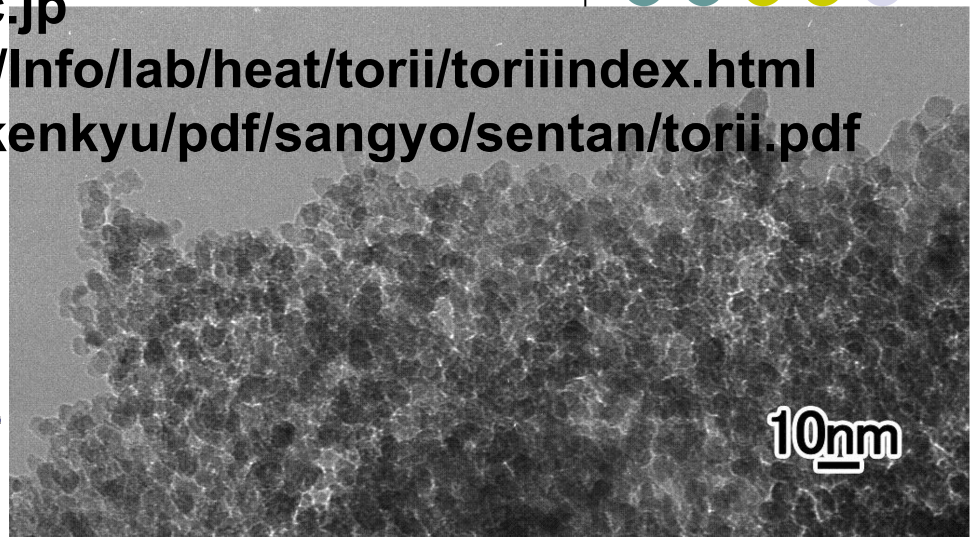
日本熱物性学会 研究分科会「マイクロナノスケールの熱物性とシステムデザ゛イン」
日時：2008年5月24日（土）13：30～17：00
場所：キャンパス・イノベーションセンター2階，多目的室4

ナノ流体を用いた熱流動特性について

鳥居　修一
熊本大学大学院自然科学研究科
産業創造工学専攻　先端機械システム講座
Tel&FAx: 096-342-3756
E-mail: torii@mech.kumamoto-u.ac.jp
http://www.mech.kumamotou.ac.jp/Info/lab/heat/torii/toriiindex.html
http://www.gsst.kumamotou.ac.jp/kenkyu/pdf/sangyo/sentan/torii.pdf

Kumamoto University



内　容

- 研究の背景
- 既存の研究成果の紹介
- 研究の目的
- 実験装置
- 結果と考察（圧力損失、熱伝導率、熱伝達係数）
- まとめ

研究背景

伝熱性能の向上：　機器の小型化

↓

伝熱性能の向上のための方法：
作動媒体への<u>微粒子の混合</u>

粒径がミリ･マイクロオーダーの粒子：
- 懸濁液の安定性不足
- 流路のつまりや侵食
- 圧力損失

研究背景

ナノ技術の進歩：
ナノオーダーの粒子が安価に製造可能

作動媒体にナノオーダーの粒子を混合した，新しい作動媒体が開発：　「ナノ流体」

Choi, U. S., 1995
"Enhancing Thermal Conductivity of Fluids with Nanoparticles", FED-Vol. 231/MD-Vol. 66, pp. 99-105, 1995,
The 1995 ASME International Mechanical Engineering Congress &Exposition, San Francisco, Nov. 12-17, 1995.

ミリ･マイクロ流体と比較

- 伝熱面積の増加
- 流路のつまりや侵食がない
- 安定性の増加

既存の研究成果

- **Lee and Choi:**
  Performance of microchannel heat exchangers with water, liquid nitrogen and nanofluids as the working fluid.
- **Pak and Cho:**
  Convective heat transfer in the turbulent flow regime using the mixing fluids of water-Al_2O_3 and water-TiO_2.
- **Xuan and Roetzel**:
  Effects of transport properties of the nanofluid.
- **Xuan and Li** :
  Convective heat transfer of water-Cu nanofluids.
- **Wen and Ding :**
  Convective heat transfer of nanofluids made of water and g-Al_2O_3 nanoparticles in the laminar flow region.

Enhancement of convective heat transfer is attributed to a non-uniform distribution of thermal conductivity and viscosity field and an attenuation of the thermal boundary layer thickness.

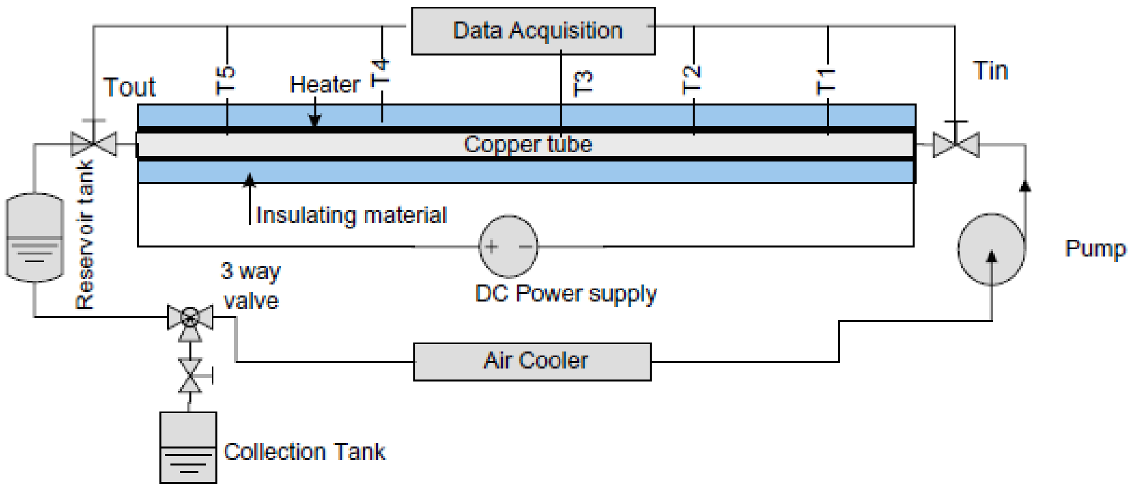
- **Ding et al.** :
  Heat transfer behavior of aqueous suspensions of multi-walled carbon nanotubes(CNT) in the laminar tube flow.

Enhancement of the convective heat transfer is ascribed to particle re-arrangement, shear induced thermal conduction enhancement, reduction of thermal boundary layer thickness, and the higher aspect ratio of CNTs.

Experimental investigation into convective heat transfer of nanofluids at the entrance region under laminar flow conditions

Dongsheng Wen, Yulong Ding

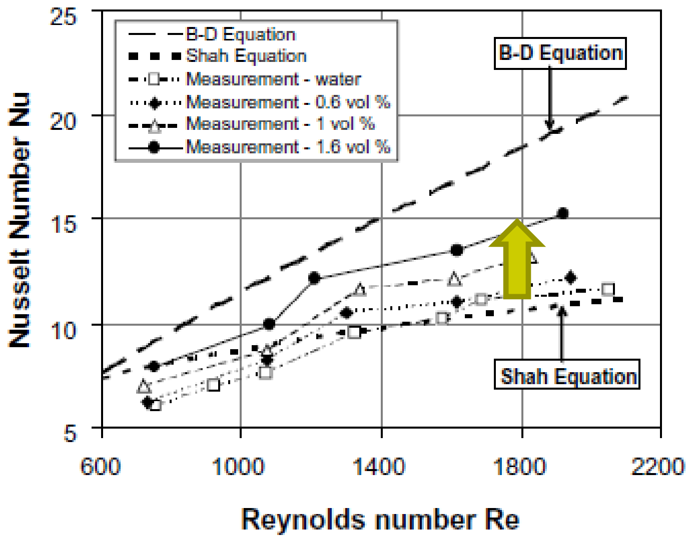
International Journal of Heat and Mass Transfer 47 (2004) 5181–5188



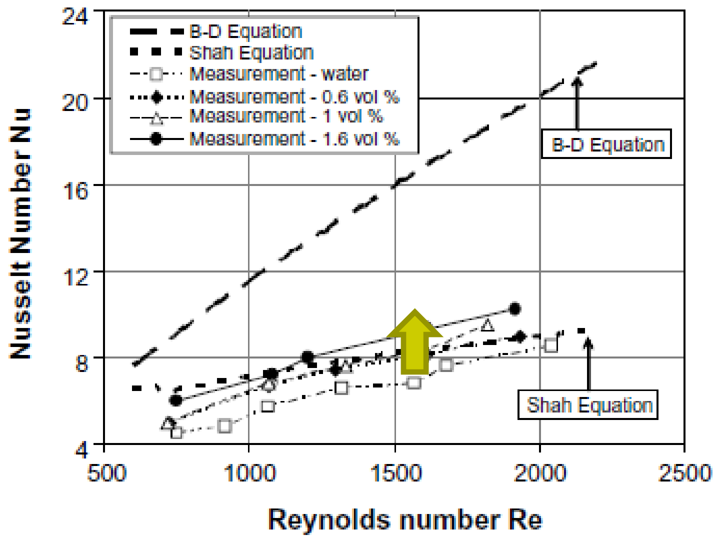
Experimental System

Laminar Flow Region
>Shah Equation

Turbulent Flow Region
>Dittus–Boelter equation
(B-D Equation)

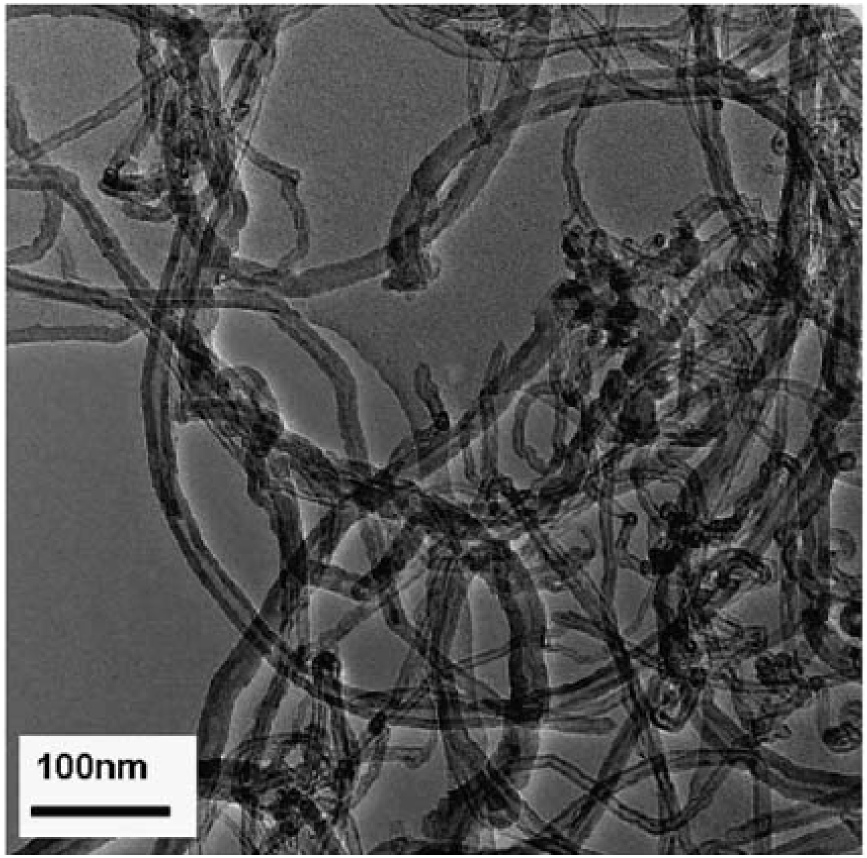


x/D=63

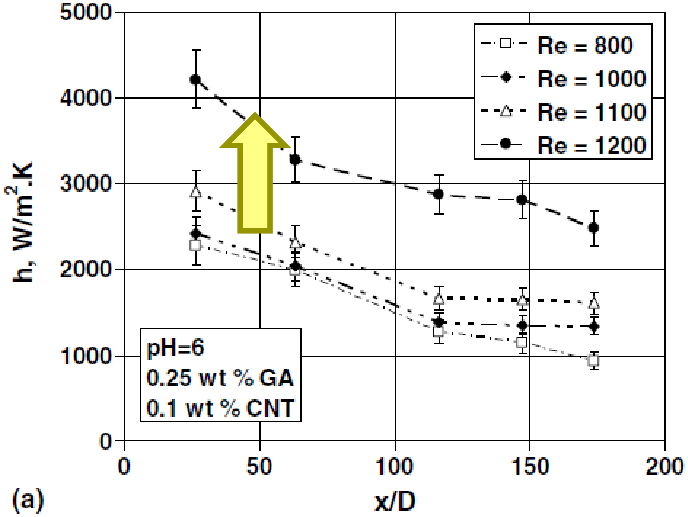


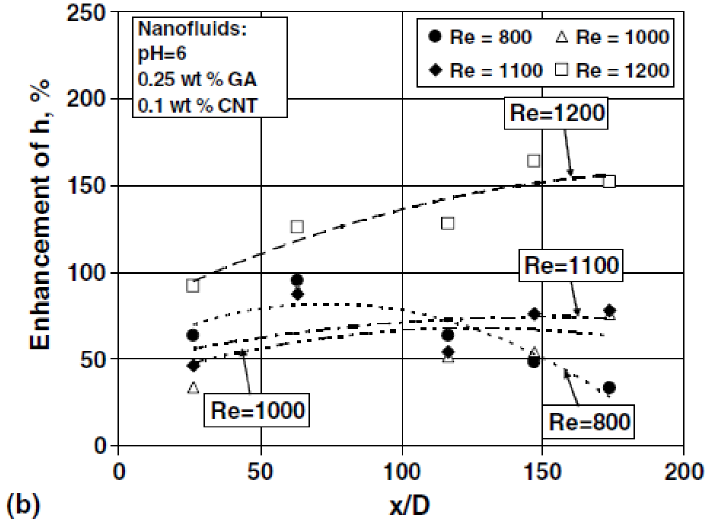
x/D=116

Heat transfer of aqueous suspensions of carbon nanotubes (CNT nanofluids)
Yulong Ding *, Hajar Alias, Dongsheng Wen, Richard A. Williams
International Journal of Heat and Mass Transfer 49 (2006) 240–250



TEM image of carbon nanotubes.





Effect of Reynolds number on the convective heat transfer coefficient (a) and heat transfer enhancement (b) for 0.1 wt.% CNT at pH = 6.

Heat transfer and flow behaviour of aqueous suspensions of TiO2 nanoparticles (nanofluids) flowing upward through a vertical pipe

Yurong He a, Yi Jin b, Haisheng Chen c, Yulong Ding a,*, Daqiang Cang b, Huilin Lu d

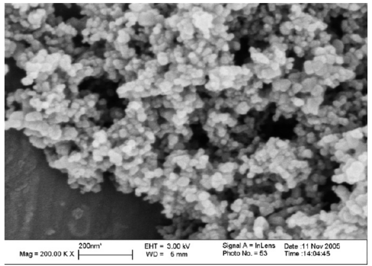
International Journal of Heat and Mass Transfer 50 (2007) 2272–2281

Shah equation for laminar flows:

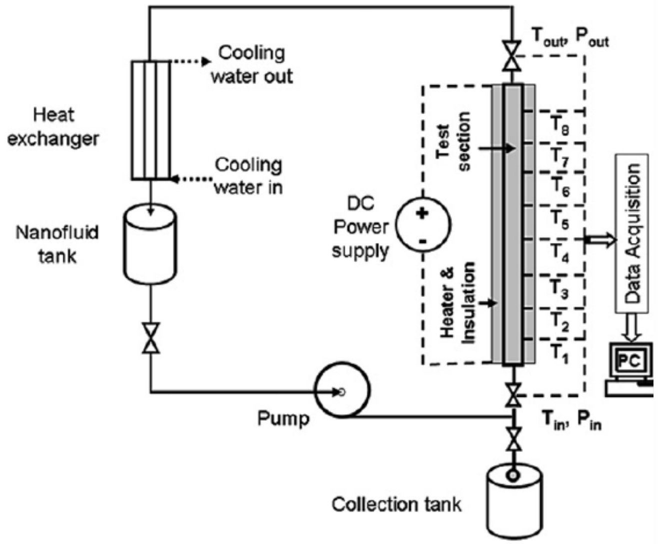
$$Nu = \begin{cases} 1.953\left(RePr\frac{D}{x}\right)^{1/3} & \left(RePr\frac{D}{x}\right) \geqslant 33.3 \\ 4.364 + 0.0722RePr\frac{D}{x} & \left(RePr\frac{D}{x}\right) < 33.3 \end{cases}$$

Gnielinski equation for turbulent flows:

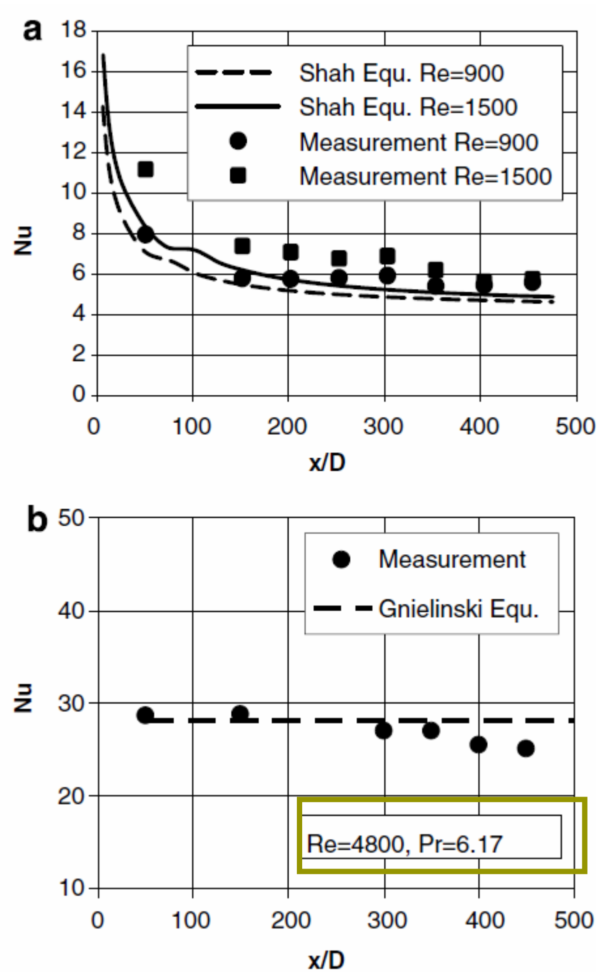
$$Nu = \frac{(f/2)(Re - 10^3)Pr}{1 + 12.7(f/2)^{1/2}(Pr^{2/3} - 1)}$$



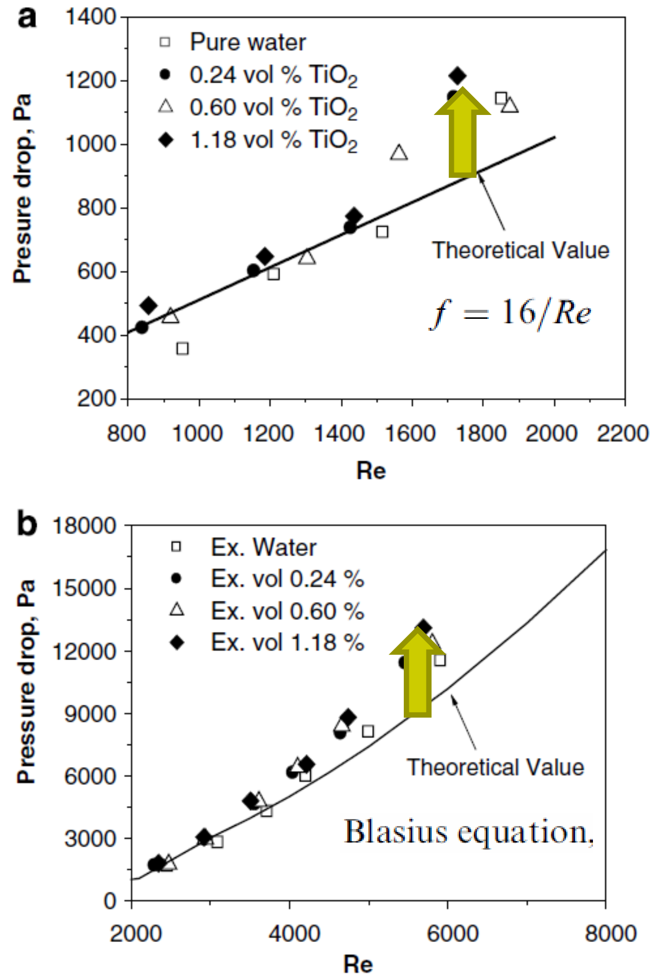
An SEM micrograph of the TiO2 nanoparticles (20nm)



Experimental System



Comparison of the measurements with the empirical Shah and Gnielinski equations for pure water flows.

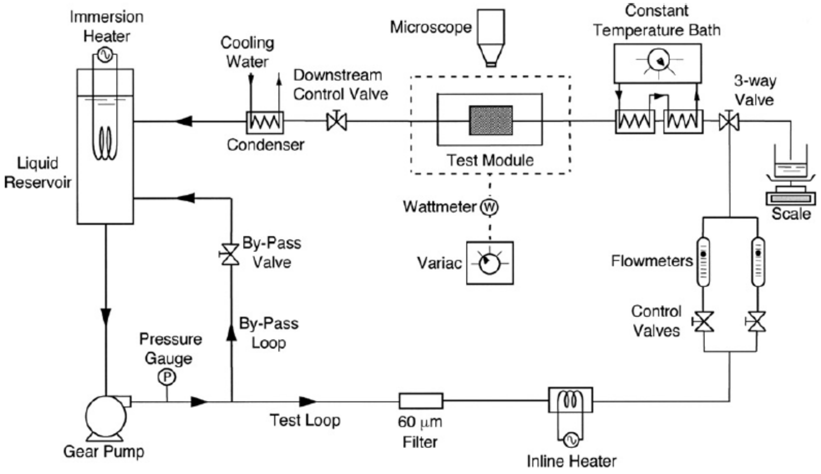


Pressure drop as a function of Reynolds number (95 nm nanoparticles)

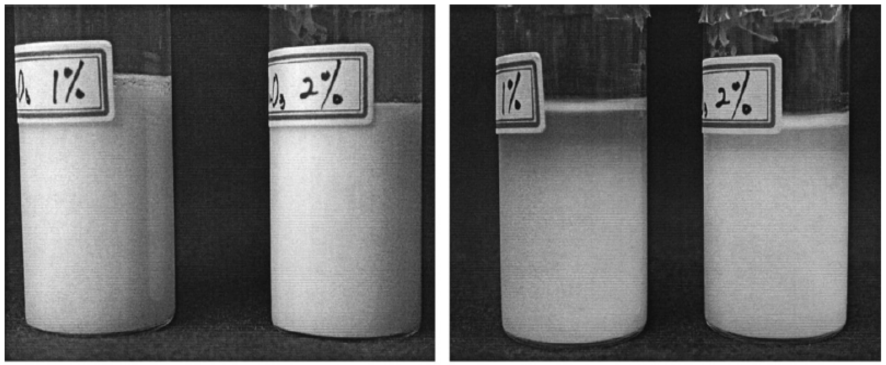
Assessment of the effectiveness of nanofluids for single-phase and two-phase heat transfer in micro-channels

Jaeseon Lee, Issam Mudawar

International Journal of Heat and Mass Transfer 50 (2007) 452–463

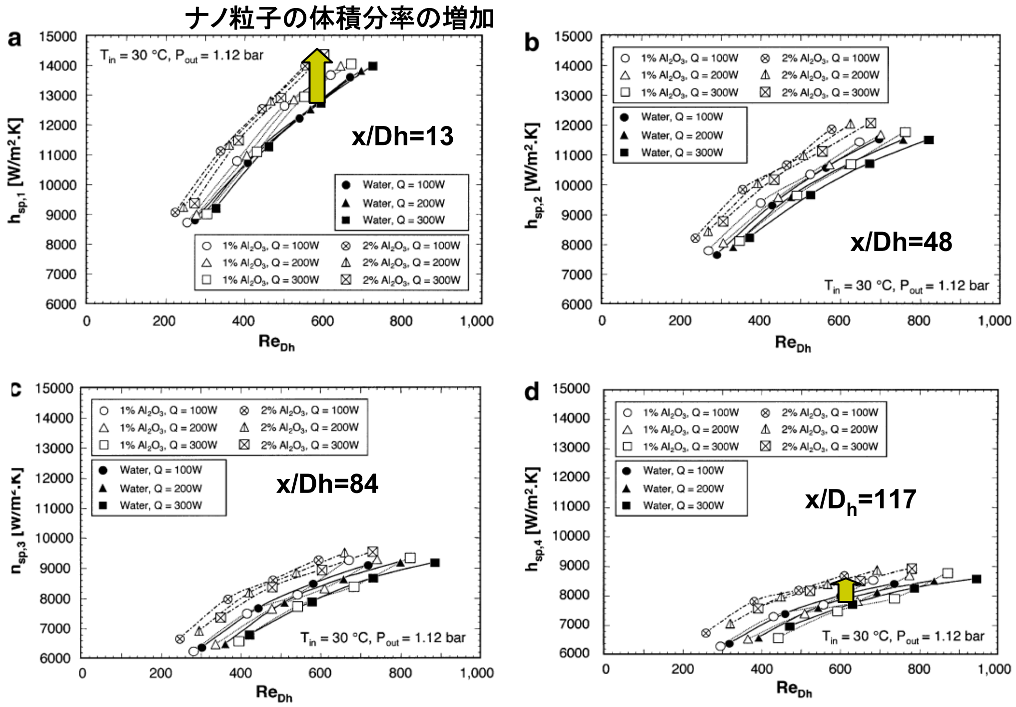


Experimental Loop



Initial After 30 days

Nanofluid settling over 30-day period.



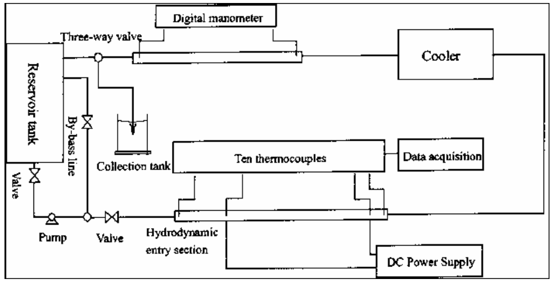
Variation of heat transfer coefficient with Reynolds number for different heat inputs and different Al2O3 concentrations

Investigation on Convective HeatTransfer and Flow Features of Nanofluids

Yimin Xuan, Qiang Li

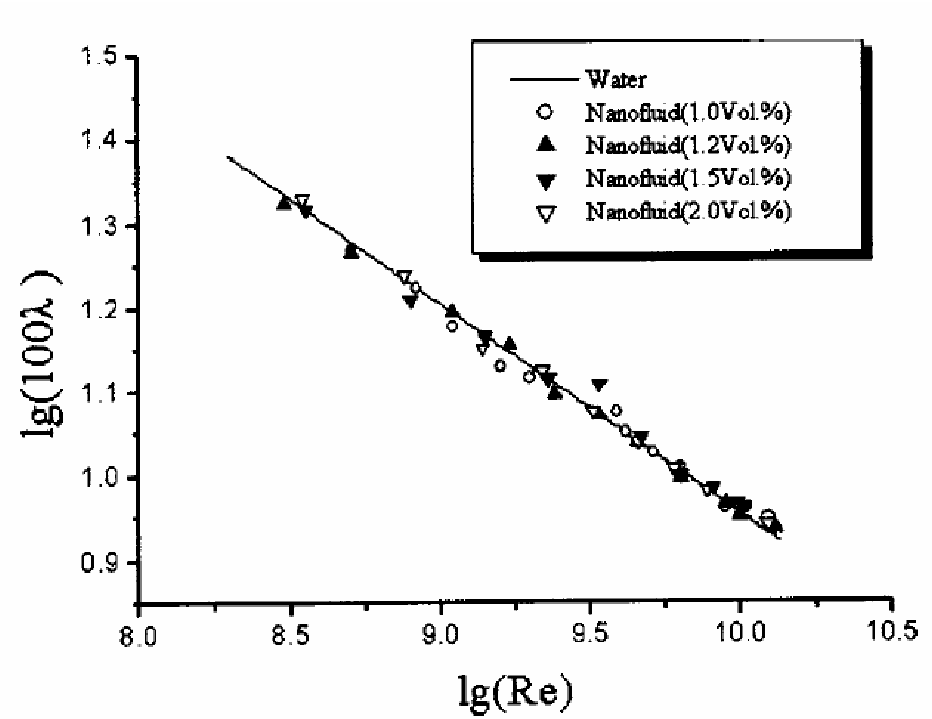
ASME Journal of Heat Transfer

Cu particles below 100 nm diameter



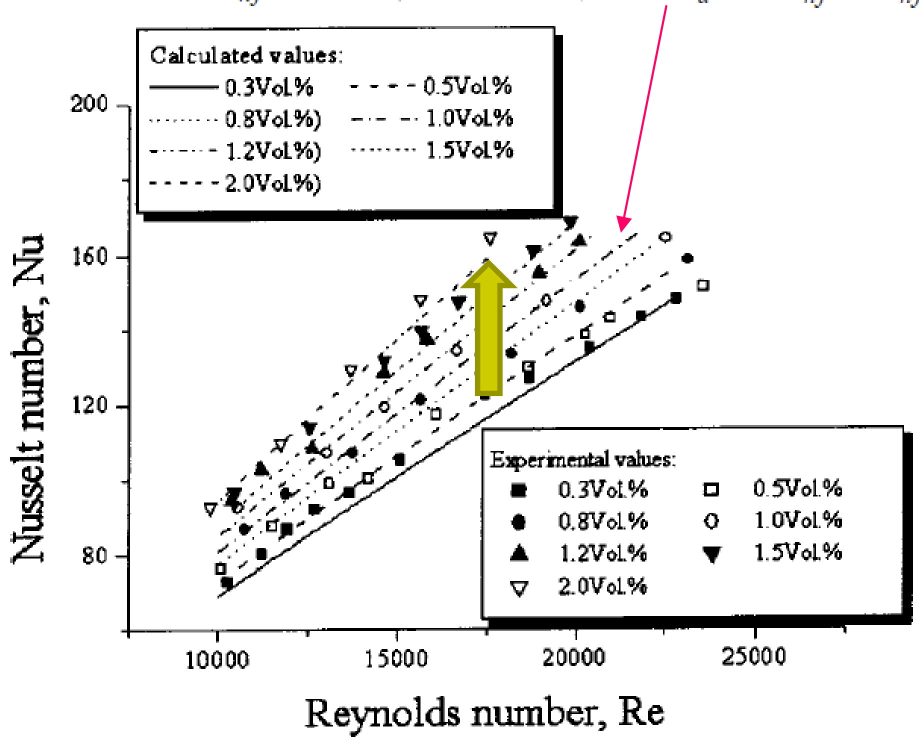
Experimental System

$$\lambda_{nf} = \frac{P_{nf} D}{L} \frac{2g}{u_m^2}$$



The friction factors of nanofluids for the turbulent flow

$$Nu_{nf} = 0.0059(1.0 + 7.6286\phi^{0.6886} Pe_d^{0.001}) Re_{nf}^{0.9238} Pr_{nf}^{0.4}$$

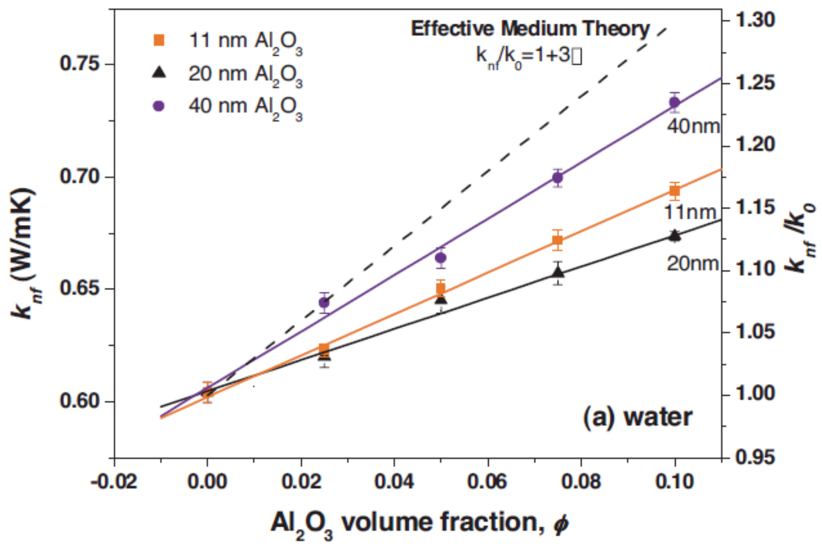


The Nusselt numbers of nanofluids with the Reynolds numbers and the predicated values from the Dittus-Boelter correlation

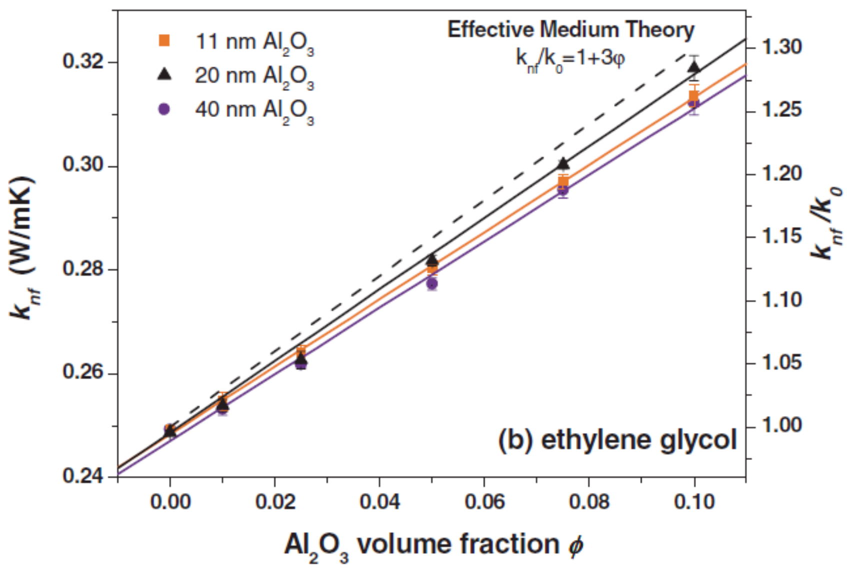
Thermal conductivity and particle agglomeration in alumina nanofluids: Experiment and theory
Elena V. Timofeeva, Alexei N. Gavrilov, James M. McCloskey, and Yuriy V. Tolmachev*
Department of Chemistry, Kent State University, Kent, Ohio 44242, USA
PHYSICAL REVIEW E 76, 061203 , 2007

$$\frac{k_{\mathrm{nf}}}{k_0} = 1 + 3\phi.$$

X. Q. Wang and A. S. Mujumdar, Int. J. Therm. Sci. 46, 1, 2007..



Water

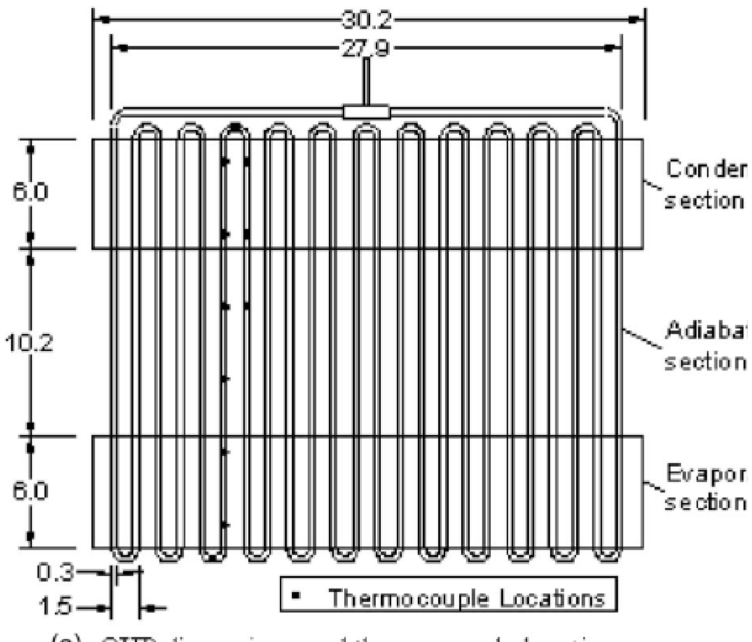


Ethylene Glycol

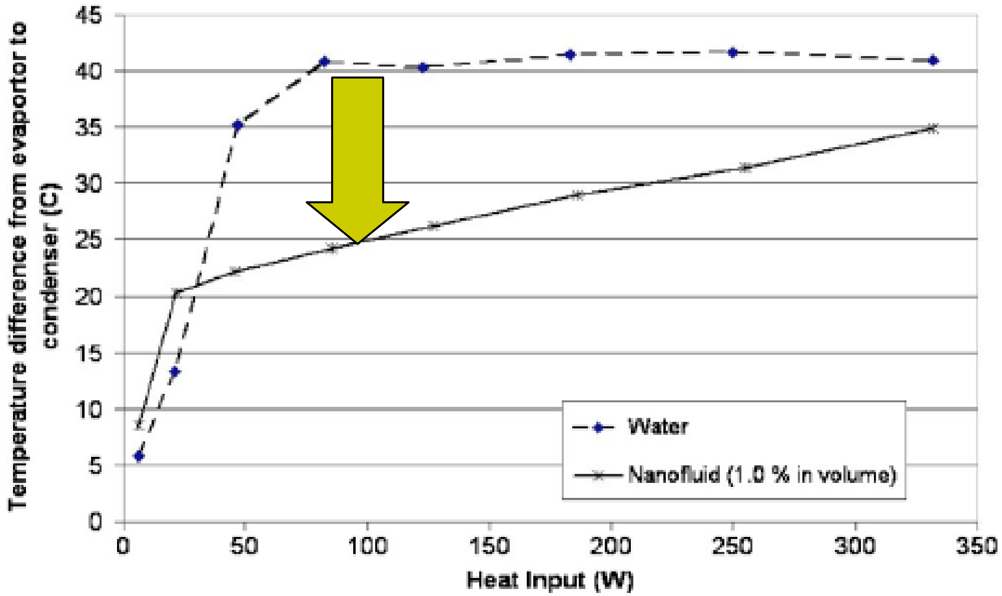
Thermal conductivity at 23 ° C of suspensions prepared from alumina nanoparticles

Effect of nanofluid on the heat transport capability in an oscillating heat pipe
H. B. Ma,a┌ C. Wilson, B. Borgmeyer, K. Park, and Q. Yu
University of Missouri—Columbia, Columbia, Missouri 65211
S. U. S. Choi
Argonne National Laboratory, Argonne, Illinois 60439

APPLIED PHYSICS LETTERS 88, 143116, 2006

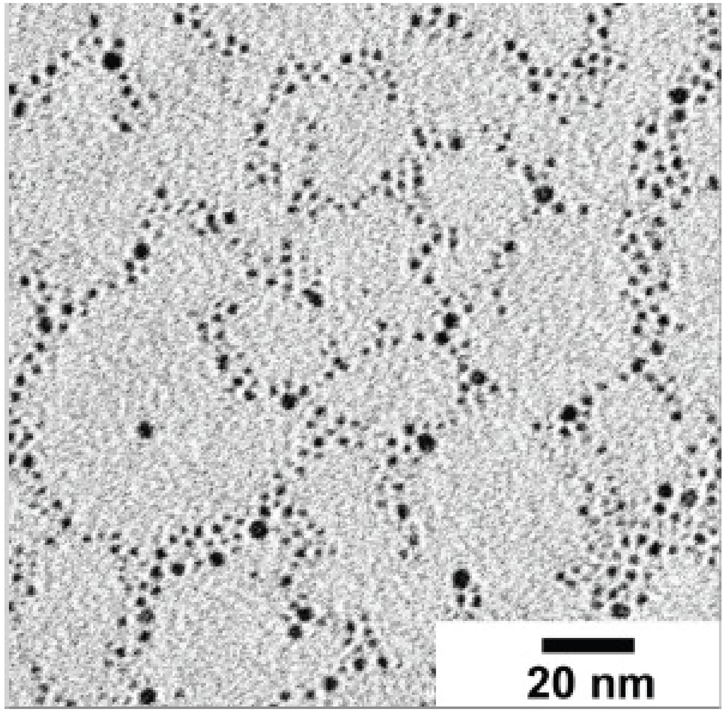


(a) OHP dimensions and thermocouple locations



Steve Choi
Energy Systems Division
Argonne National Laboratory

The thermal conductivity enhancement of the nanoparticle-water increases with both nanoparticle concentration and temperature.



TEM micrograph of 2 nm gold nanoparticles

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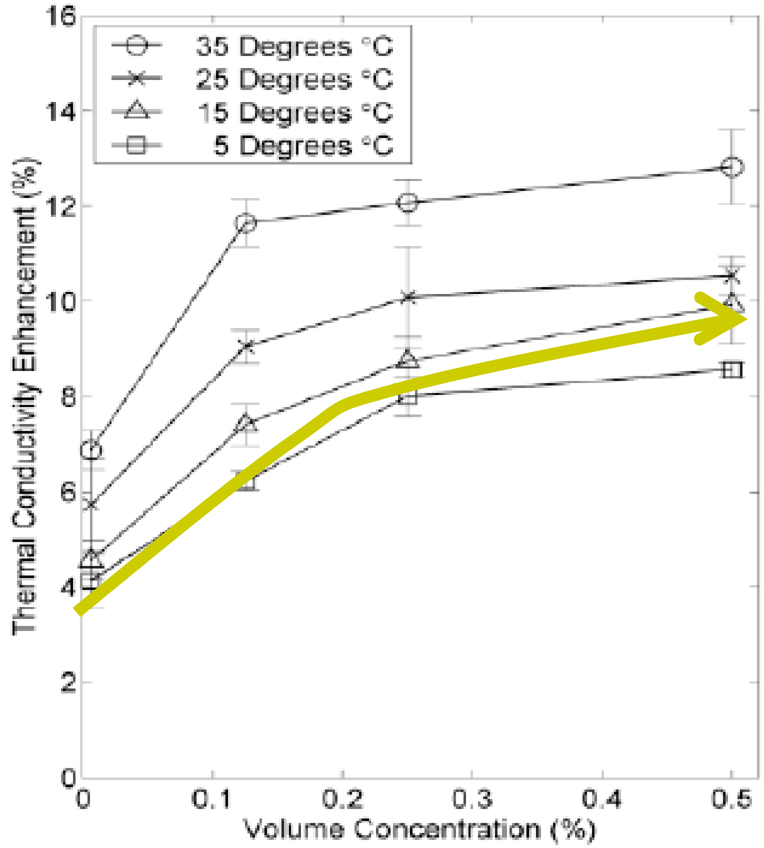
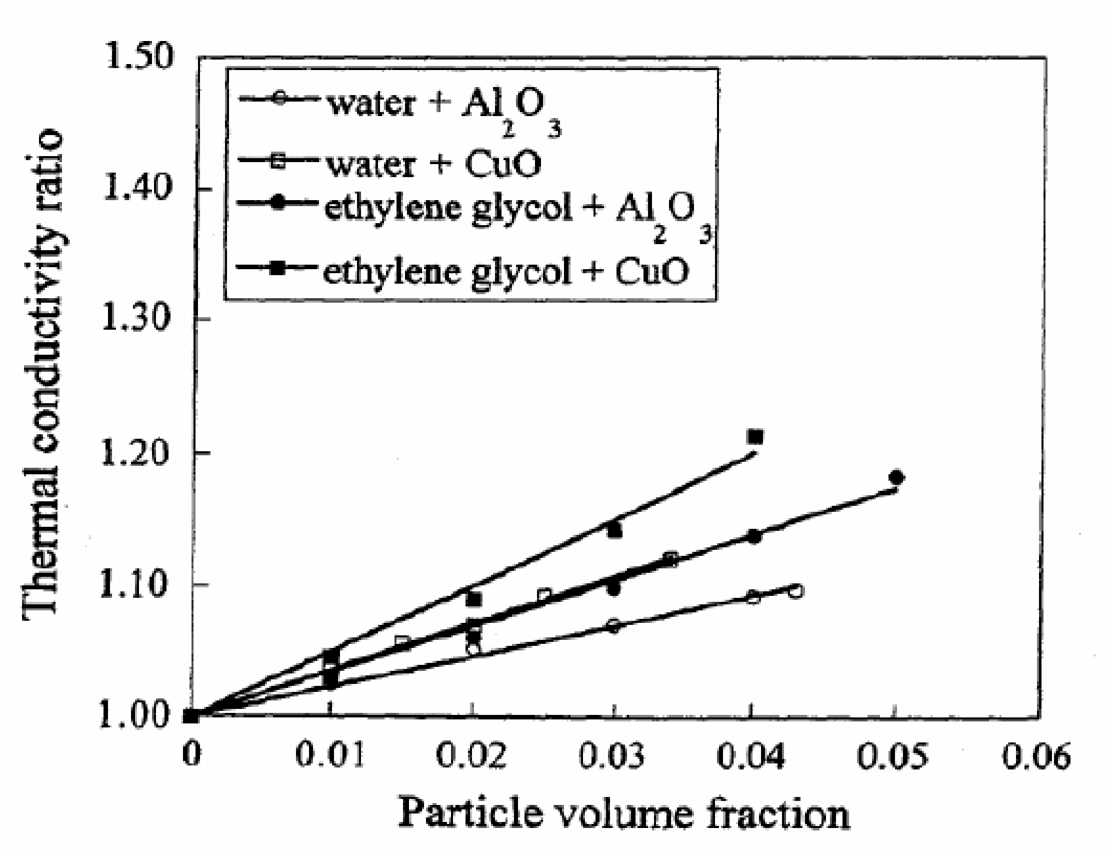
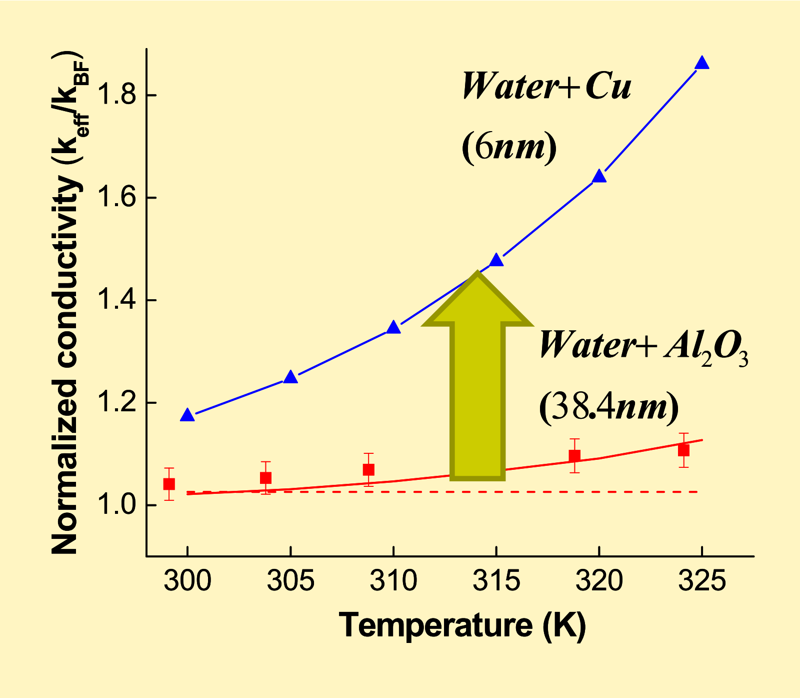


Thermal conductivity enhancement of 2nm gold nanoparticle in water

Choi. Stephen,
"Nanofluid Technology: Current Status and Future Research"
theSecond Korean-American Scientists and Engineers Association Research Trend Study,Vienna, 1998



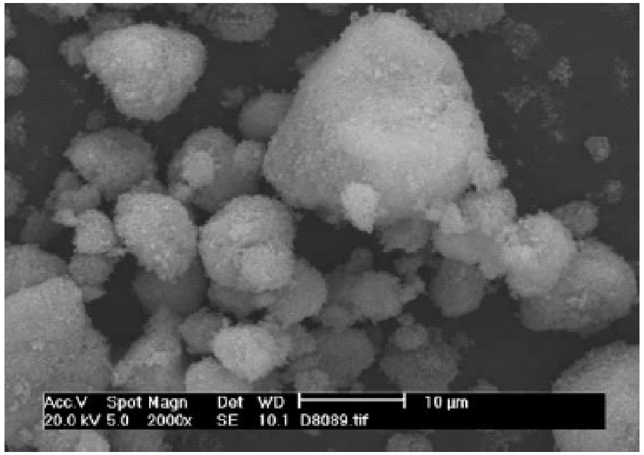
Prof. M. Kostic
Mechanical Engineering
NORTHERN ILLINOIS UNIVERSITY



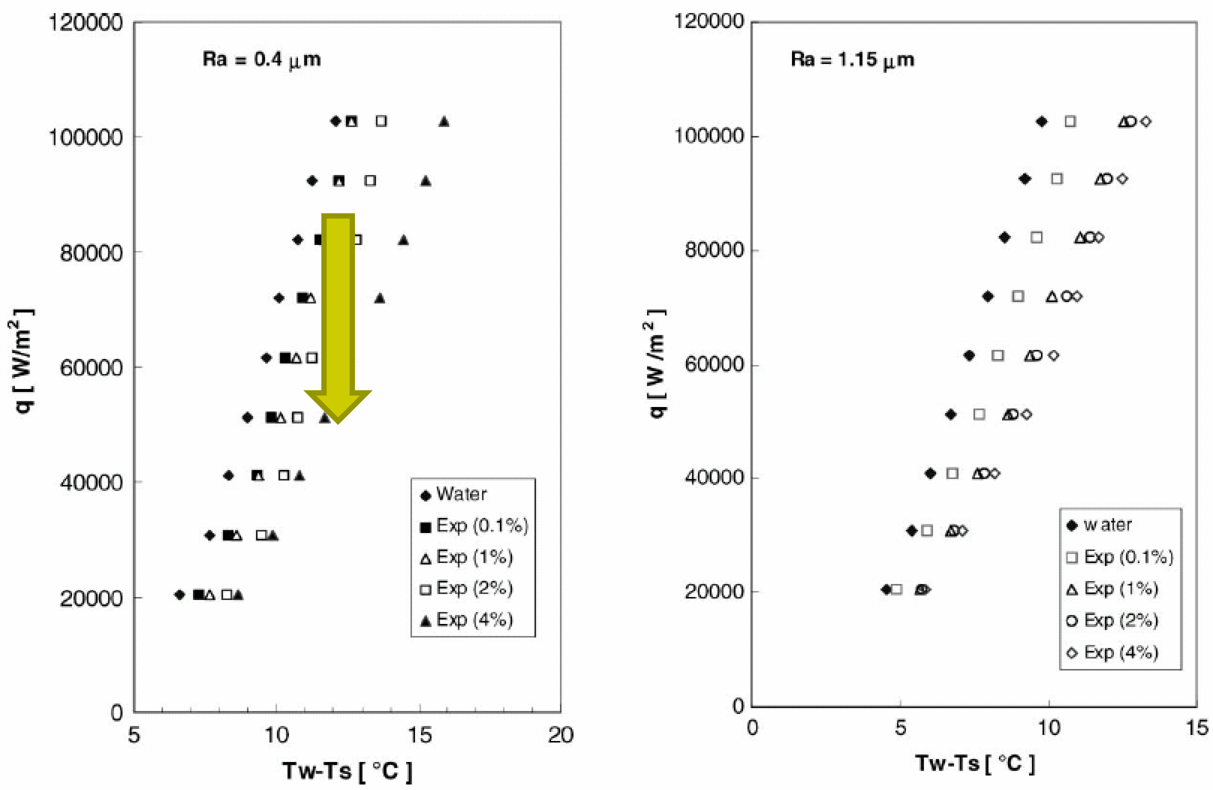
Temperature-dependent thermal conductivities of nanofluids at a fixed concentration of 1 vol.%, normalized to the thermal conductivity of the base fluid.

- **A new model that accounts for the Brownian motion of nanoparticles in nanofluids captures the concentration and temperature-dependent conductivity.**
- **In contrast, conventional theories with motionless nanoparticles fail to predict this behaviour (horizontal dashed line).**
- **The model predicts that water-based nanofluids containing 6-nm Cu nanoparticles (curve with triangles) are much more temperature sensitive than those containing 38-nm Al_2O_3 particles, with an increase in conductivity of nearly a factor of two at 325 K.**

Pool boiling characteristics of nano-fluids
Sarit K. Das a, Nandy Putra b, Wilfried Roetzel
International Journal of Heat and Mass Transfer 46 (2003) 851–862



TEM of agglomerated nano-aluminium oxide powder.



Pool boiling characteristic of nano-fluids

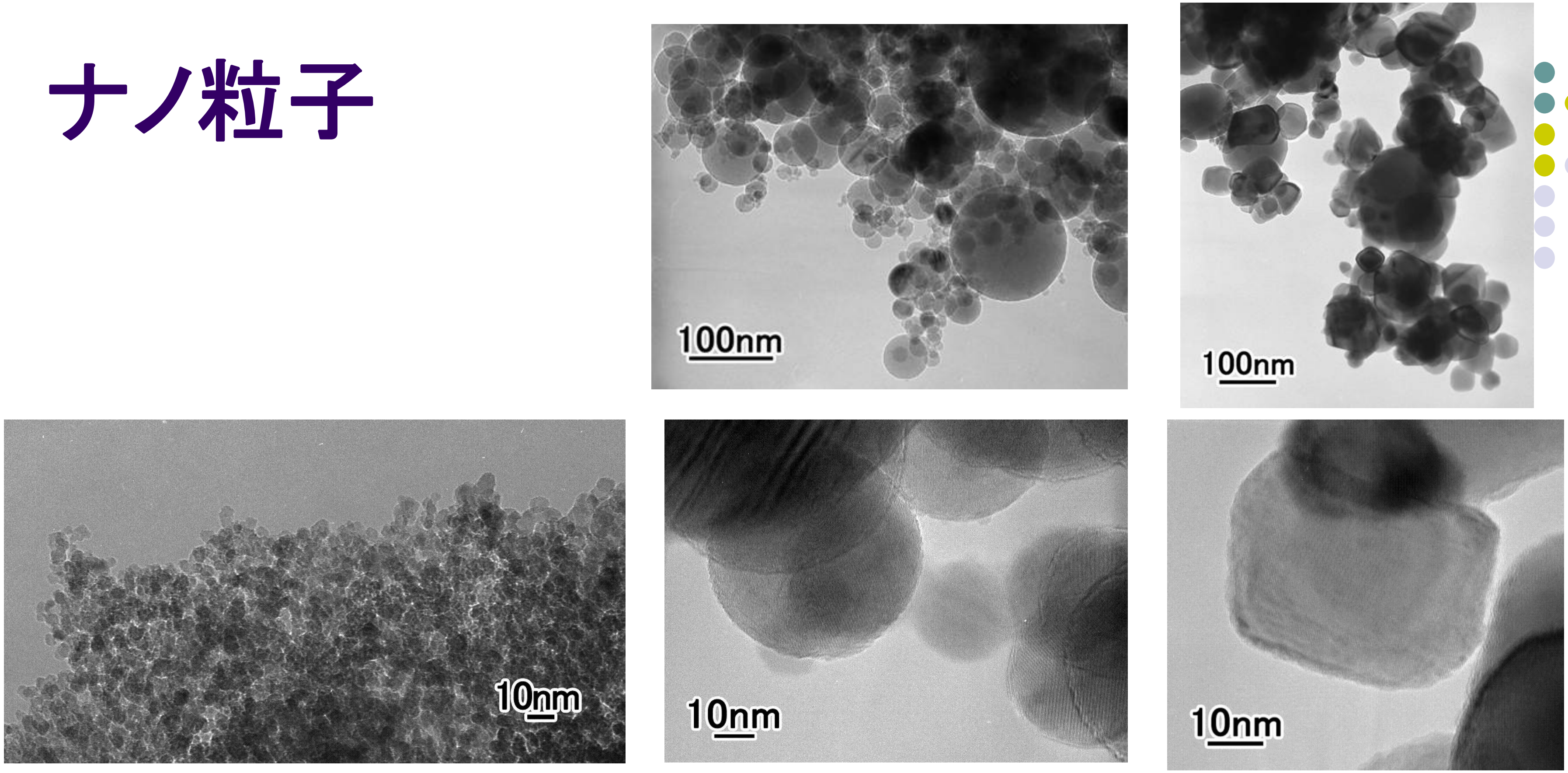
研究目的

作動媒体： ナノ流体（ダイヤモンド，Al_2O_3，CuO）

乱流領域における

- 粘度
- 圧力損失
- 伝熱性能

ナノ粒子



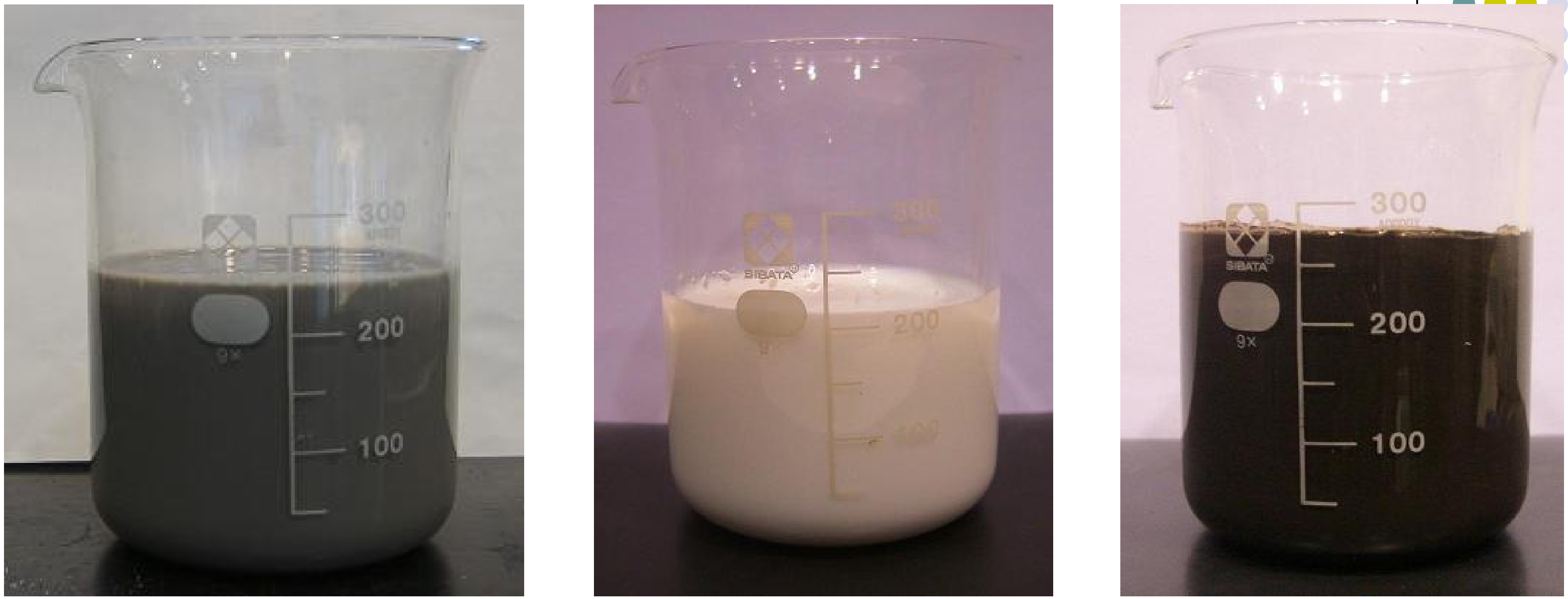
(a) Diamond (b) Al_2O_3 (c) CuO

TEM image of nanoparticles

Table Physical property of nanoparticles

Nanoparticle	Particle diameter [nm]	Thermal conductivity [W/mk]	Particle shape
Diamond	2~10	2000	Sphere
Al_2O_3	33	36	Sphere
CuO	47	20	Polyhedron

ナノ流体

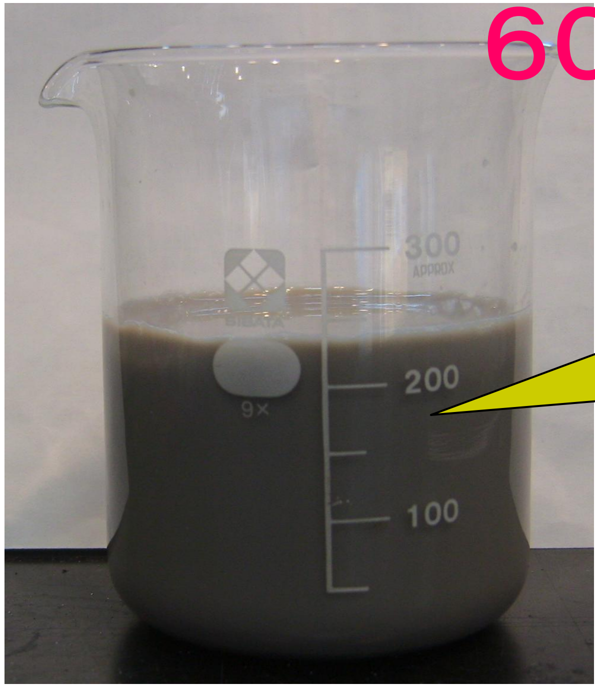


(a) Diamond (b) Al_2O_3 (c) CuO

Photographs of nanofluids

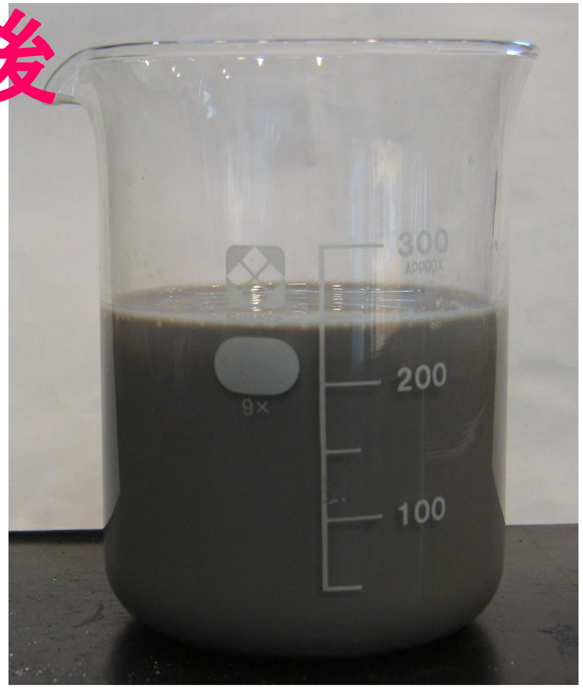
体積分率：1%

60日経過後

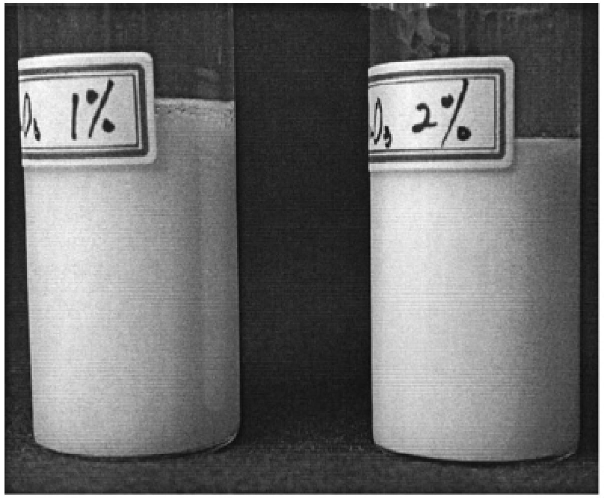


•Water
•Nanodiamonod(10nm)

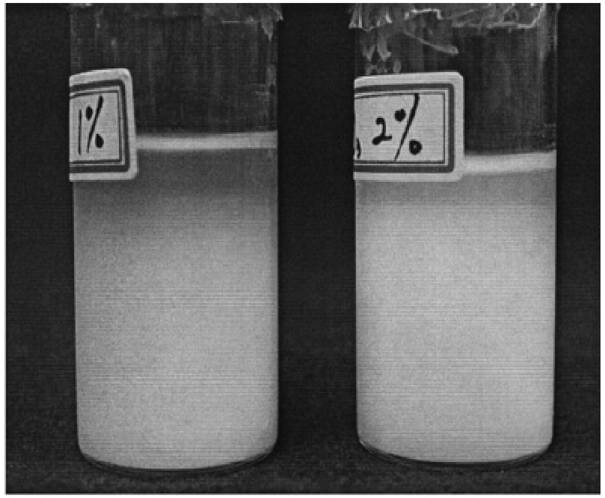
(a) 0.4 % and pH=6.62



(b) 1.0 % and pH=6.35



Initial



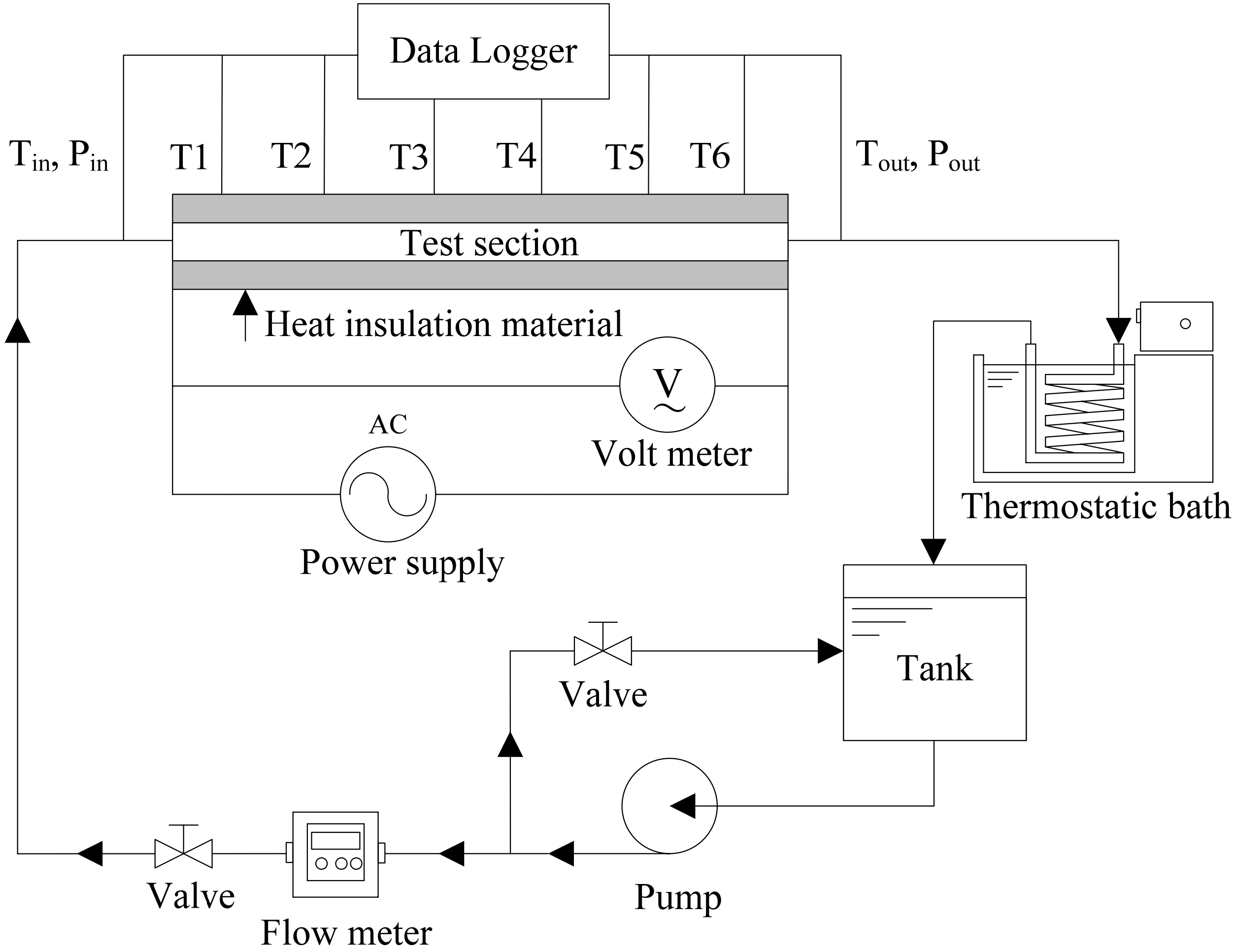
After 30 days

Nanofluid settling over 30-day period.

Jaeseon Lee, Issam Mudawar

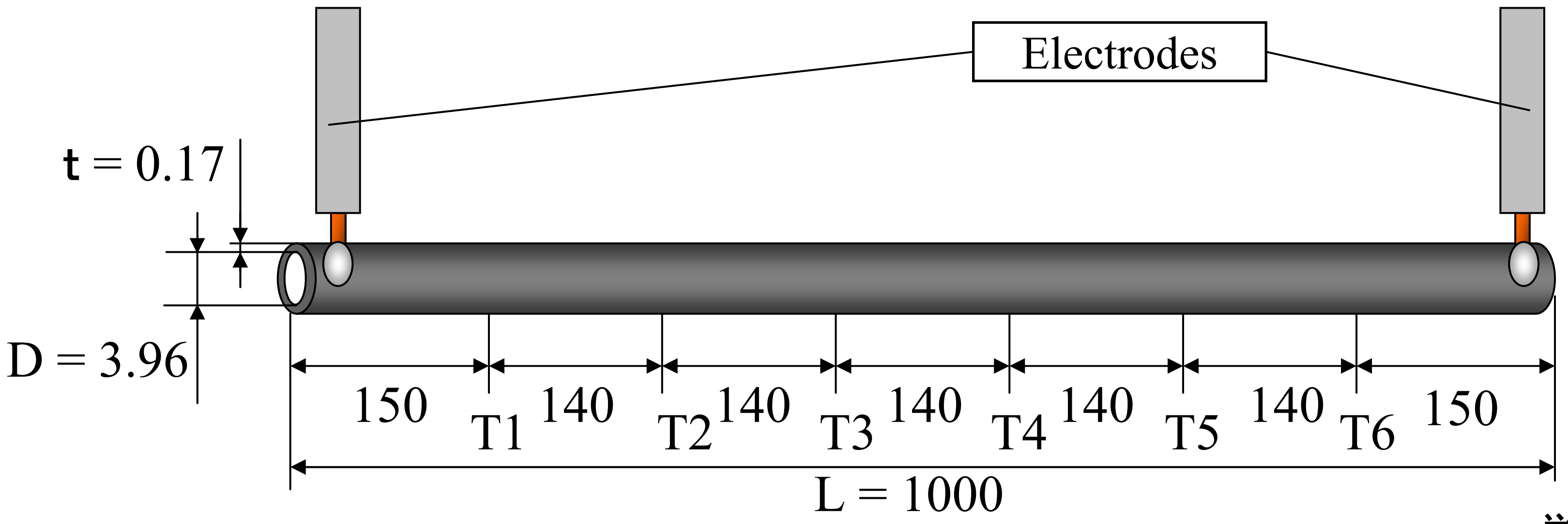
International Journal of Heat and Mass Transfer 50 (2007)

実験装置



Experimental apparatus

加熱部



Test section

ステンレス管を使用

熱電対 : 等間隔に設置

直接通電によって流体を加熱

実験条件

Experimental conditions

Re	～ 8000
Power [W]	200, 235, 270, ・・・
Heating surface area [m^2]	1.24×10^{-2}
Cross-sectional area [m^2]	1.23×10^{-5}

流入温度：20^{o}C

加熱量：流入，流出温度の差が約5^{o}Cに設定

ナノ流体の熱伝導率

Hamilton, R.L. and Crosser, O.K.,
Thermal conductivity of heterogenenous two-component system
I&EC Fundamentals， 1(1962), 182-191.

Hamilton and crosserの式

$$k = k_f \left[\frac{k_s + (n-1)k_f - (n-1)V(k_f - k_s)}{k_s + (n-1)k_f + V(k_f - k_s)} \right]$$

Table Thermal conductivity of test materials

	Thermal conductivity coefficient k [W/m·K]
Water	0.589
Diamond	2000
Al_2O_3	36
CuO	20

理論熱伝導率

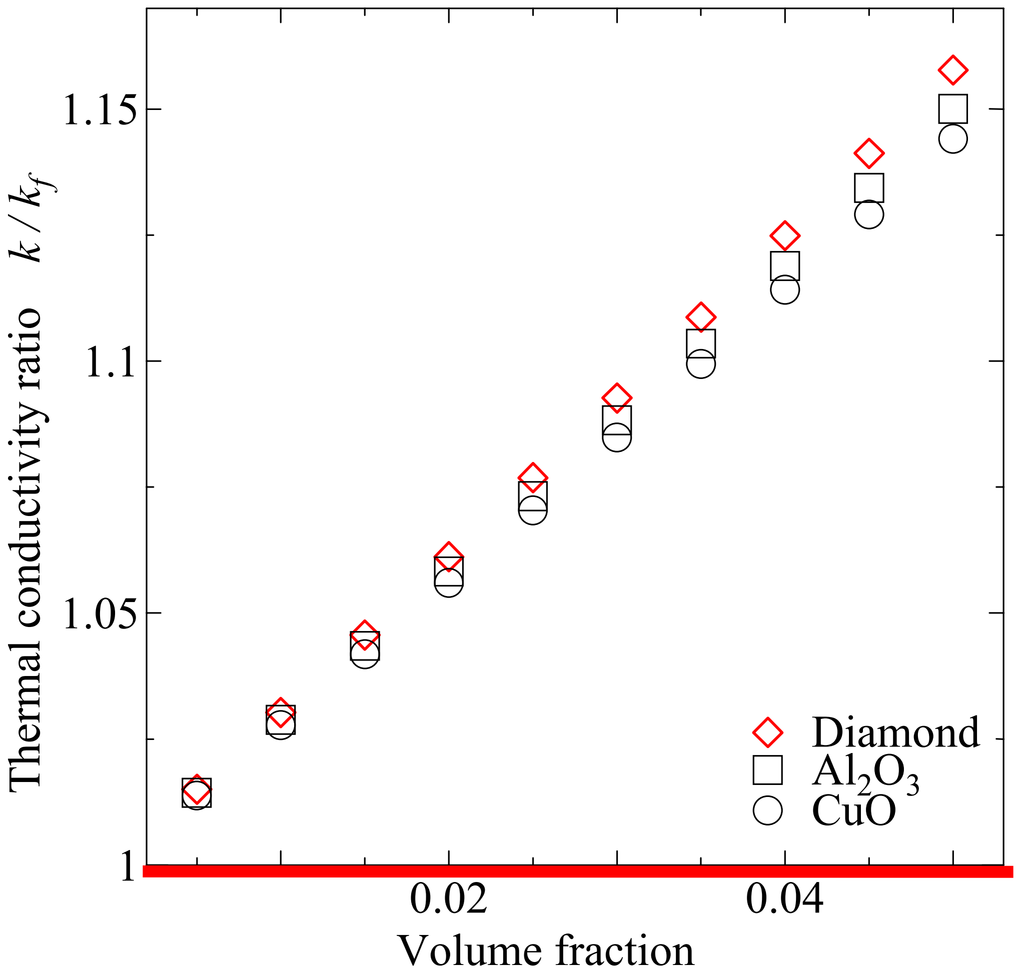


Fig. Thermal conductivity of nanofluids

体積分率5%において
ダイヤモンドナノ流体の
熱伝導率は約16%増加

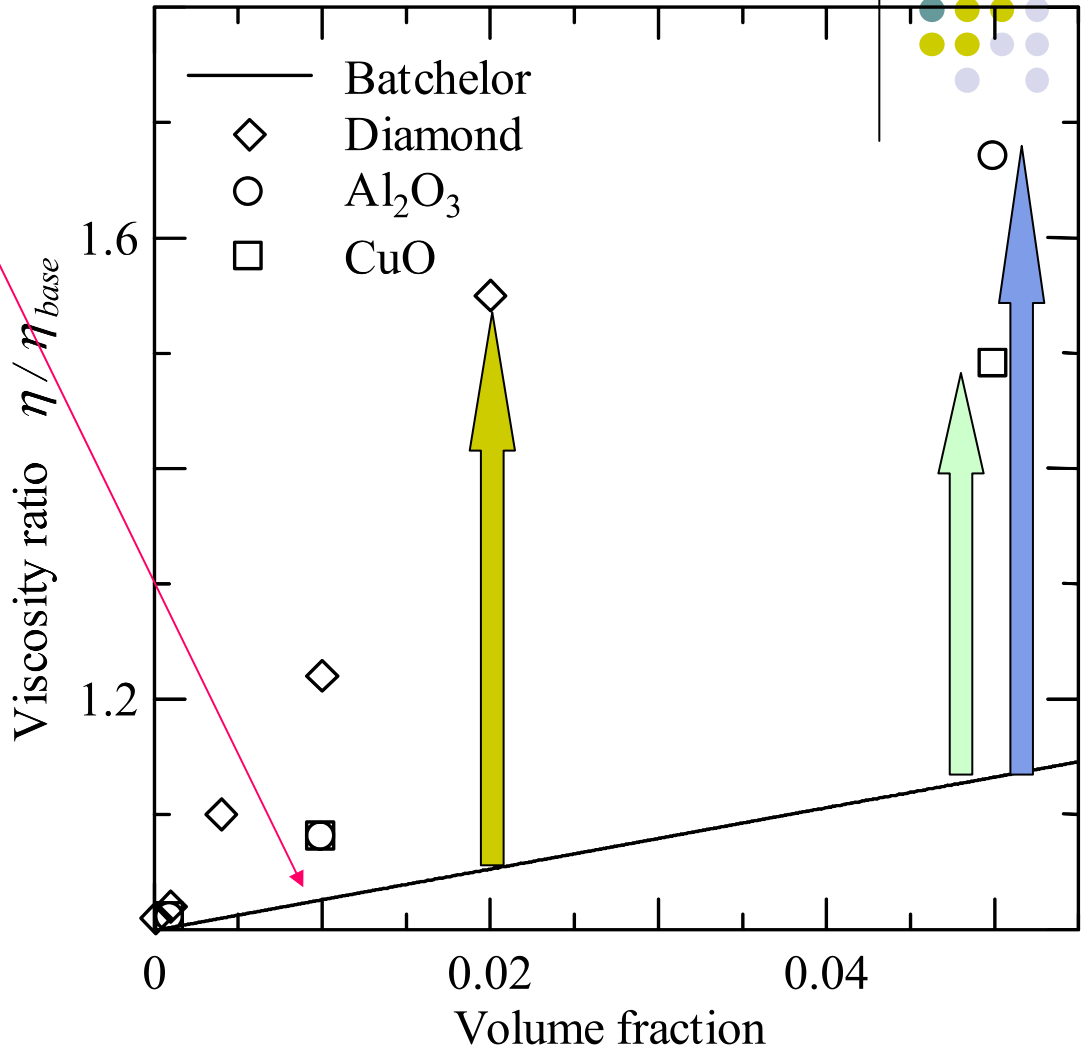
ダイヤモンドナノ流体の
熱伝導率が最も優れている

結果と考察 [粘度]

Batchelorの式

$$\eta / \eta_{base} = 6.2V^2 + 2.5V + 1$$

ウベローデ粘度計



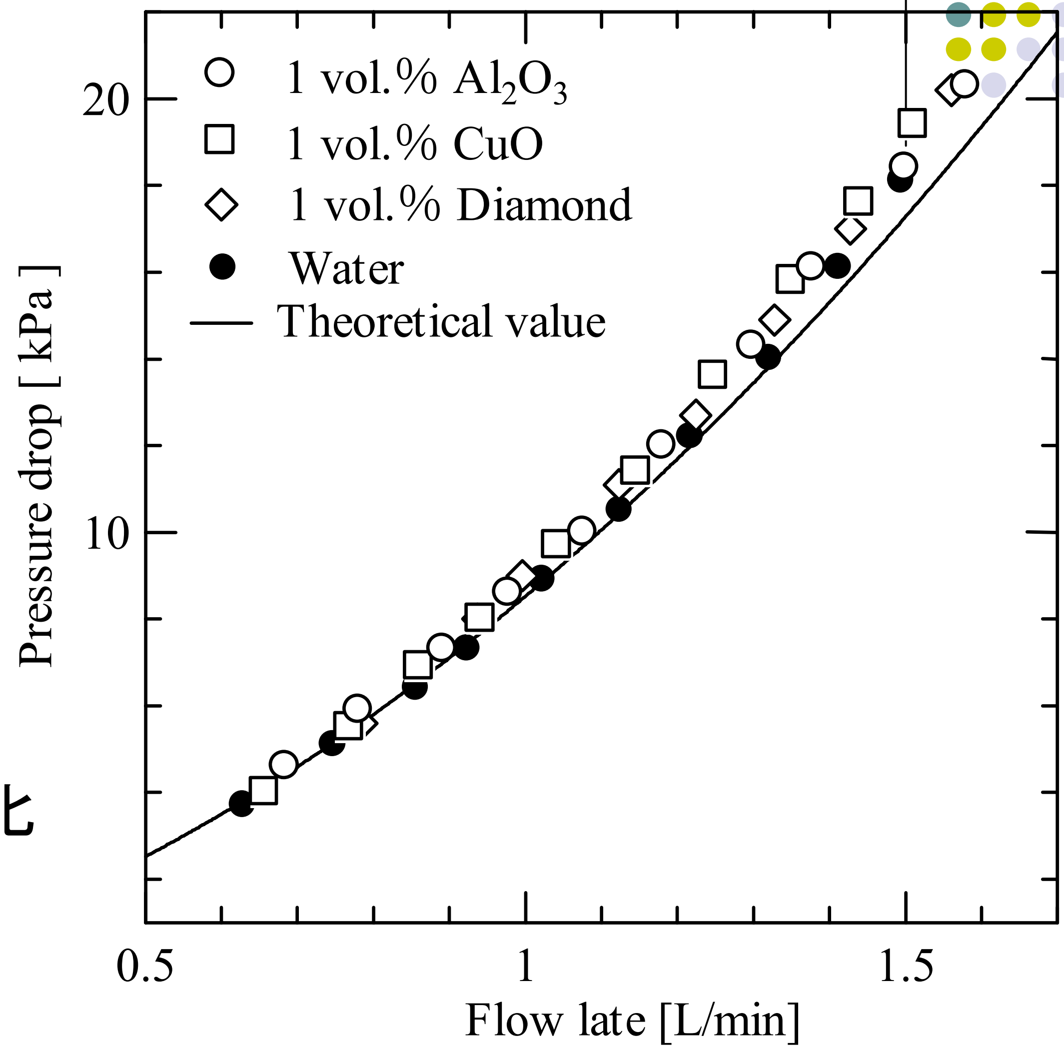
Comparison between experimental and theoretical values of viscosity at 20°C

結果と考察 [圧力損失]

計算式

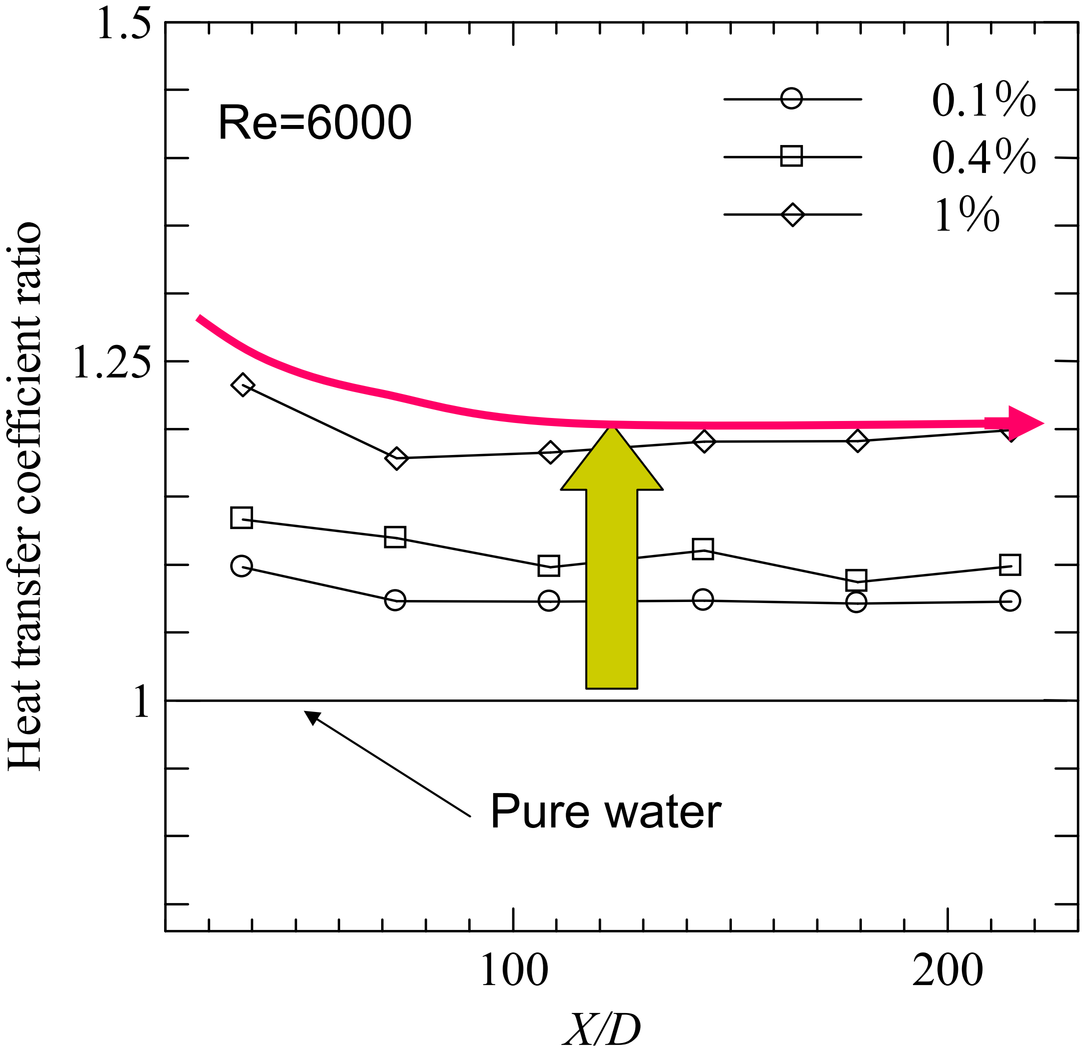
$$\Delta p = \lambda \frac{l}{d} \cdot \frac{v^2}{2g} \cdot \rho g$$

- ナノ流体の圧力損失
- ナノ流体の種類による変化



Pressure drops of water and nanofluids

軸方向の局所熱伝達係数



Streamwise variation of local heat transfer for different particle concentrations (Nano-diamond)

Enhancement of Heat Transfer

- Xuan and Li :
Turbulent flow regime.

- Wen and Ding :
The entrance region in the laminar flow regime.

結果と考察 [伝熱性能]

$$Nu = \frac{h\,D}{k}$$

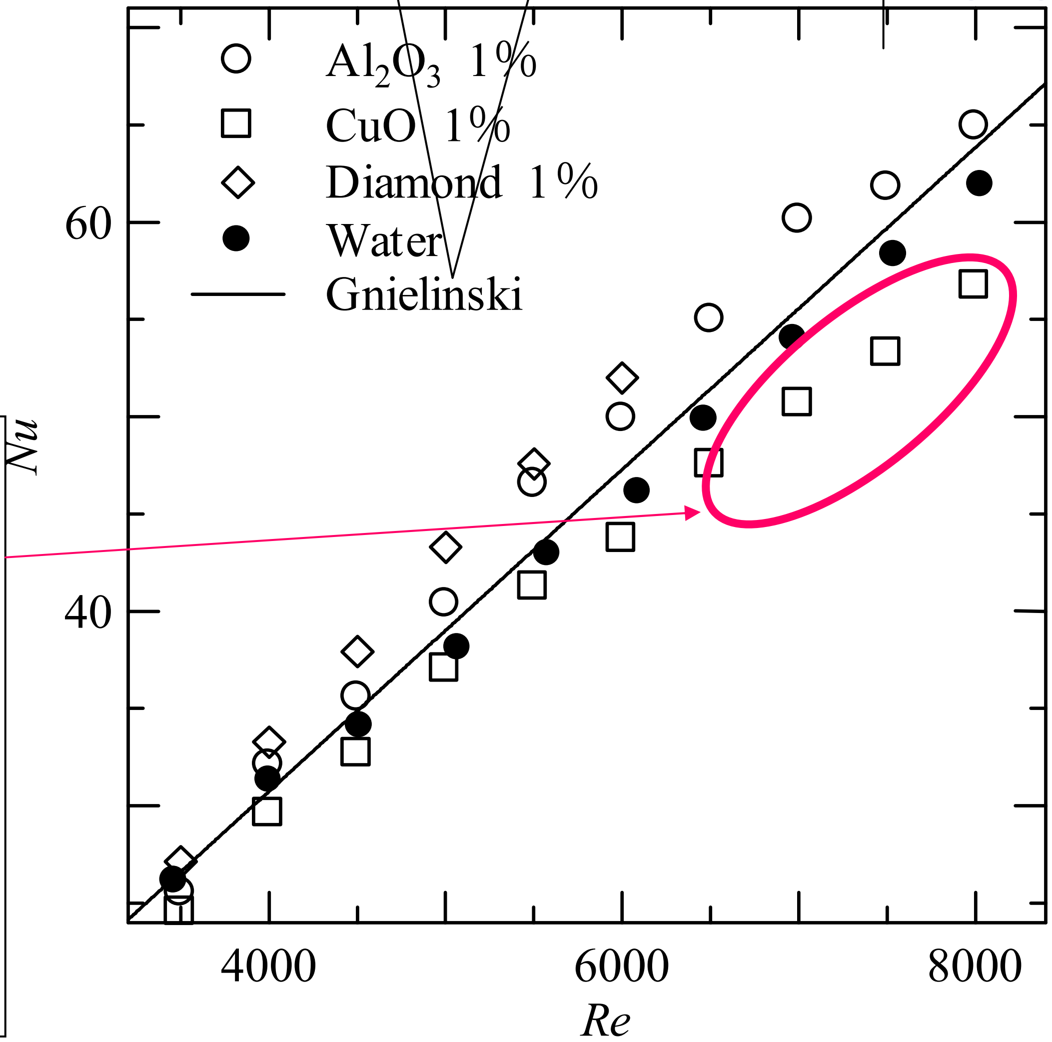
熱伝導率よりも熱伝達率の向上率の方が大きい

CuOナノ流体について
はNuが減少

粒子の凝縮が原因？

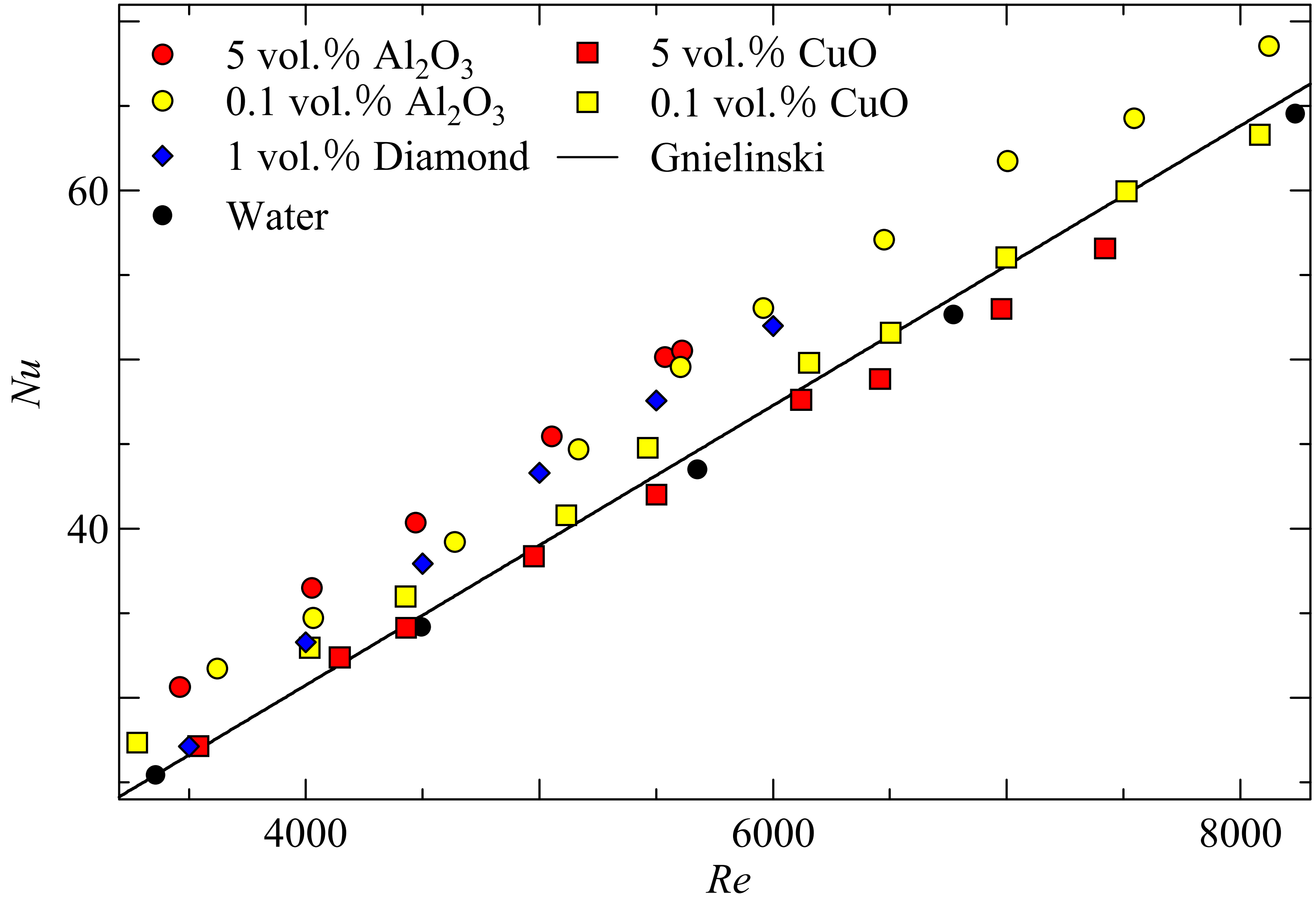
$$Nu = \frac{(f/8)(Re-1000)Pr}{1.07+12.7\sqrt{f/8}\left(Pr^{2/3}-1\right)}$$

$$f = \left[1.82\log_{10}(Re)-1.64\right]^{-2}$$



Nusselt numbers of water and nanofluids

現在実験中の結果



Nusselt numbers of water and nanofluids with different volume fractions

結言

①ナノ流体の粘度はBatchelorの式で算定することができない。

②圧力損失は単相流と比較して大きい。

③ナノ流体は単相流と比較して優れた伝熱性能を示した。ナノ流体によっては、単相流に比べて伝熱性能が低下する傾向が見られた。これに対しては更なる考察と研究は必要。

ご静聴ありがとうございました