

This is to certify that the thesis entitled, **"Study of Conjugate Heat Transfer in Microchannel Heat Sink using Nanofluid as Convection Working Fluid"**, being submitted by **Mr. Sandeep Gupta** to the Indian Institute of Technology Delhi, India, for an award of the degree of **Doctor of Philosophy** is a record of bonafide research work carried out by him. He has worked under my guidance and supervision and has fulfilled the requirements for the submission of this thesis, which to my knowledge, has reached the requisite standard.

The results contained in the thesis have not been submitted, in part or full, to any other university or institute for the award of any degree or diploma.

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ABSTRACT

Effective cooling is crucial and poses a significant challenge in the electronics industry as devices become increasingly miniaturized. This Ph.D. thesis explores the use of nanofluids as an alternative to traditional coolants in microchannel heat sinks, specifically addressing challenges related to miniaturization in electronic devices. The focus is on alumina nanofluids with concentrations ranging from 1% to 4% in a microchannel heat sink at low Reynolds numbers ($10 \leq Re \leq 50$). The main objective is to comprehensively evaluate and compare the cooling effectiveness, back axial conduction, heat transfer coefficient, pressure drop, friction factor in nanofluids against deionized water, and assess thermohydraulic performance, as well as the loss in concentration in nanofluids.

The research demonstrates that nanofluids exhibit superior thermal performance due to enhanced thermal conductivity induced by Brownian motion and thermophoresis. There is a significant reduction in backward conduction, enhancing the heat sink capacity. Key findings include a substantial decrease in back axial conduction, up to 51.54% at 4% nanoparticle concentration, indicating the potential of nanofluids to mitigate this effect and lower surface temperatures in the microchannel heat sink, with reductions of up to 29% at 4% nanoparticles concentration compared to the base fluid.

There is a progressive increase in heat transfer coefficient and Nusselt number with higher nanoparticle concentration and Reynolds number, resulting in improvements of 43.34% and 35.85%, respectively, for Reynolds number 50 at 4% nanoparticles concentration. However, this improvement comes with a trade-off, as higher nanoparticle concentrations lead to rise in pressure drop and friction factor, observed as a penalty to pumping power, particularly notable at higher concentrations. Optimal thermohydraulic performance is observed at 3% nanoparticle concentration, with a decreasing trend at 4%, reaching a maximum value of 1.17 for Reynolds number 50. An inverse proportional relationship is found between percentage loss in nanofluid concentration and Reynolds number, attributed to settling, agglomeration, and deposition, reaching a maximum loss of 2.93% for Reynolds number 10 at 1% nanoparticles concentration.

This research provides valuable insights into the application of nanofluids for efficient cooling in microchannel heat sinks, offering a comprehensive understanding of their thermal and hydraulic performance. These insights are critical for advancing heat dissipation technologies in the electronics industry. In conclusion, the study affirms the potential of nanofluids in efficiently cooling electronic devices, showcasing superior heat transfer performance at low Reynolds numbers.

सार

प्रभावी शीतलन महत्वपूर्ण है और इलेक्ट्रॉनिक्स उद्योग में एक महत्वपूर्ण चुनौती पेश करता है क्योंकि उपकरण तेजी से लघुकृत होते जा रहे हैं। यह पीएचडी थीसिस माइक्रोचैनल हीट सिंक में पारंपरिक शीतलक के विकल्प के रूप में नैनोफ्लुइड्स के उपयोग की पड़ताल करती है, विशेष रूप से इलेक्ट्रॉनिक उपकरणों में लघुकरण से संबंधित चुनौतियों को संबोधित करती है। इसका केंद्र कम रेनॉल्ड्स संख्या ($10 \leq Re \leq 50$) पर माइक्रोचैनल हीट सिंक में 1% से 4% तक की सांद्रता वाले एल्यूमिना नैनोफ्लुइड्स पर है। मुख्य उद्देश्य शीतलन प्रभावशीलता, बैक एक्सियल कंडक्शन, ताप हस्तांतरण गुणांक, दबाव की गिरावट, विआयनीकृत पानी के खिलाफ नैनोफ्लुइड्स में घर्षण कारक का व्यापक रूप से मूल्यांकन और तुलना करना और थर्मोहाइड्रोलिक प्रदर्शन के साथ-साथ नैनोफ्लुइड्स में सांद्रता में कमी का आकलन करना है।

शोध से पता चलता है कि नैनोफ्लुइड्स बेहतर थर्मल प्रदर्शन प्रदर्शित करते हैं, जिसके प्रमुख कारण है - ब्राउनियन गति और थर्मोफोरेसिस । इसके कारण बैक एक्सियल कंडक्शन में उल्लेखनीय कमी होती हैं, जिससे ऊष्मा सिंक क्षमता में वृद्धि होती है। प्रमुख निष्कर्षों में बैक एक्सियल कंडक्शन में पर्याप्त कमी, जिसमें 4% नैनोकण सांद्रता पर 51.54% तक कमी शामिल है, जो इस प्रभाव को कम करने के लिए नैनोफ्लुइड्स की क्षमता और माइक्रोचैनल हीट सिंक में कम तापमान को दर्शाता है, जिसमें बेस द्रव की तुलना में 4% नैनोकण सांद्रता पर 29% तक की कमी होती है।

उच्च नैनोकण सांद्रता और रेनॉल्ड्स संख्या के साथ ताप हस्तांतरण गुणांक और नसेल्ट संख्या में प्रगतिशील वृद्धि होती है, जिसके परिणामस्वरूप 4% नैनोकण सांद्रता पर रेनॉल्ड्स संख्या 50 के लिए क्रमशः 43.34% और 35.85% का सुधार होता है। हालांकि, यह सुधार एक चुनौती के साथ आता है, क्योंकि

उच्च नैनोकण सांद्रता से दबाव में गिरावट और घर्षण कारक में वृद्धि होती है। इष्टतम थर्मोहाइड्रोलिक प्रदर्शन 3% नैनोकण सांद्रता पर देखा जाता है, जिसमें घटती प्रवृत्ति 4% पर होती है, जो रेनॉल्ड्स संख्या 50 के लिए 1.17 के अधिकतम मूल्य तक पहुंचती है। नैनोफ्लुइड सांद्रता और रेनॉल्ड्स संख्या में प्रतिशत हानि के बीच एक व्युत्क्रम आनुपातिक संबंध पाया जाता है, जो निपटान, संकुलन और जमाव के लिए जिम्मेदार होता है, जो 1% नैनोकणों की सांद्रता पर रेनॉल्ड्स संख्या 10 के लिए 2.93% की अधिकतम हानि तक पहुंच जाता है।

यह शोध माइक्रोचैनल हीट सिंक में कुशल शीतलन के लिए नैनोफ्लुइड्स के अनुप्रयोग में बहुमूल्य अंतर्दृष्टि प्रदान करता है, जो उनके थर्मल और हाइड्रोलिक प्रदर्शन की व्यापक समझ प्रदान करता है। ये अंतर्दृष्टि इलेक्ट्रॉनिक्स उद्योग में ताप अपव्यय प्रौद्योगिकियों को आगे बढ़ाने के लिए महत्वपूर्ण हैं । निष्कर्ष में, अध्ययन ने इलेक्ट्रॉनिक उपकरणों को कुशलतापूर्वक ठंडा करने में नैनोफ्लुइड्स की क्षमता की पुष्टि की है, तथा कम रेनॉल्ड्स संख्या पर बेहतर ताप हस्तांतरण प्रदर्शन को प्रदर्शित किया है।

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NOMENCLATURE

A	Surface area, m^2
C_p	Specific heat, kJ/kg.K
d	Diameter of the microchannel, m
I	Current supplied to the heater, A
k	Thermal conductivity, W/m.K
l	Length of the microchannel, m
M	Maranzana number
$\dot{m}$	Coolant mass flow rate, kg/ s
n	Number of microchannels in heat sink
Nu	Nusselt number
Δp	Pressure difference across microchannel, N/m^2
Q	Heat, W
q''	Surface heat flux, kW/m^2
Re	Reynolds number
T	Temperature, °C
v	Velocity, m/s
V	Voltage, V
z	Distance between thermocouple and microchannel, m
Subscripts	
Avg	Average
bc	Backward conduction
bf	Base fluid
conv.	Convected
eff	Effective
f	Fluid
In	Inlet
L	Loss
nf	Nanofluid

np	Nanoparticle
Out	Outlet
p	Particle
s	surface
Th	Thermocouple
W	Wall
x	Axial position

Greek symbols

ρ	Density, kg/m ^{3}
ϕ	Nanoparticle concentration, v/v
μ	Viscosity, Pa.s
λ	Density ratio

Acronyms

CWT	Constant wall temperature
CWHF	Constant wall heat flux
DI	Deionized
DLS	Dynamic light scattering
FF	Friction factor
HTC	Heat transfer coefficient
MCHS	Microchannel heat sink
NF	Nanofluid
NP	Nanoparticle
PD	Pressure drop
PDS	Particle diameter size
RPM	Revolutions per minute
SEM	Scanning electron microscopy
THP	Thermo-hydraulic performance
wt.%	Weight Percentage
w/w	Weight by weight percentage