UNIVERSITY OF TWENTE.

# Energy and heat transfer research at the UT (Thermal Engineering)

Theo van der Meer

# Research lines in Thermal Engineering

Fuel conversion processes

7 PhD's, 3 PD

Brem/Bramer/Pozarlik

Gas technology

Wolters

Clean energy

Sustainable energy

(focal area of Twente University)

V.d.Meer/Kok/Stoffels/Pozarlik

7 PhD's, 1 PD

Turbulent combustion and thermo-acoustics

3 PhD's

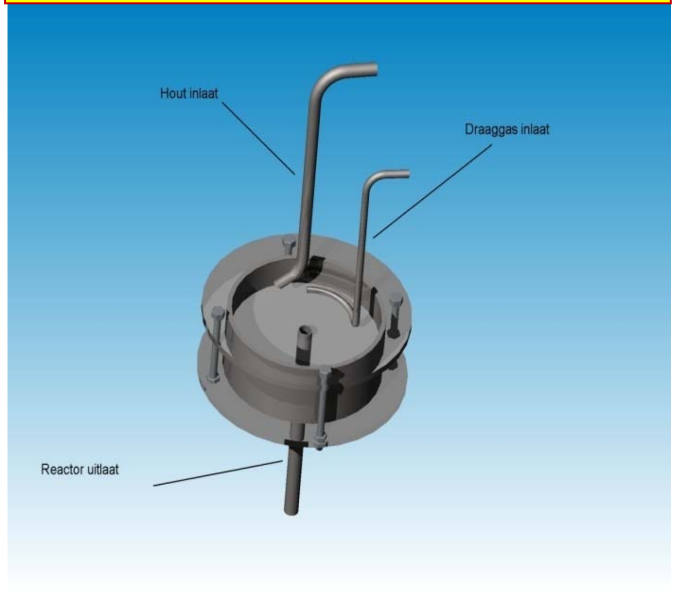
convective heat transfer

V.d. Meer

# From fundamental research to applications

## Fuel conversion processes

A novel TGA for the study of kinetics of pyrolysis reactions

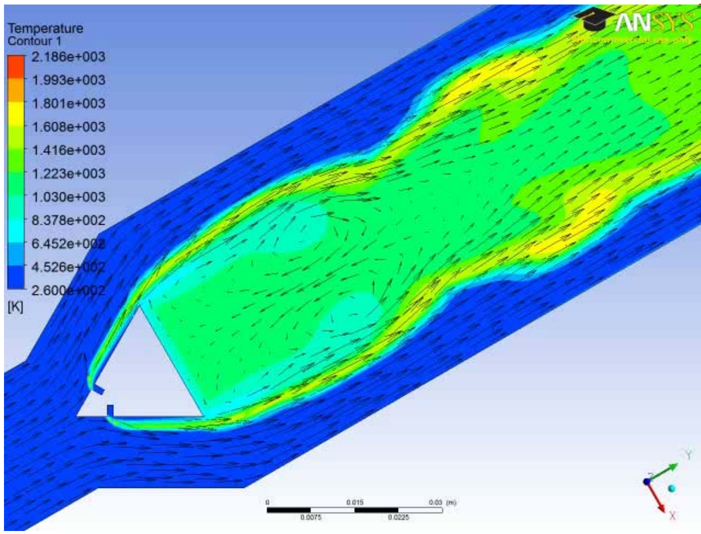



TGA: thermogravimetric analyser

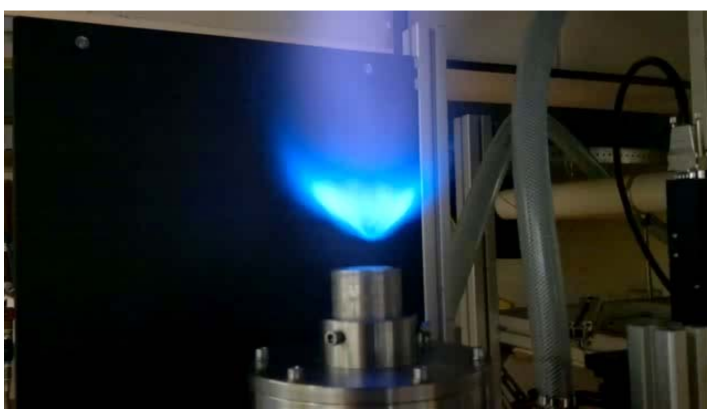
The Pyros reactor
TNO
NL/China/Malaysia/Spain/USA

# From fundamental research to applications

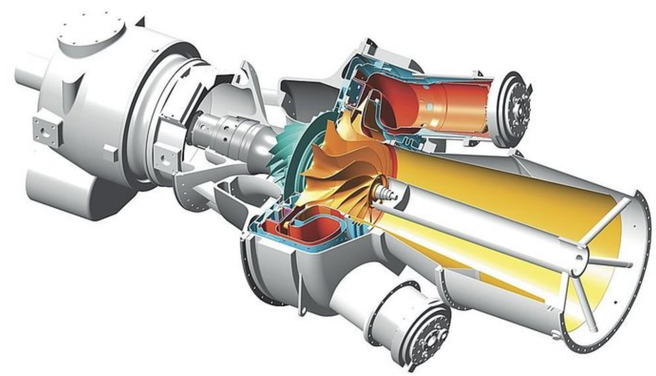
## Turbulent combustion and thermo-acoustics




Limit cycles in gas turbines (EU)

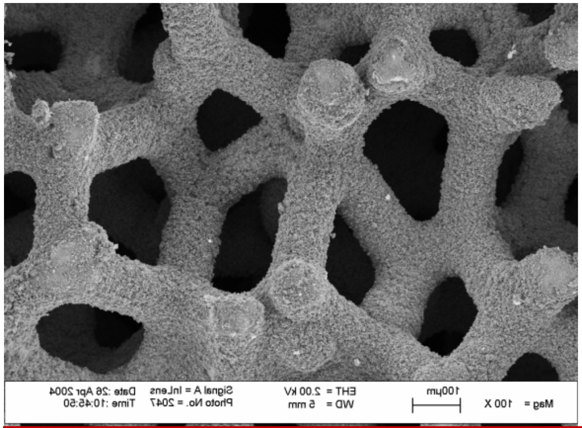


Multi-scale modification of low swirl combustion (STW)

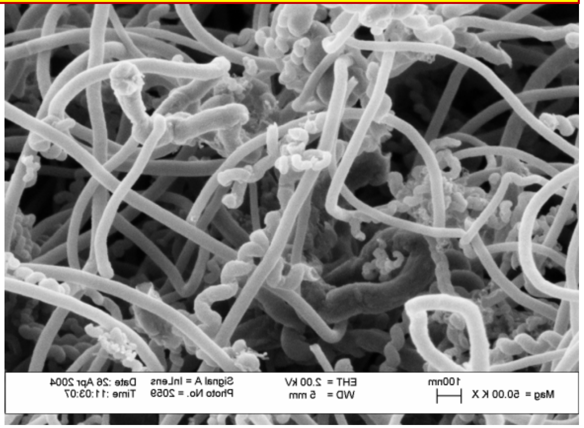


Siemens
Opra
INNECS
Bioplus systems

# From fundamental research to applications
## Convective heat transfer



New heat transfer materials (ADEM)



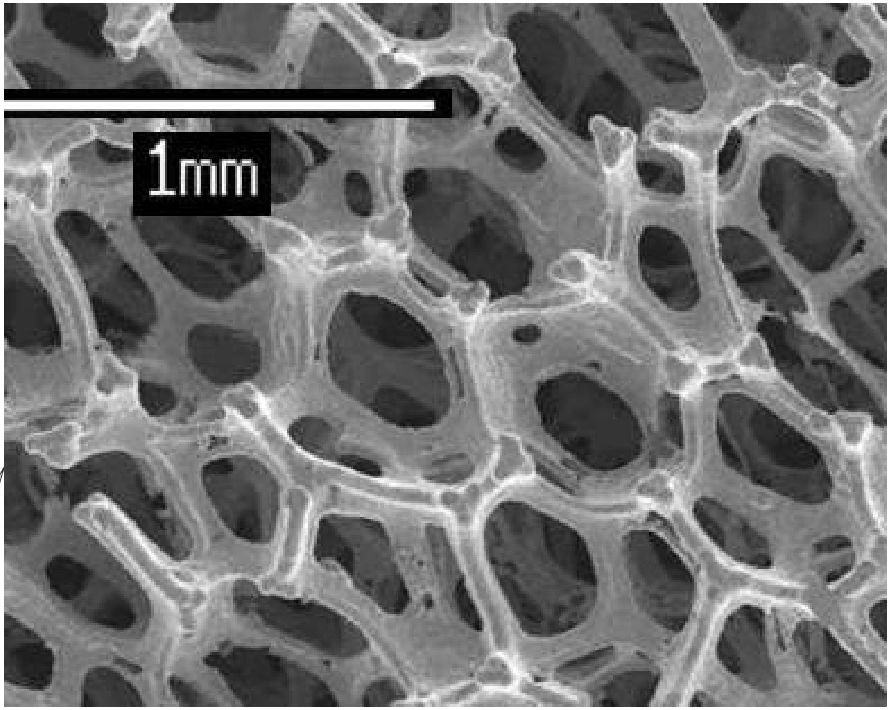
Application in heat engines and heat pumps

## New heat exchange materials

Experimental research to heat transfer enhancement by carbon nano fibers

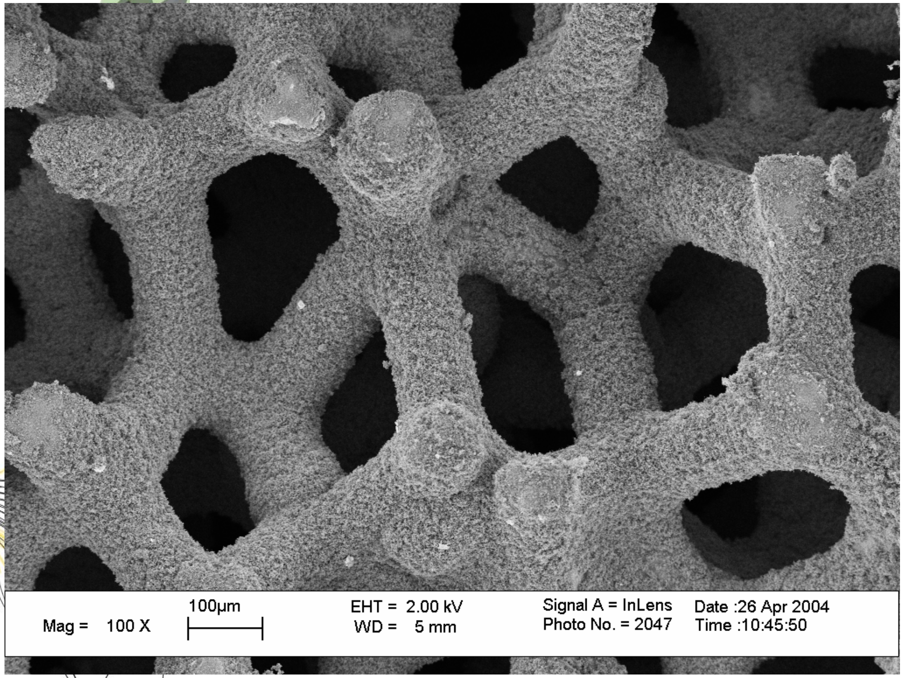
Numerical research to optimize topology and morphology of the carbon nano fibers layer

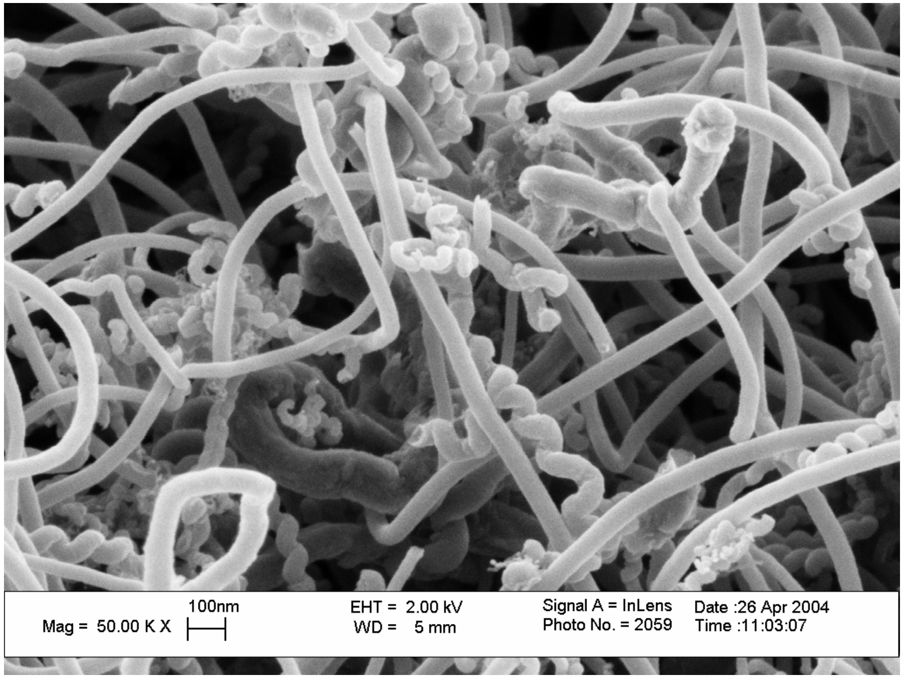
# New heat exchange material



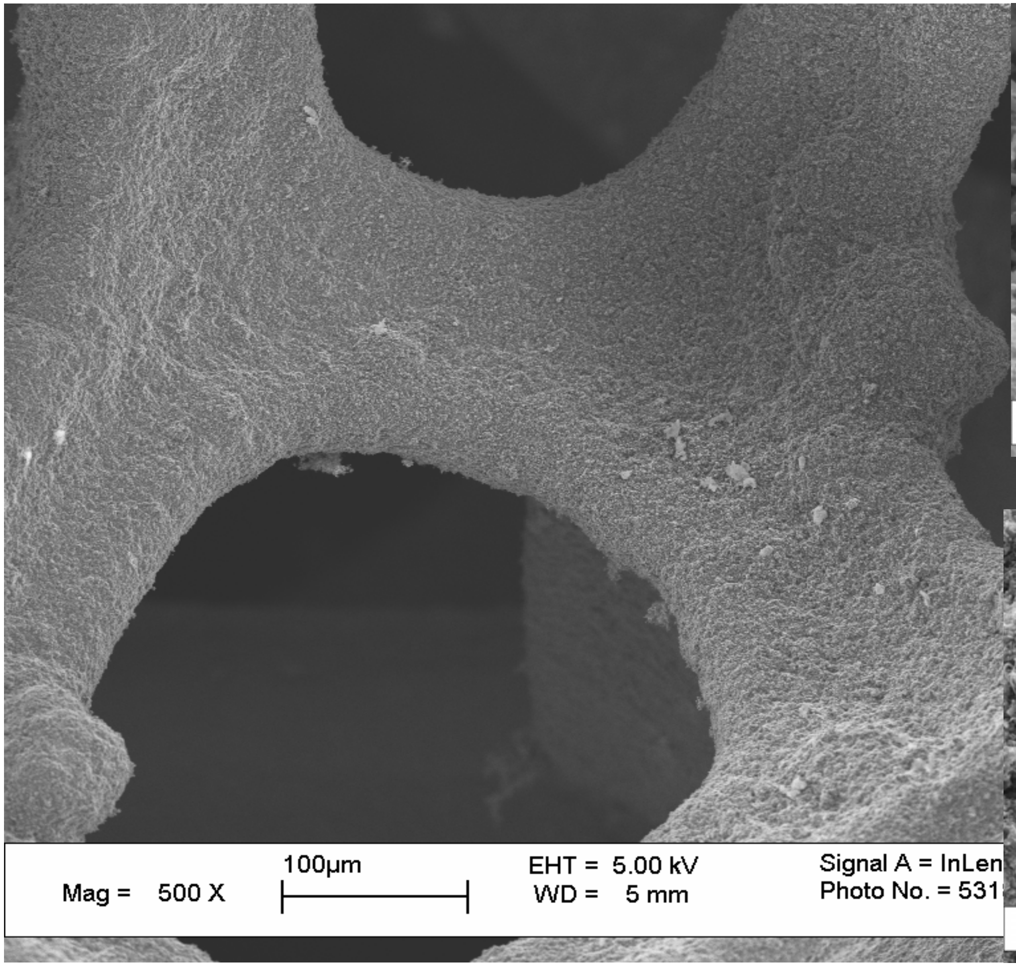

- High porosity (up to 97%)
- Surface area up to $1m^2/g$
- High thermal and electrical conductivity
- Relatively low flow resistance

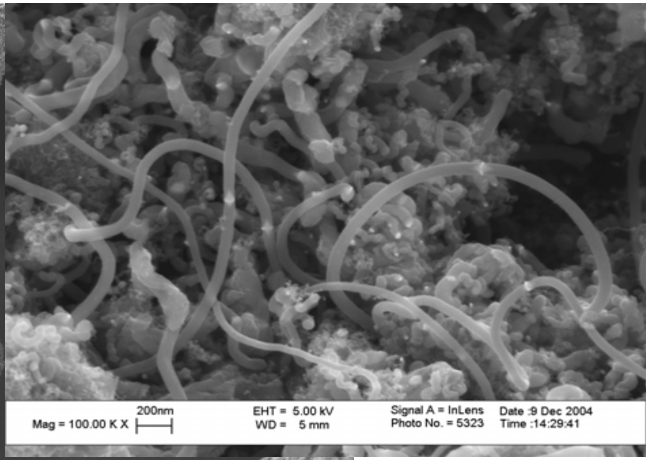
# Nickel foam with 30 wt% of carbon nano fibers

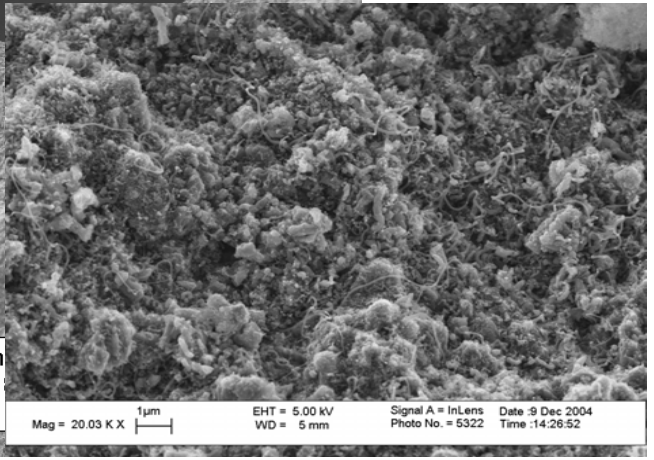


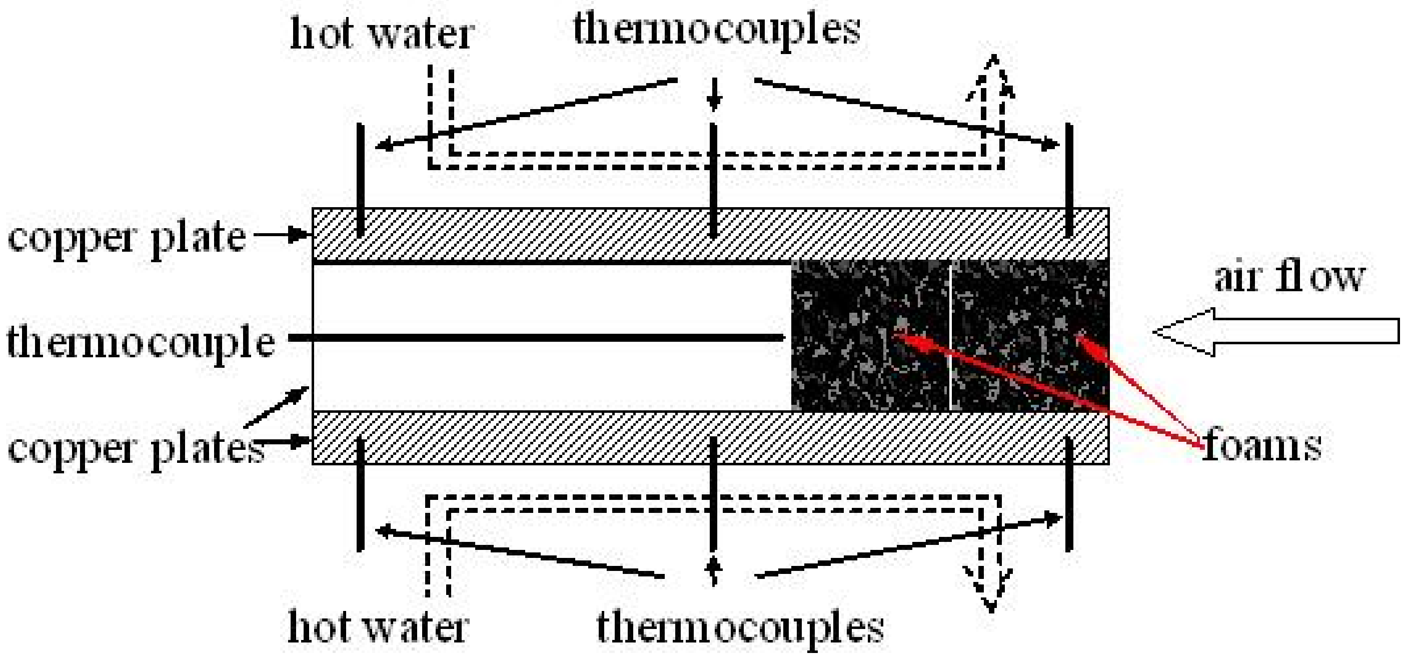
# Nickel foam with 10 wt% of carbon nano fibers



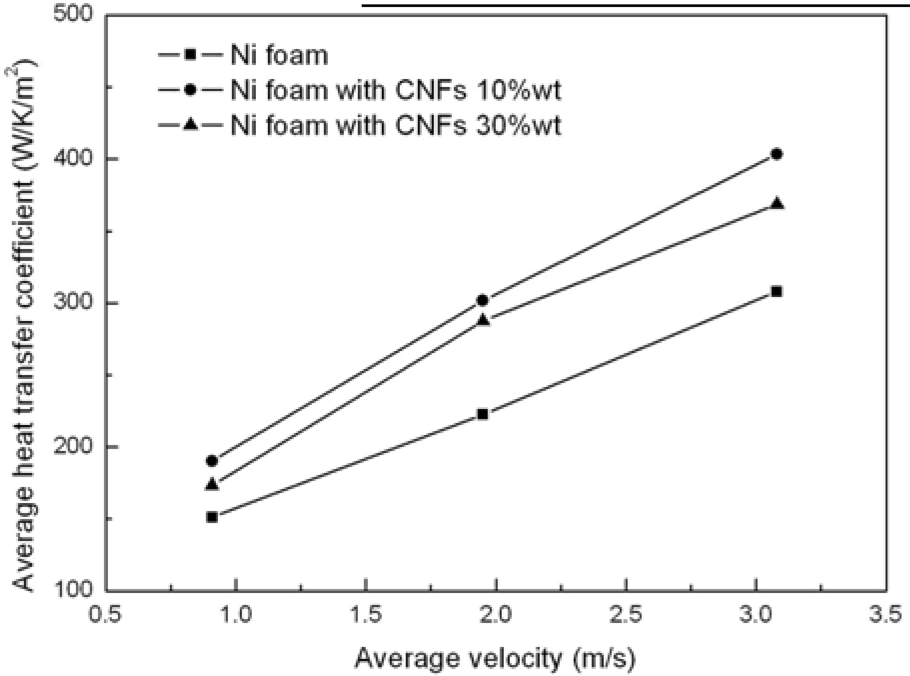



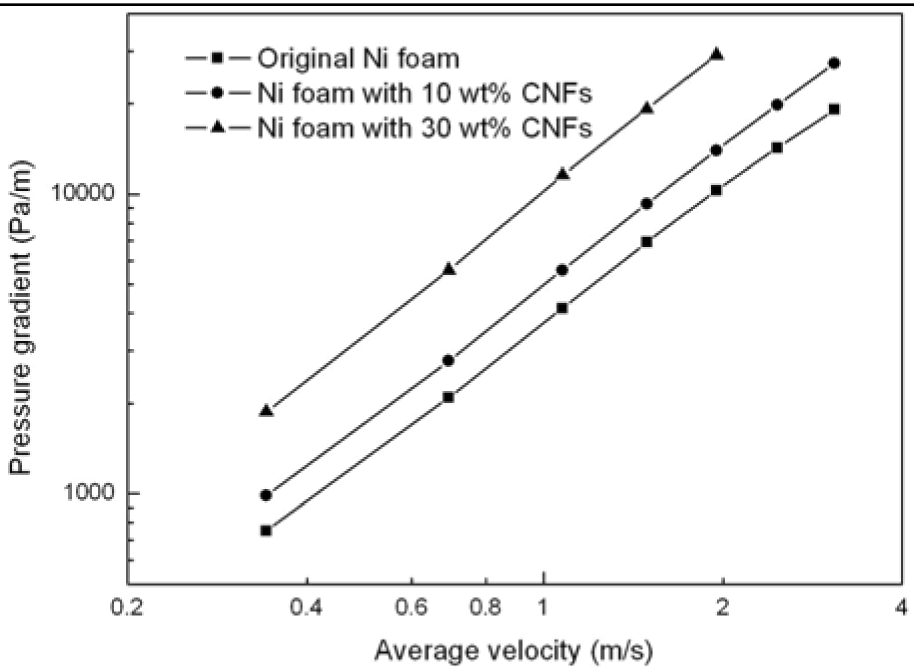
# Experimental set up for heat transfer measurements




- Channel flow (size of the measurement section: 20mm X 10mm X 100 mm)
- Constant wall temperature (controlled by recycling hot water)
- Wall (copper plates) temperature and the temperature behind foams measured

# Heat transfer and pressure drop




Heat transfer and flow resistance of channel flow with metallic foams with different wt% of CNF's

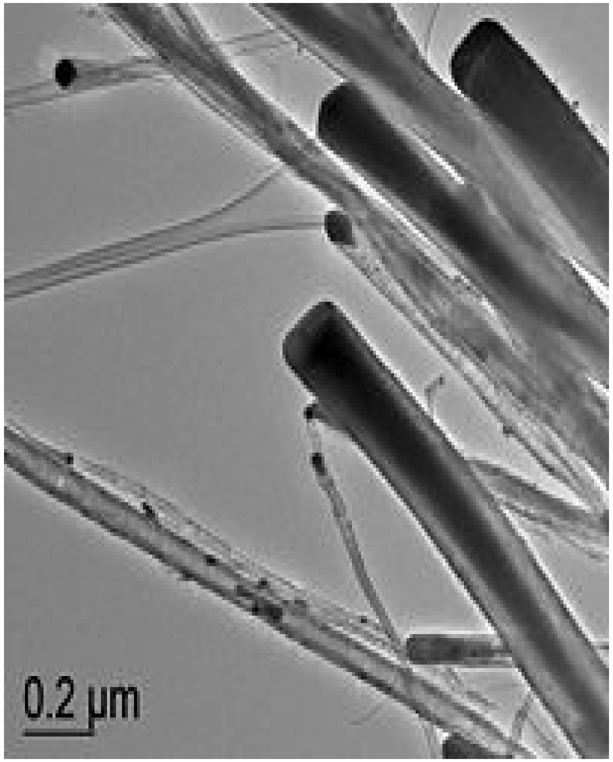
Main result: 10wt% CNF's gives highest heat transfer, but not highest pressure drop.

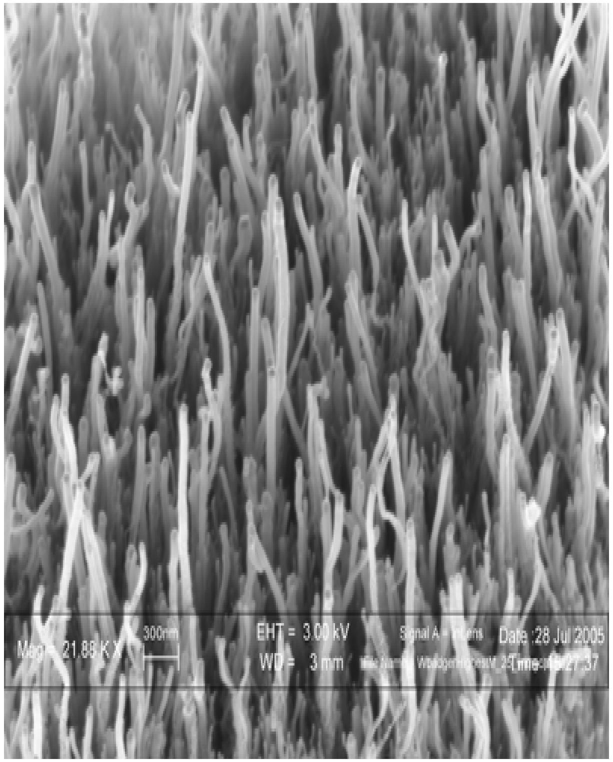
# Heat exchangers and regenerators in heat pumps

Heat exchanger

Regenerator

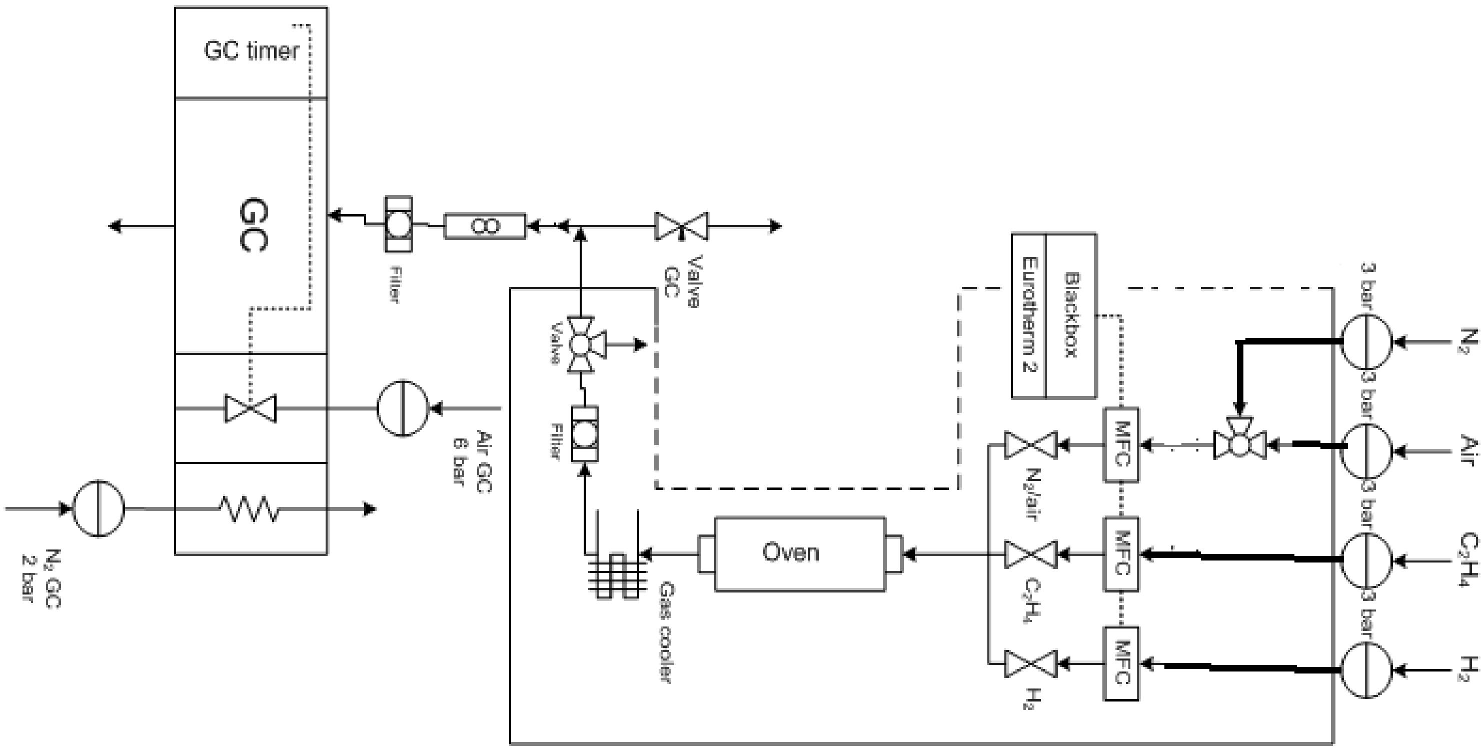
# Carbon Nano-Fibers attached on Ni surface



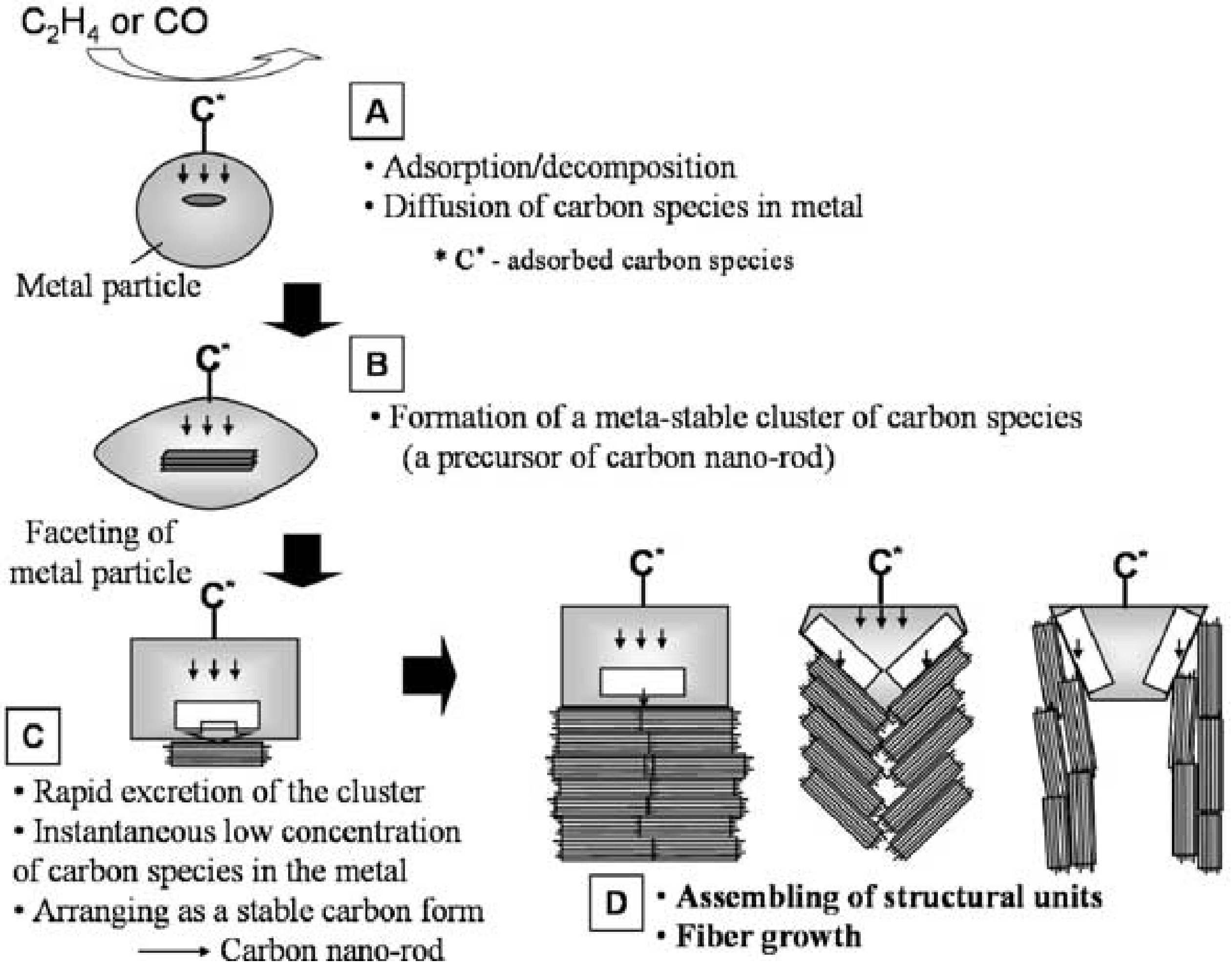




Carbon Nano Fibers

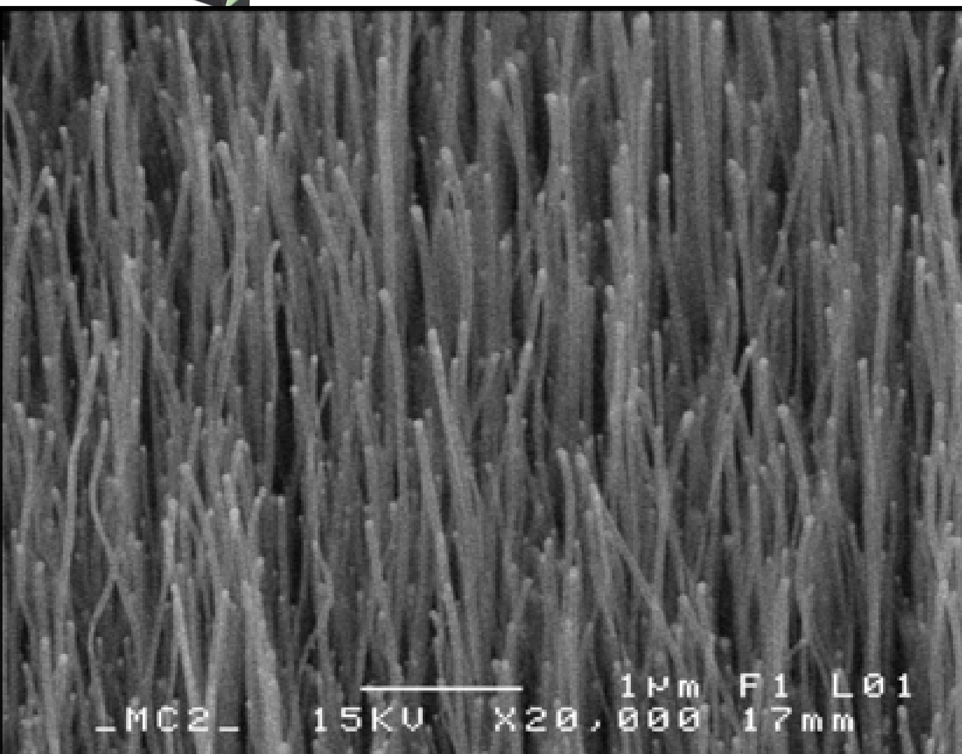
# How to grow CNF’s: Cataytic Vapor Deposition Process

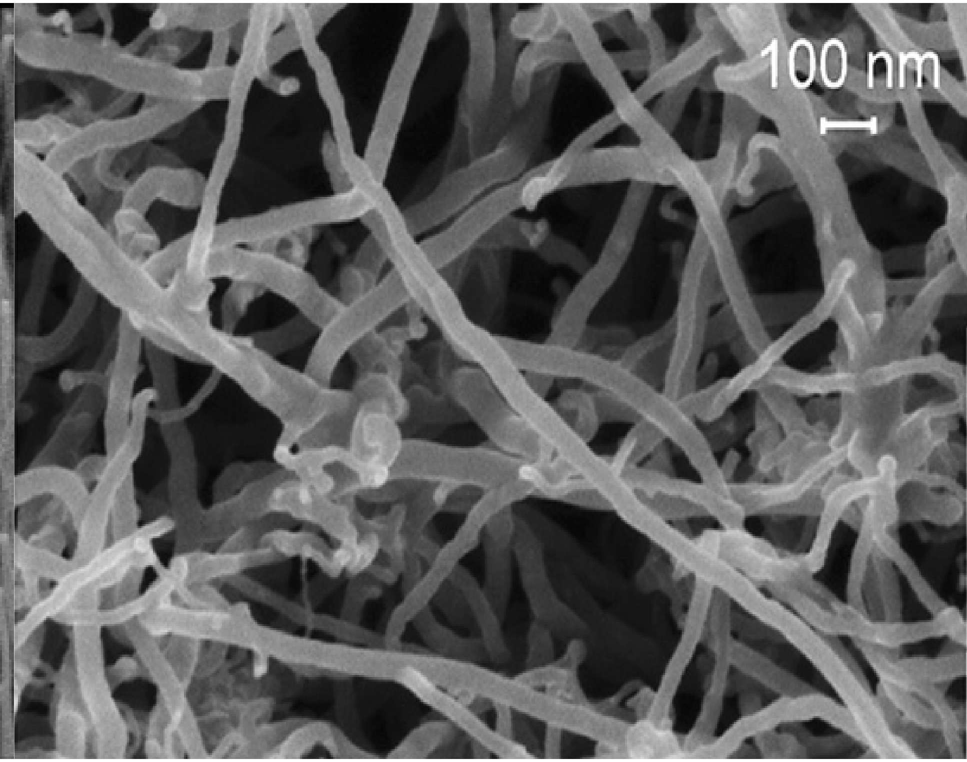


# CNFs growth using CVD mechanism



# Growth structure



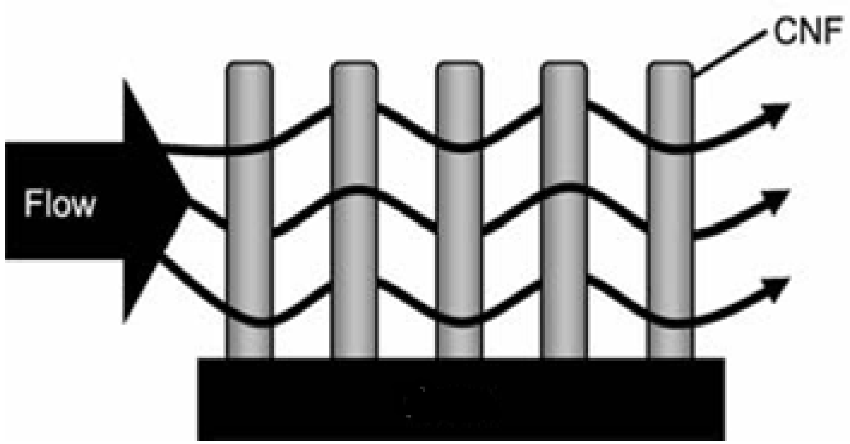




Straight

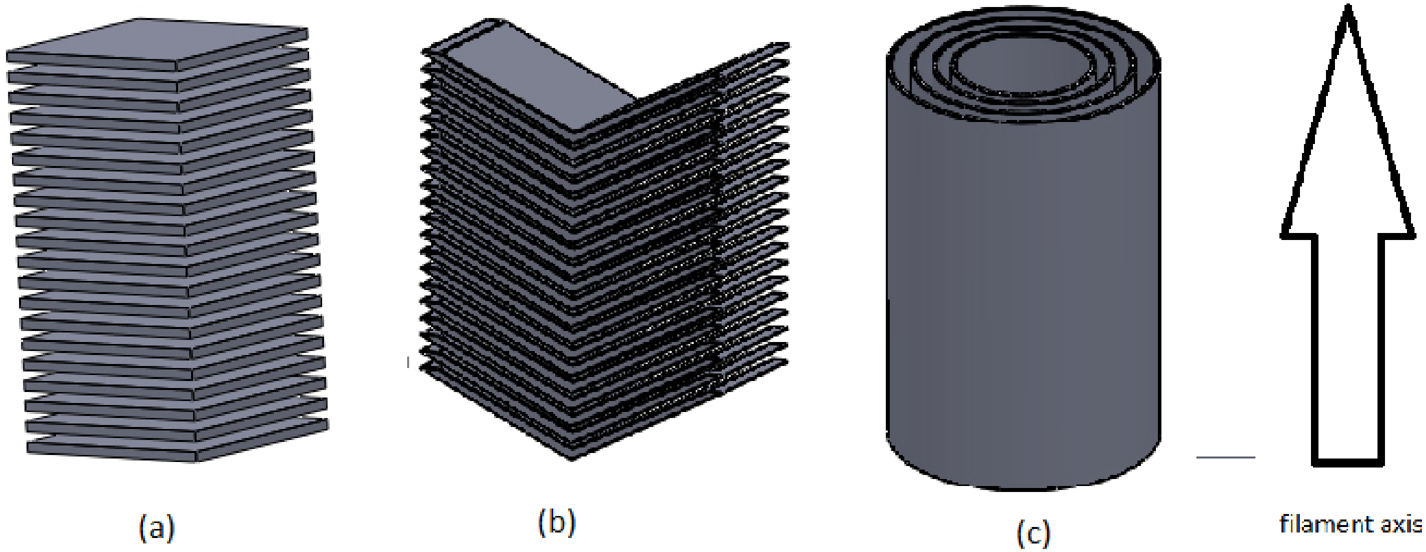
Curled (spaghetti) shaped

# Research objectives

- Identifying the optimal heat transfer characterstics of CNFs and CNTs.
  - Morphology and topology of the CNF's.
  - Thermal properties of CNFs.
- Studying the trade-off between the heat transfer and pressure drop will be studied for a complete heat pump system.

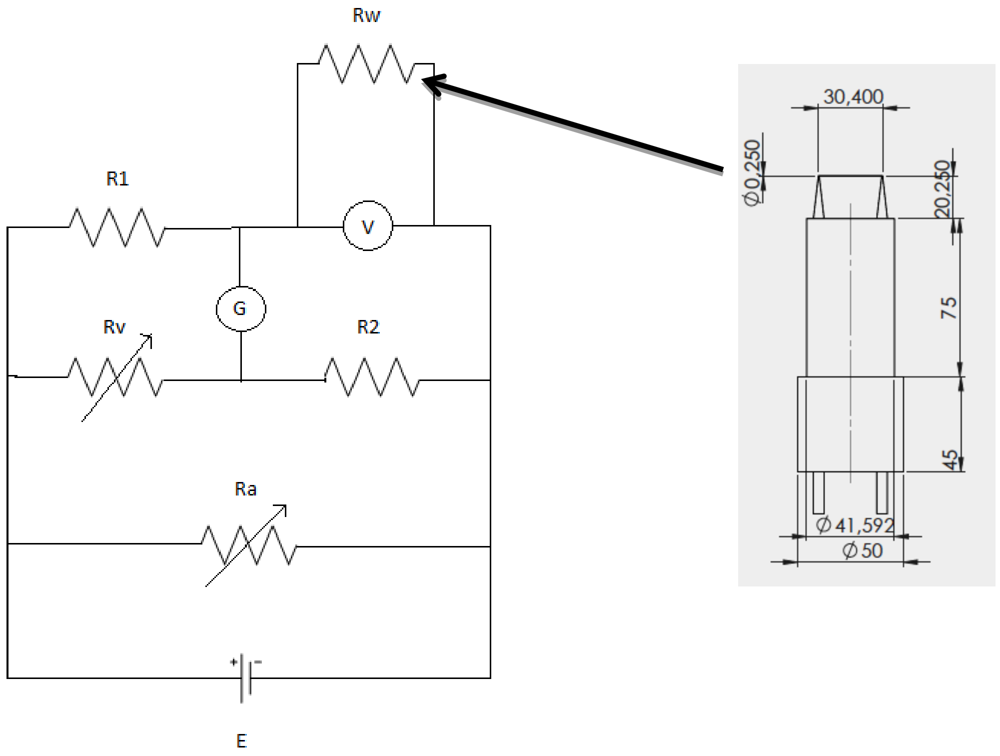


# Assembly of structural units of CNFs



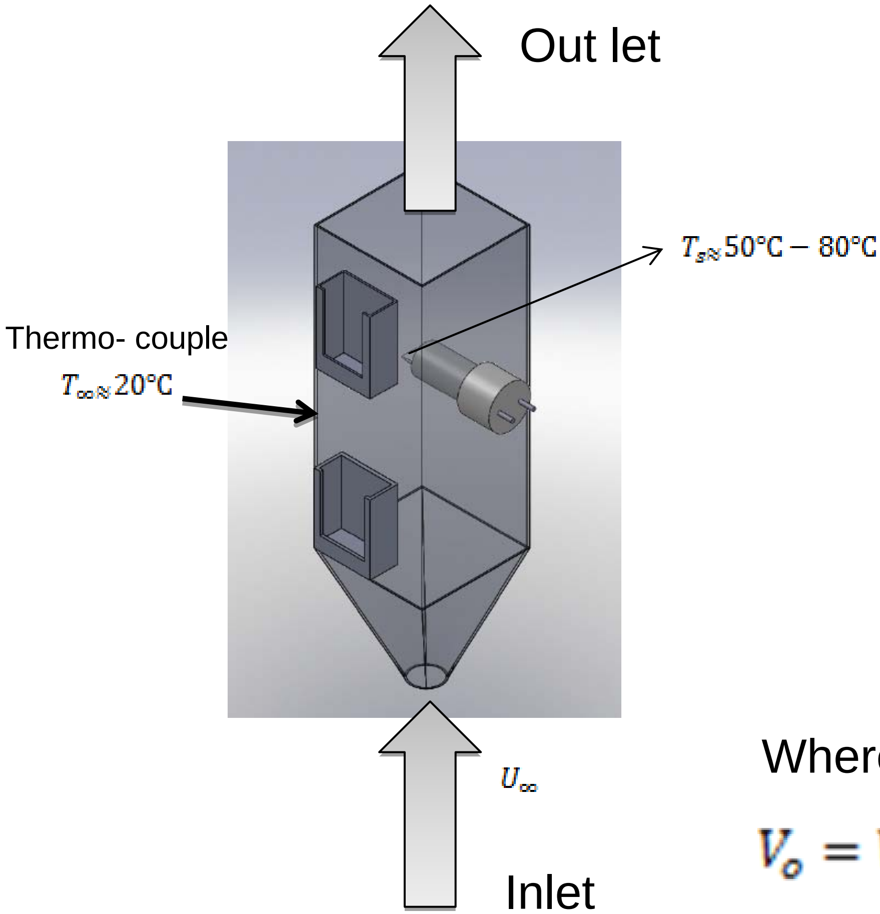

stacked Fish-bone Tubes

# Experimental approach




Wheatstone brigde Circuit

# Step-up configuration




Electrical power loss

$$Q_{el} = \frac{V_f^2 - V_0^2}{R_w}$$

Convective heat transfer

$$Q = h \cdot A \cdot (T_s - T_\infty)$$

$$Q = Qel$$

$$h = \frac{V_f^2 - V_0^2}{R_w \cdot A \cdot (T_s - T_\infty)}$$

Where:

$$V_o = Voltage\ measured\ @\ U_\infty = 0$$

$$V_f = Voltage\ measured\ @ U_\infty \neq 0$$

# Numerical approach: Lattice Boltzmann

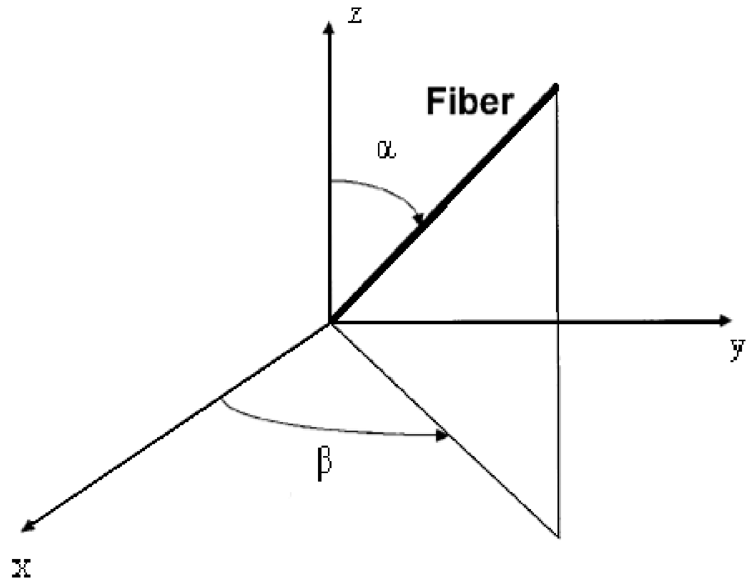
- Boltzmann Equation

$$f_a(\vec{r},\vec{v}) = \rho(\vec{r})\left[\frac{m}{2\pi T(\vec{r})}\right]^{\frac{3}{2}} exp\left\{\frac{-m[\vec{v}-\vec{v_0}(\vec{r})]^2}{2kT(\vec{r})}\right\}$$

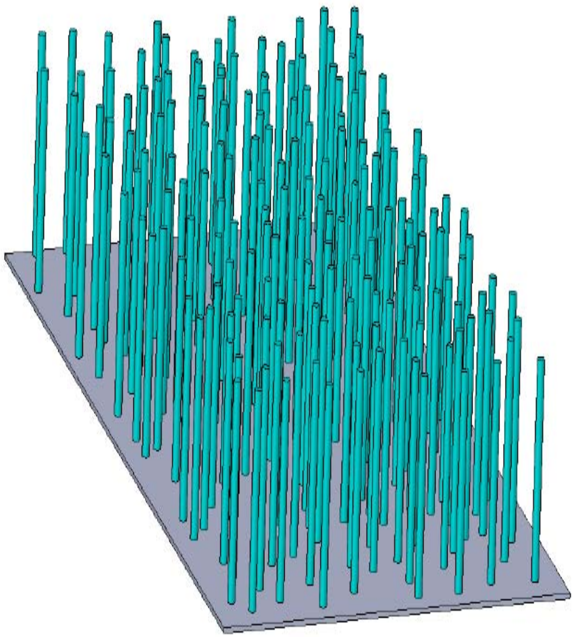
- Discretized Boltzmann Equation (Lattice Boltzmann Equation)

$$f_a(\mathbf{x}+\mathbf{e}_a\Delta t, t+1) = f_a(\mathbf{x},t) - \frac{\left[f_a(\mathbf{x},t) - f_a^{eq}(\mathbf{x},t)\right]}{\tau}$$

# Carbon Nano-Fibers attached on Ni surface




Fiber orientation



Fibers grown with stochastic model

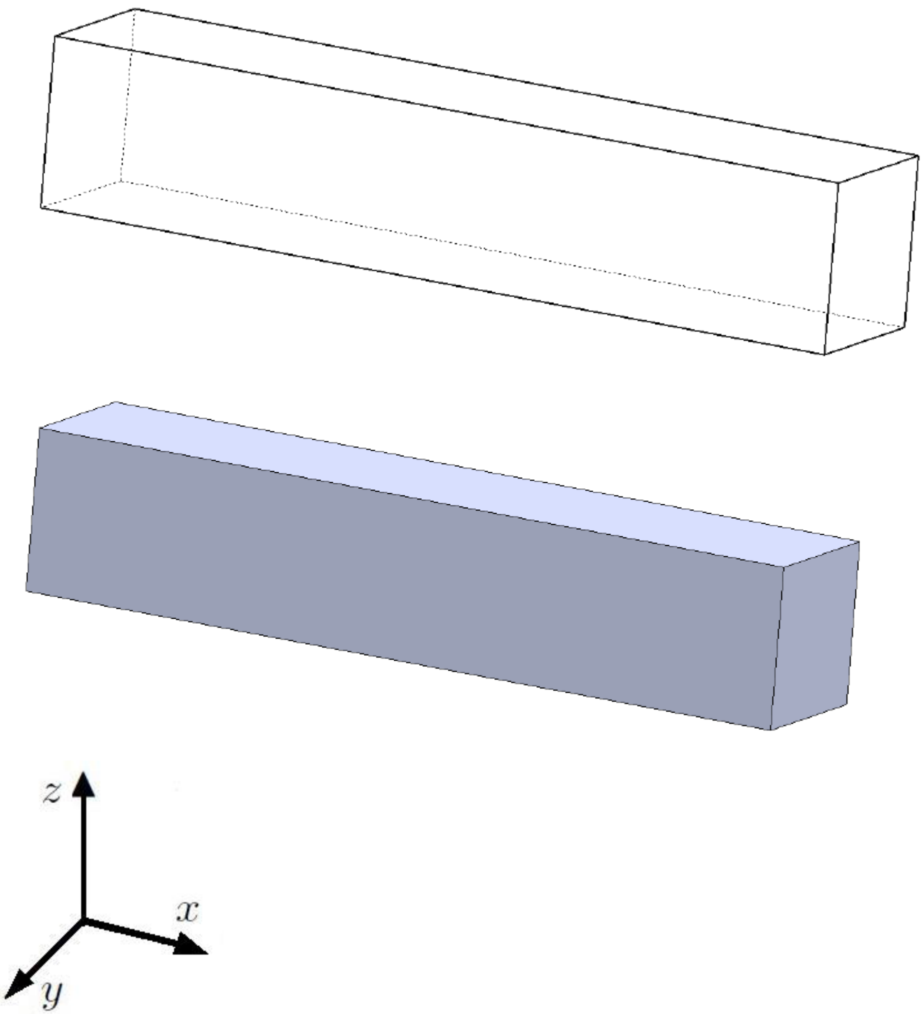
# Heat Transfer

- Laminar Flow
- Inlet Temperature

  320 K
- Walls Temperature

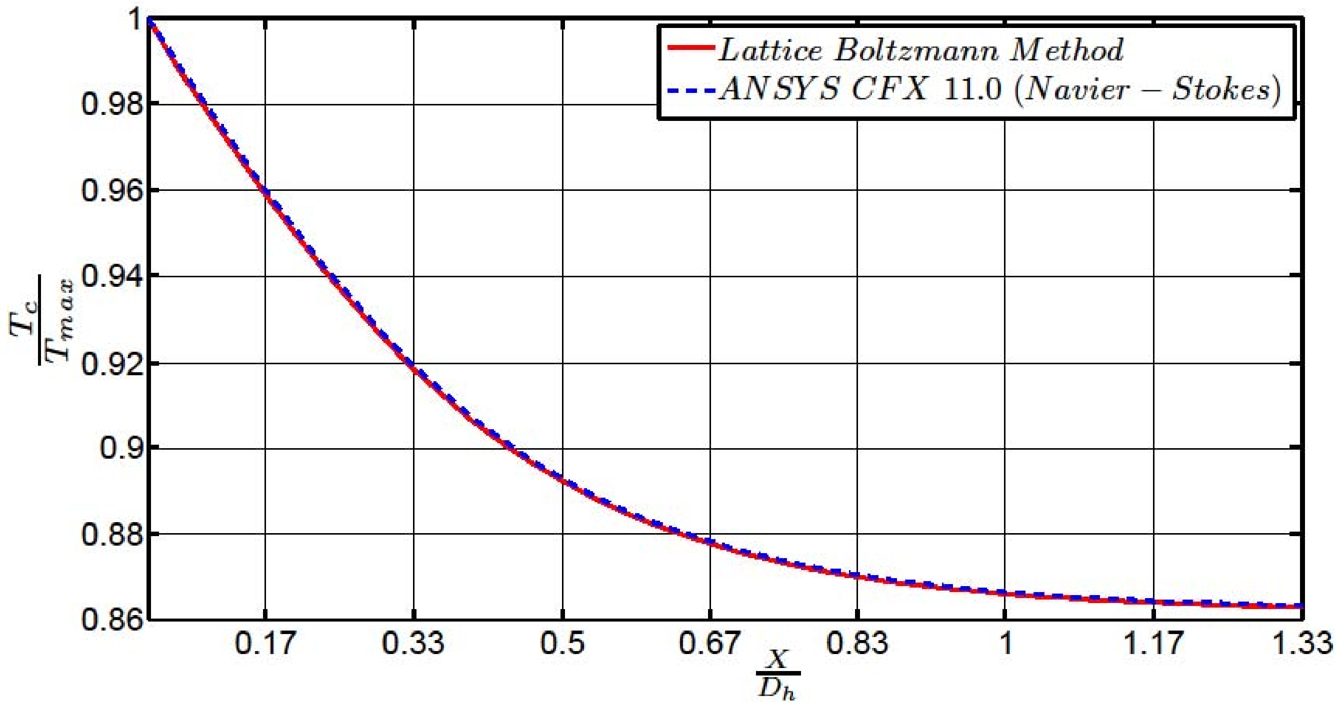
  276 K
- Grid Size

  61x61x300



# Heat Transfer

- $\frac{T_c}{T_{max}}$ Centerline Temperature Profile Along the Channel



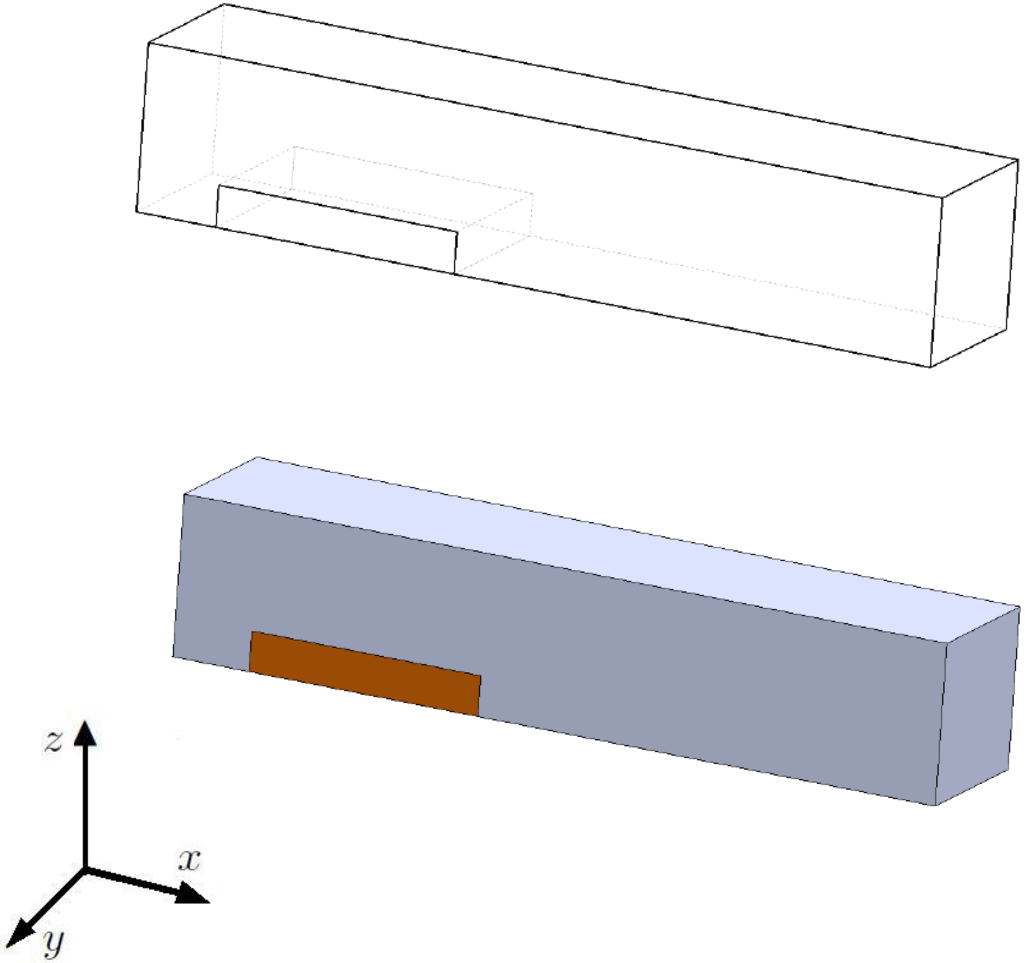
# Conjugate Heat Transfer

- Laminar Flow
- Inlet Temperature

  320 K
- Walls Temperature

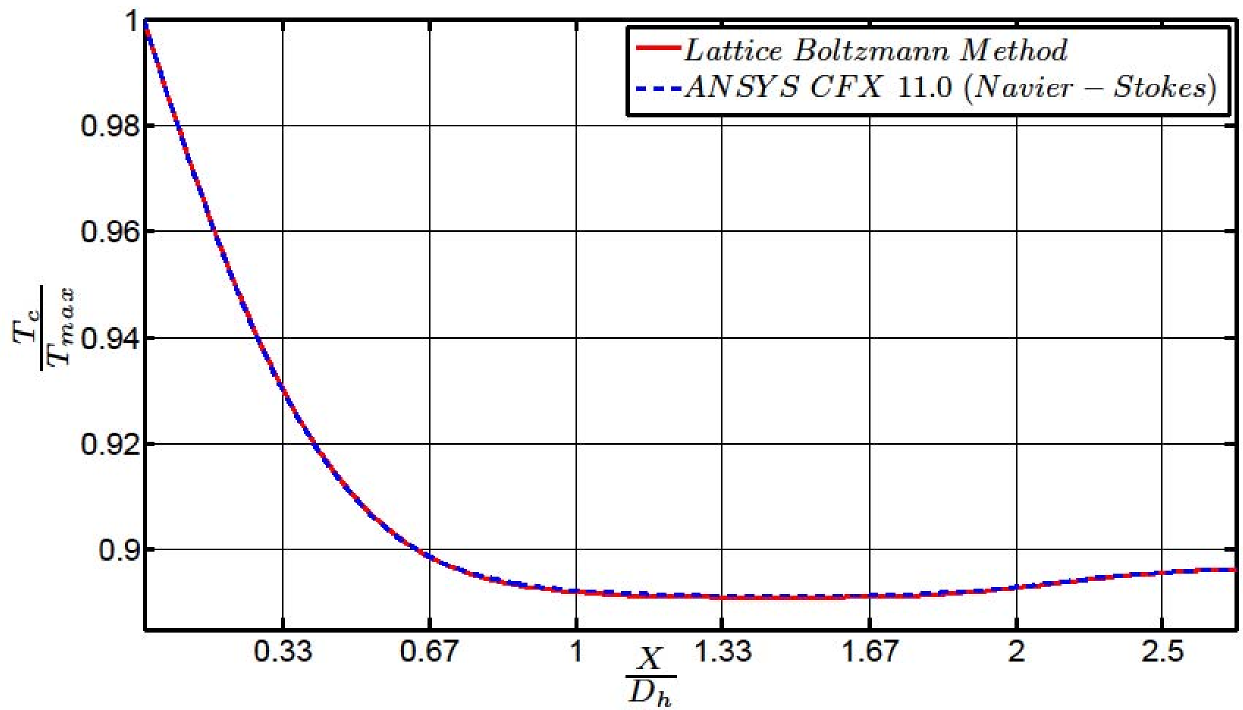
  276 K
- Grid Size

  61x61x300

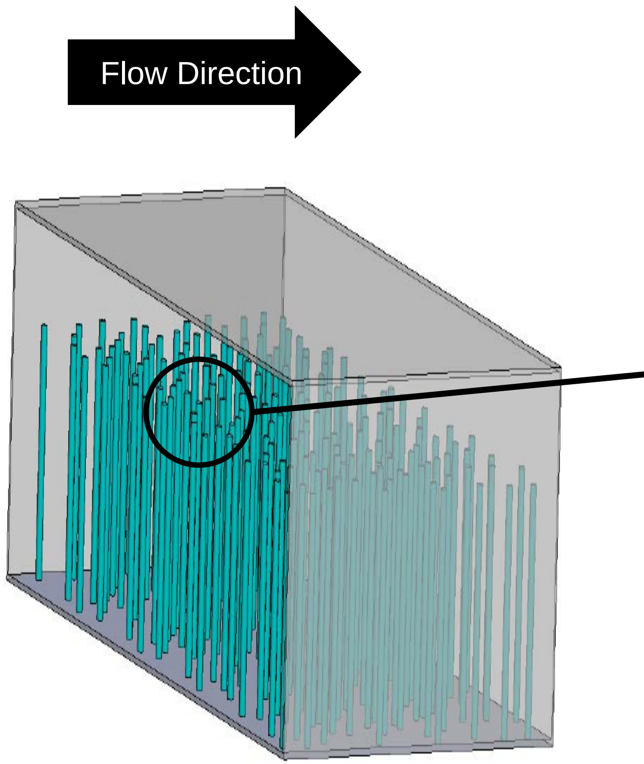


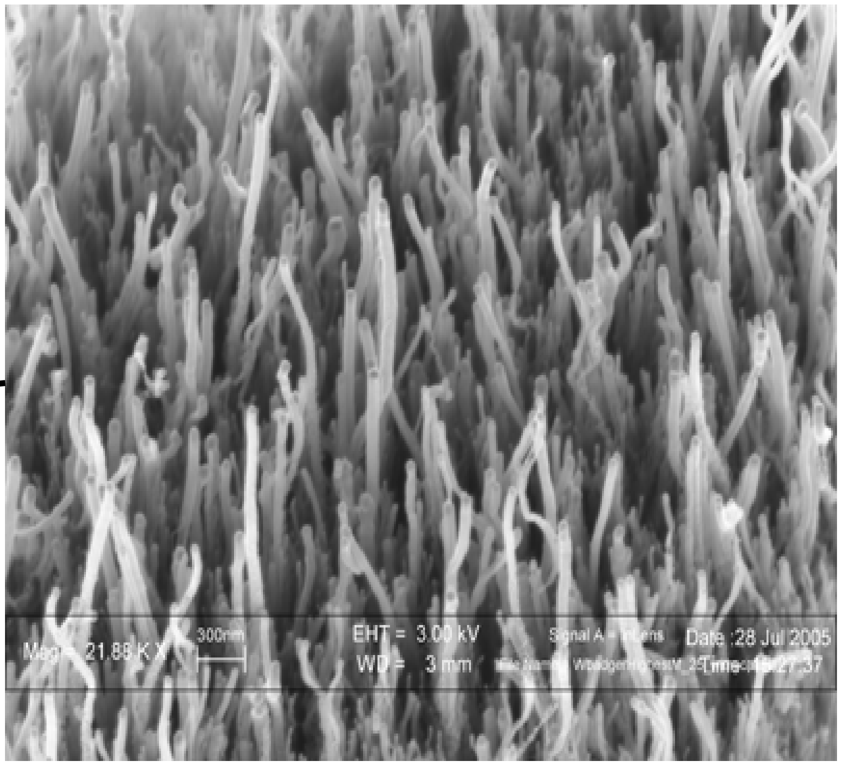
# Conjugate Heat Transfer

- $\frac{T_c}{T_{max}}$ Centerline Temperature Profile Along the Channel



# Results

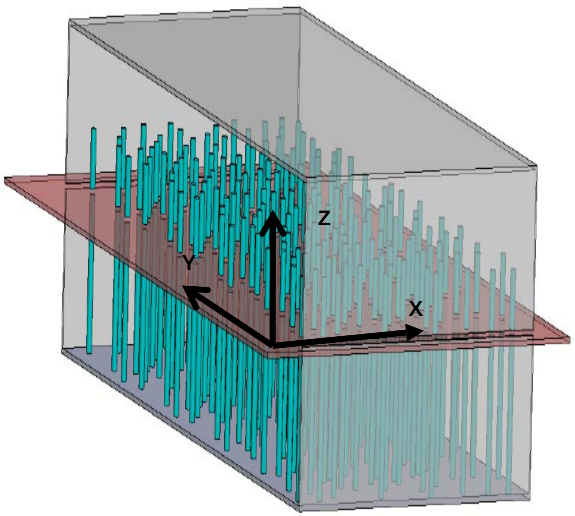


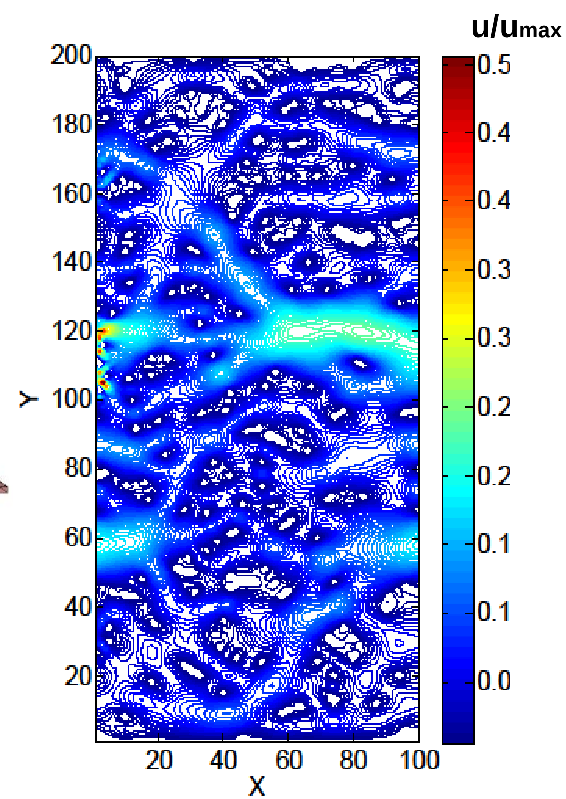



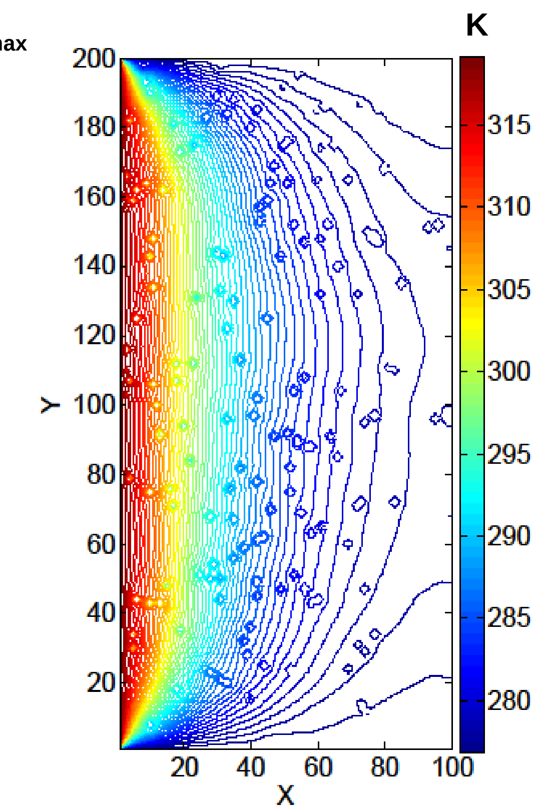

Carbon Nano-Fibers Attached at a Bottom of a Micro-Channel

Enlarged Carbon Nano Fibers

# Results

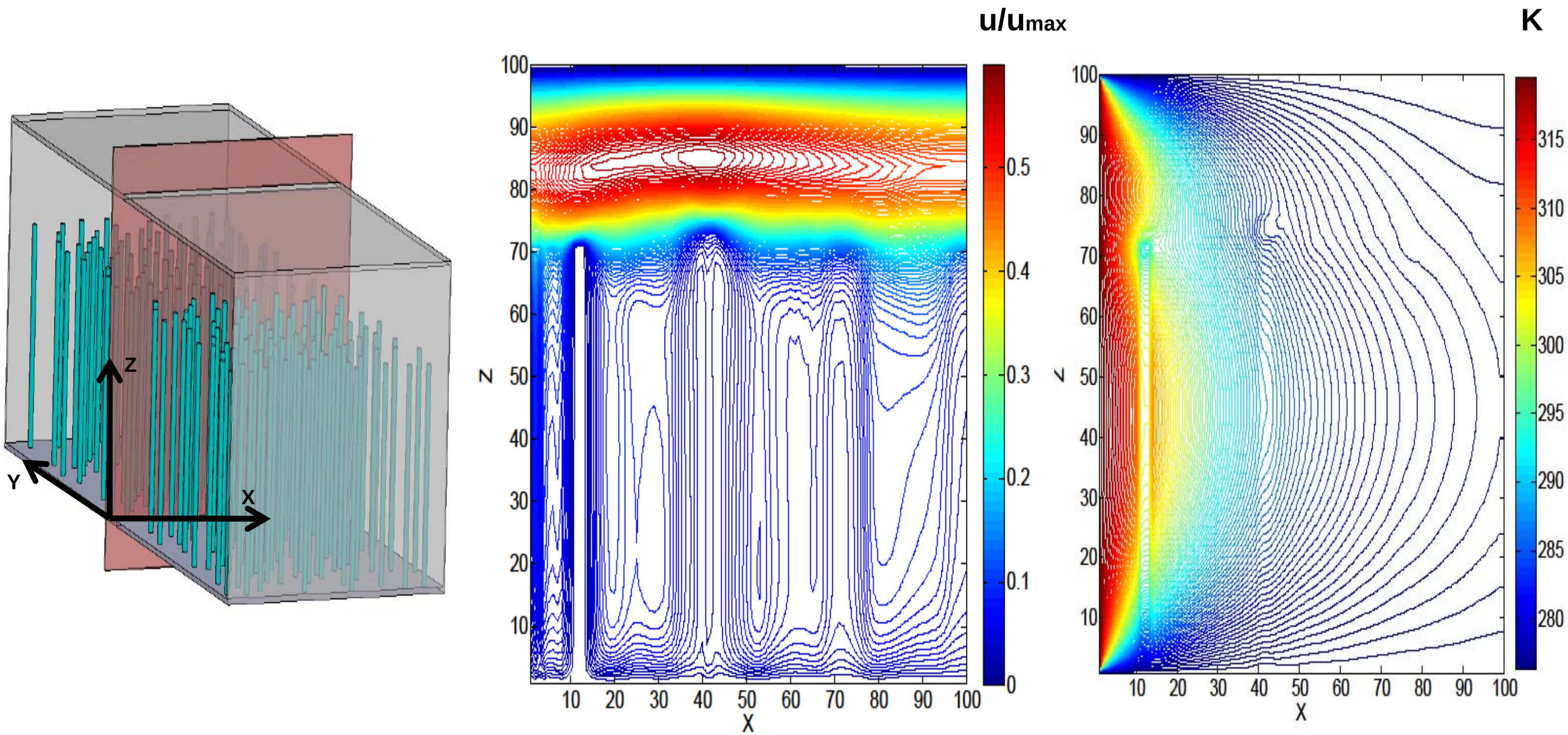


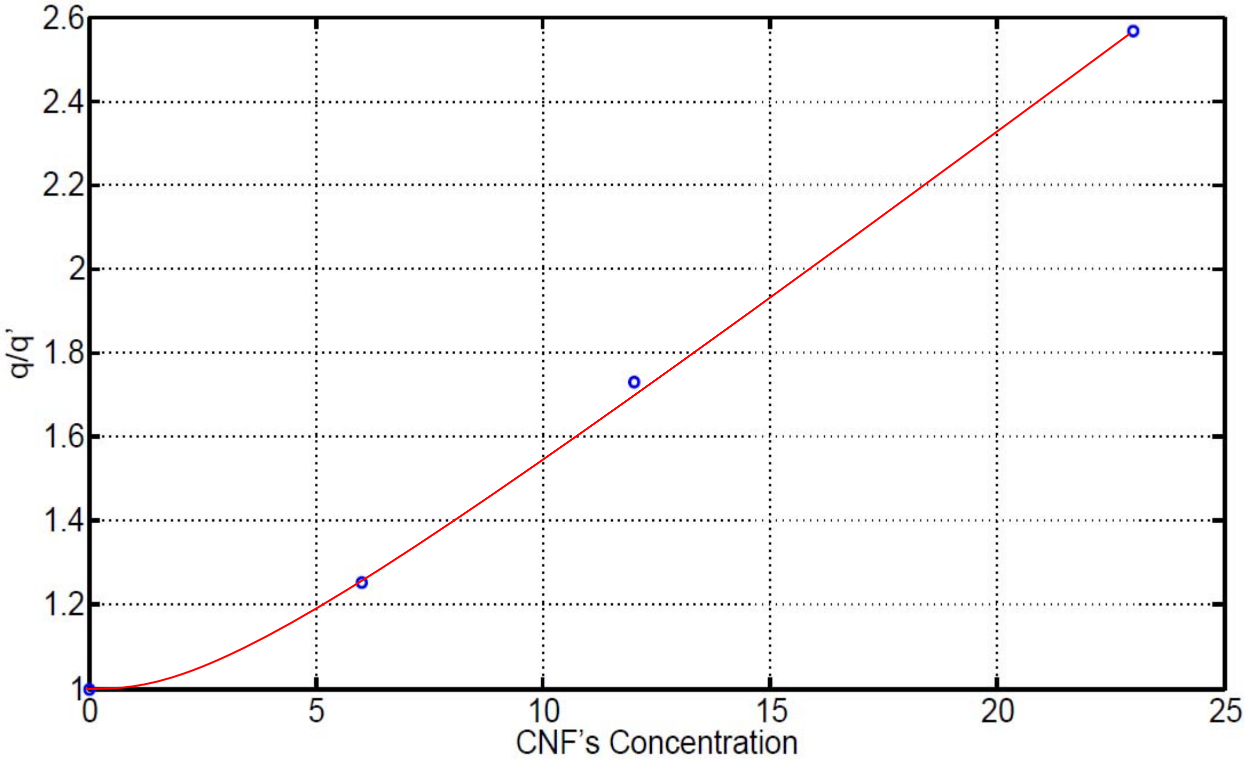

Isocontour velocity and t

# Results




Isocontour velocity and temperature profile through the CNF's layer at the center layer from the side of the channel

# Results




Density Influence on the Heat Transfer

# Conclusions

- An experimental set up has been designed for measurements of heat transfer to a cylinder in cross flow
- A stochastic model for three-dimensional CNF's structural description is developed.
- A three-dimensional fluid-dynamic and thermal-dynamic numerical code has been developed for the prediction of the thermal behavior of the CNF's attached to a wall using the lattice Boltzmann equation.
- The predicted thermal behavior of the CNF's shows that there is a high heat transfer enhancement through the CNF's layer.
- Future research: Simulations with a higher Reynolds number.