Augmented Heat Transfer Surface

Concept

Develop a low pumping power augmented surface based on experimentally and mathematically based optimization of surface roughness or concavities.

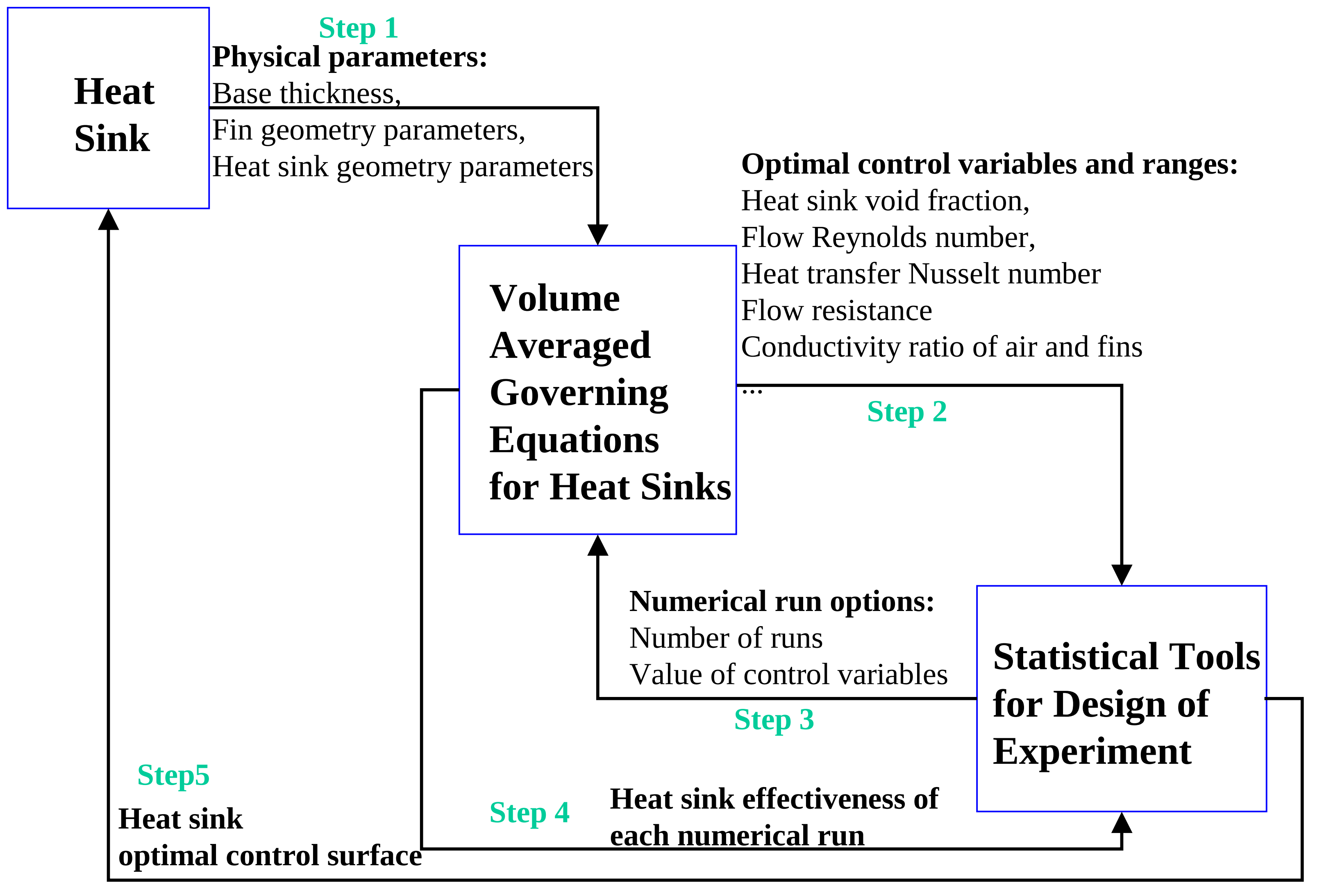
Project Goals

Design, Test, and implement an experimentally and numerically optimized thermal heat sink that for heat removal from the heatpipes and microchips.

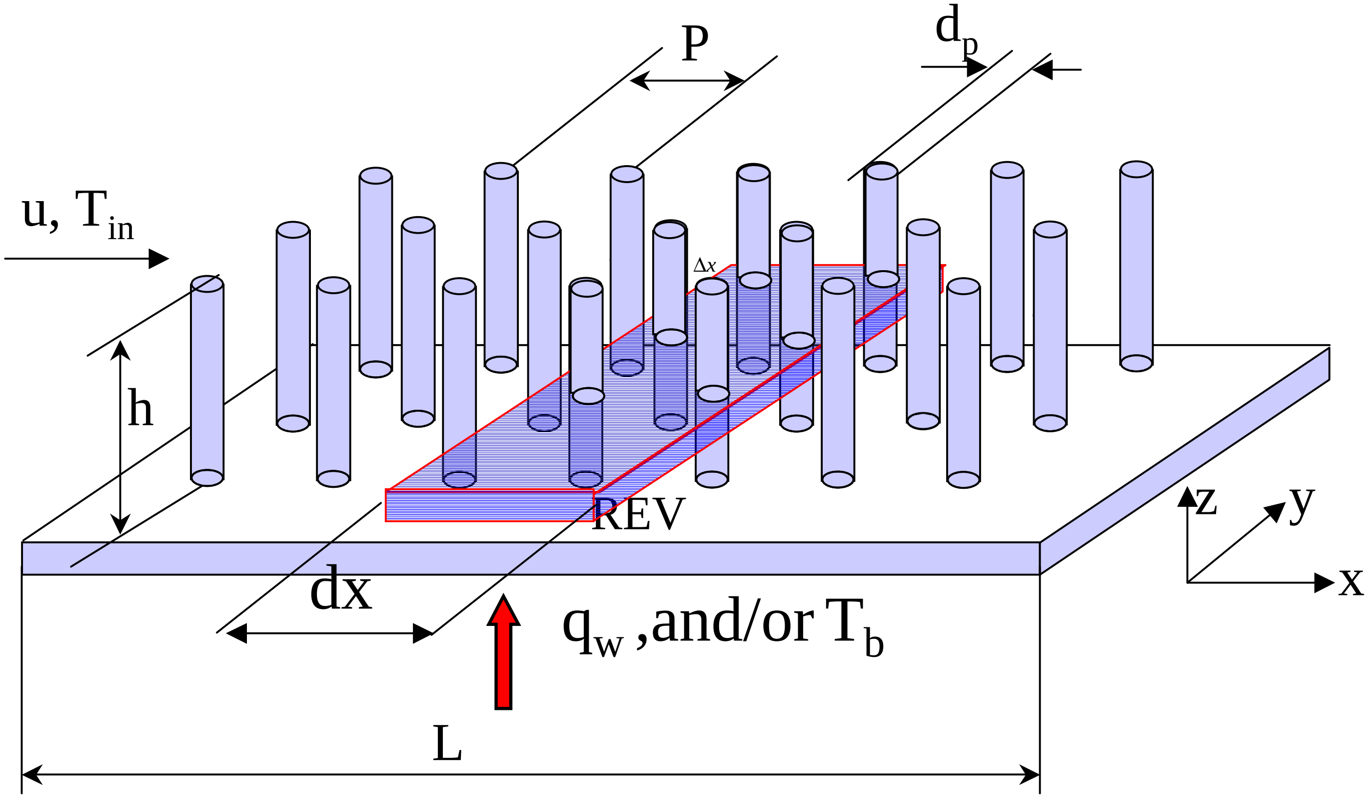
Approach

Develop optimized volumetric heat dissipation device (VHDD) for surface heatflux removal based on the heterogeneous scaled VAT approach. In order to accomplish this, numerical optimization and a literature survey will be performed in order to predict several candidate VHDD. These heat sinks will be individually tested for heat transfer and flow resistance characteristics. The experiemntal and numerical data will be used to optimize the physical parameters to obtain an optimal heat sink for system design and testing.

Heat Sink Optimization Procedures



Heat Sink Model



Heat Sink Optimization

Optimization goal: Maximize Heat sink Effectiveness

Heat sink effectiveness evaluation

- **Pumping power per unit volume**

$$P_p = \frac{P}{\Omega} = \frac{\dot{m}\,\Delta p}{\rho_f \Omega} = f_f \,\mathrm{Re}_{por}^3 \langle m_{yz} \rangle \left(\frac{S_{all}^{*\,4}}{\langle m \rangle^4} \right) \frac{\mu^3}{128 \rho_f^2} \quad \left[\frac{W}{m^3} \right]$$

$$f_f = \left[\frac{2 \langle m \rangle \Delta p}{\rho_f \tilde{\tilde{U}}^2 S_{all}^* L_x} \right]$$

- **Heat transfer rate per unit volume**

$$H_r = \frac{S_b \alpha_w^*}{\Omega} = Nu_b \frac{k_f S_{all}^*}{4 \langle m \rangle} S_b^* , \quad \left[\frac{W}{m^3 K} \right]$$

$$Nu_b = \frac{q_w d_{por}}{\left(T_b - T_{in} \right) k_f}$$

- **Heat sink heterogeneous effectiveness**

$$E_{eff-het} = \frac{H_r}{P_p} = \left[\frac{Nu_b}{f_f \,\mathrm{Re}_{por}^3} \left(32 \frac{S_b^*}{\langle m_{yz} \rangle} \frac{\langle m \rangle^3}{S_{all}^{*\,3}} \right) \frac{k_f \rho_f^2}{\mu^3} \right] , \quad \left[\frac{1}{K} \right] ,$$

VAT Control Equations

MOMENTUM EQUATION

$$\frac{\partial}{\partial z^*}\left(L_{M4N}\frac{\partial \tilde{\bar{u}}\left(z^*\right)^*}{\partial z^*}\right)+U_{MConv}+U_{MFriction}-U_{MDrag}=\frac{1}{m_0}$$

ENERGY EQUATION IN THE FLUID PHASE

$$\tilde{\bar{u}}^*\frac{\partial \tilde{T}^*\left(x^*,z^*\right)}{\partial x^*}=\frac{\partial}{\partial z^*}\left(L_{P5}\frac{\partial \tilde{\bar{T}}^*\left(x^*,z^*\right)}{\partial z^*}\right)+\frac{\partial}{\partial x^*}\left(L_{P5}\frac{\partial \tilde{\bar{T}}^*\left(x^*,z^*\right)}{\partial x^*}\right)$$

$$+\tilde{T}_{MConvX}+\tilde{T}_{MConvZ}+\tilde{T}_{MSurfX}+\tilde{T}_{MSurfZ}+\tilde{T}_{MExchange}$$

ENERGY EQUATION IN THE SOLID PHASE

$$\frac{\partial}{\partial x^*}\left(L_{P7}\frac{\partial T_s^*\left(x^*,z^*\right)}{\partial x^*}\right)+\frac{\partial}{\partial z^*}\left(L_{P7}\frac{\partial T_s^*\left(x^*,z^*\right)}{\partial z^*}\right)$$

$$+T_s^*{}_{MSurfX}+T_s^*{}_{MSurfZ}+T_s^*{}_{MExchange}=0$$

Examples of Control Terms

$$U_{MConv}\left(\hat{u}, \hat{w}, \partial S_w, \Delta\Omega_f, \Delta\Omega_s\right) = \frac{\partial}{\partial z}\left(\left\langle -\hat{u}\hat{w}\right\rangle_f\right)$$

$$U_{MFriction}\left(U, \partial S_w, \nu\right) = \frac{\nu}{\Delta\Omega}\int_{\partial S_w}\frac{\partial U}{\partial x_i}d\vec{s}$$

$$U_{MDrag}\left(p, \partial S_w\right) = \frac{\nu}{\rho_f \Delta\Omega}\int_{\partial S_w} p\,d\vec{s}$$

$$T_{fMConvX}\left(\hat{u}, \hat{T}_f, \Delta\Omega_f, \Delta\Omega_s\right) = c_{pf}\rho_f\frac{\partial}{\partial x}\left(\left\langle m\right\rangle\left\{-\hat{T}_f\hat{u}\right\}_f\right)$$

$$T_{fMConvZ}\left(\hat{w}, \hat{T}_f, \Delta\Omega_f, \Delta\Omega_s\right) = c_{pf}\rho_f\frac{\partial}{\partial z}\left(\left\langle m\right\rangle\left\{-\hat{T}_f\hat{w}\right\}_f\right)$$

$$T_{fMSurfX}\left(k, T_f, \partial S_w\right) = k\frac{\partial}{\partial x}\left[\frac{1}{\Delta\Omega}\int_{\partial S_w} T_f\,d\vec{s}\right]$$

$$T_{fMSurfZ}\left(k, T_f, \partial S_w\right) = k\frac{\partial}{\partial z}\left[\frac{1}{\Delta\Omega}\int_{\partial S_w} T_f\,d\vec{s}\right]$$

$$T_{fMExchange}\left(k, T_f, \partial S_w\right) = k\frac{1}{\Delta\Omega}\int_{\partial S_w}\frac{\partial T_f}{\partial x_i}d\vec{s}$$

$$T_{sMSurfX}\left(k_s, T_s, \partial S_w\right) = k_s\frac{\partial}{\partial x}\left[\frac{1}{\Delta\Omega}\int_{\partial S_w} T_s\,d\vec{s}_1\right]$$

$$T_{sMSurfZ}\left(k_s, T_s, \partial S_w\right) = k_s\frac{\partial}{\partial z}\left[\frac{1}{\Delta\Omega}\int_{\partial S_w} T_s\,d\vec{s}_1\right]$$

$$T_{sMExchange}\left(k_s, T_s, \partial S_w\right) = k_s\frac{1}{\Delta\Omega}\int_{\partial S_w}\frac{\partial T_s}{\partial x_i}d\vec{s}_1$$

Optimization of Multiple Dimensional Cases

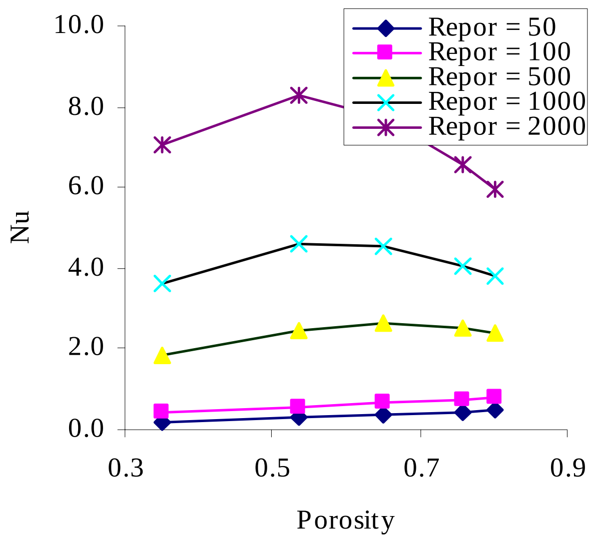
(6D Laminar or 8D Turbulent flow)

Use the statistical design of experiment (DOE) Methodology:

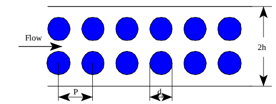
- Choose an optimization variable; $E_{\text{Eff-het}}$
- Systematically define the problem parameters and their ranges.
- Statistically analyze the numerical results to find the response surface.
- A commercial version of the DOE method was used to carry out the numerical simulation option.
- Choose the type of the response surface to be used and construct the response surface:

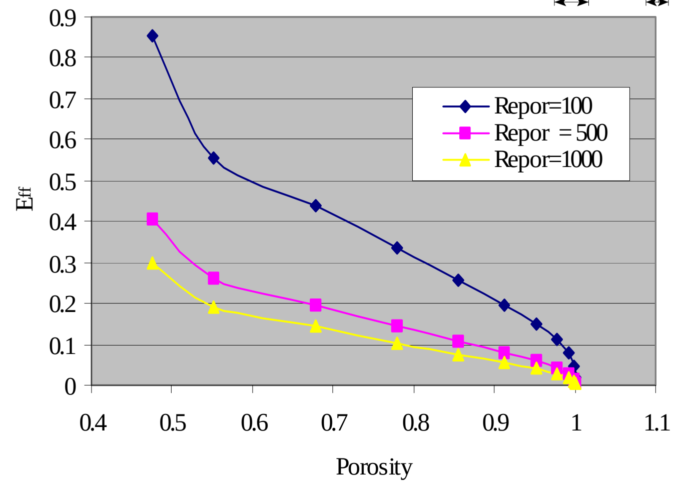
$$E_{ff} = a_0 + a_1X_1 + a_2X_2 + ... + a_nX_n + a_{11}X_1^2 + a_{12}X_1X_2 + ... + a_{nn}X_n^2$$

Channel Flow Heat Transfer Optimization

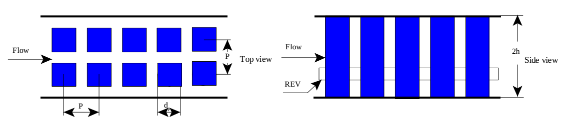


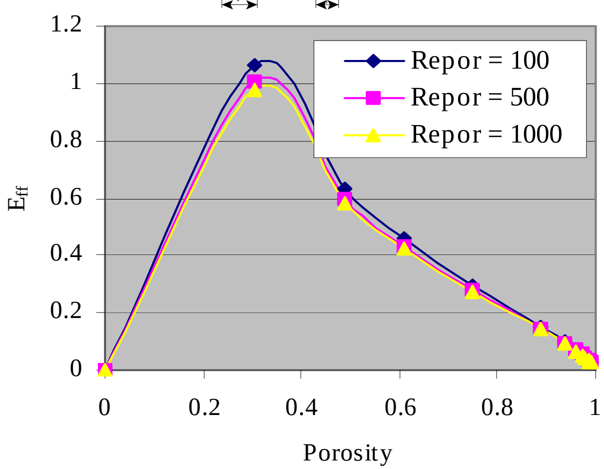
Spheres



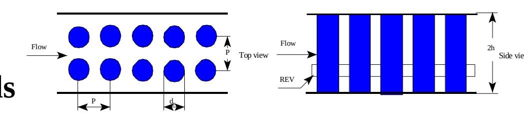


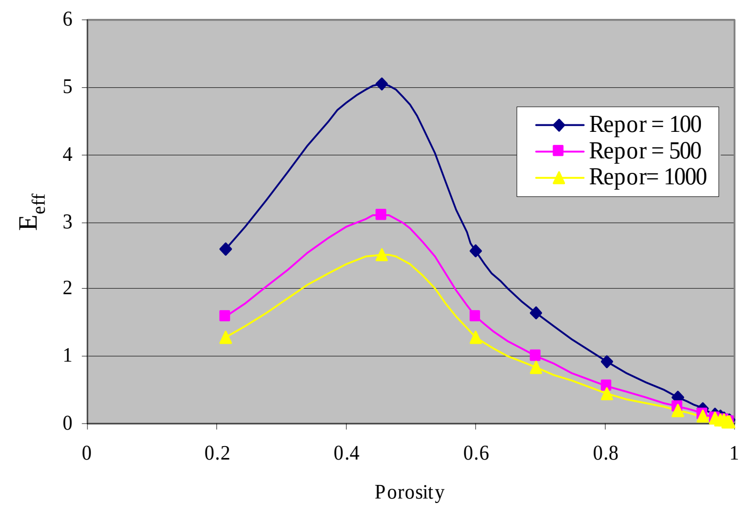
Square rods



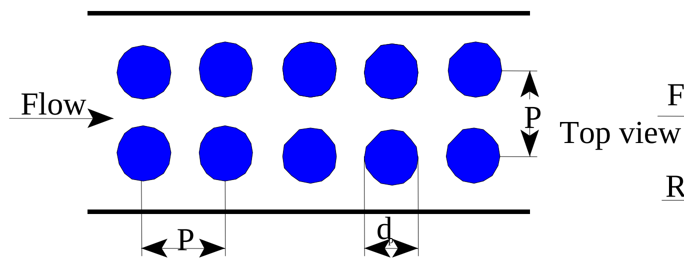


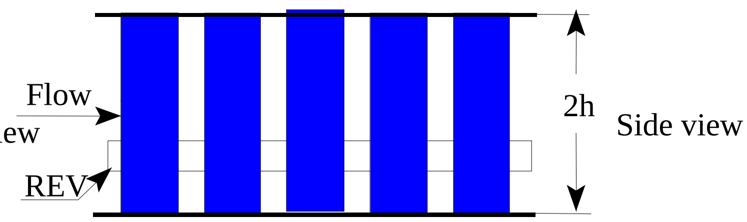
Cylindrical rods

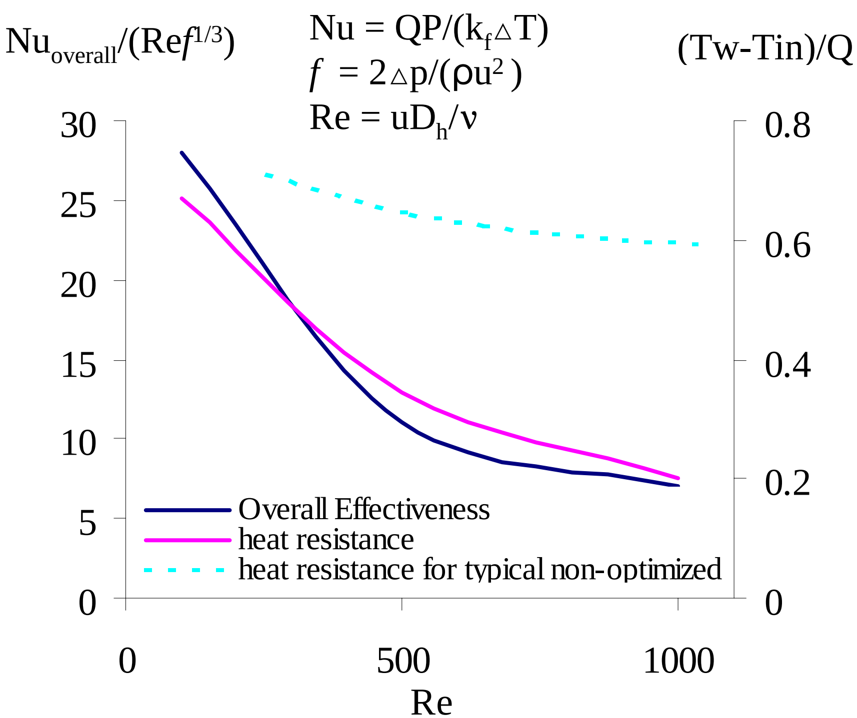


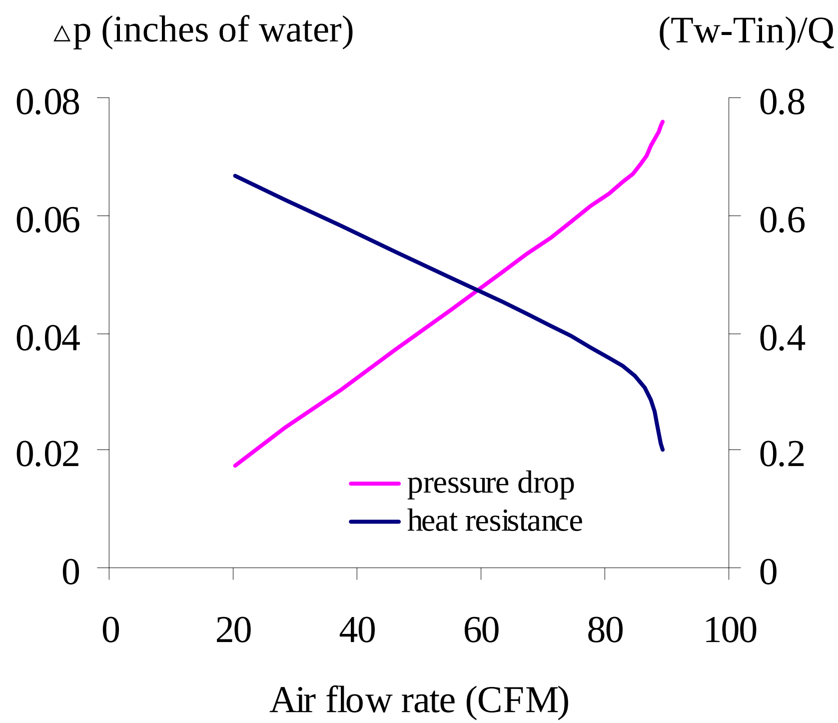


Example of Optimization of Simple Pin Fins



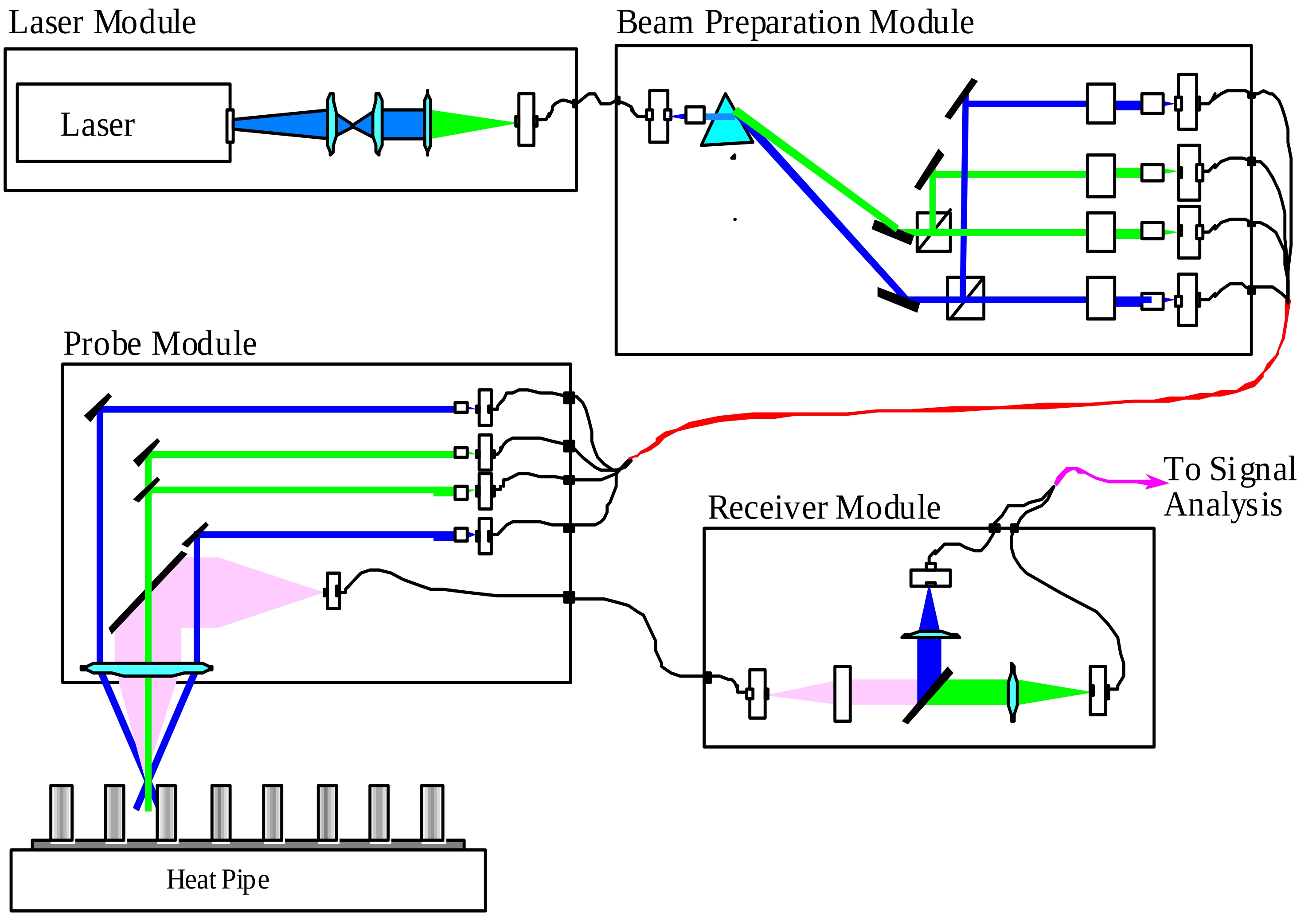




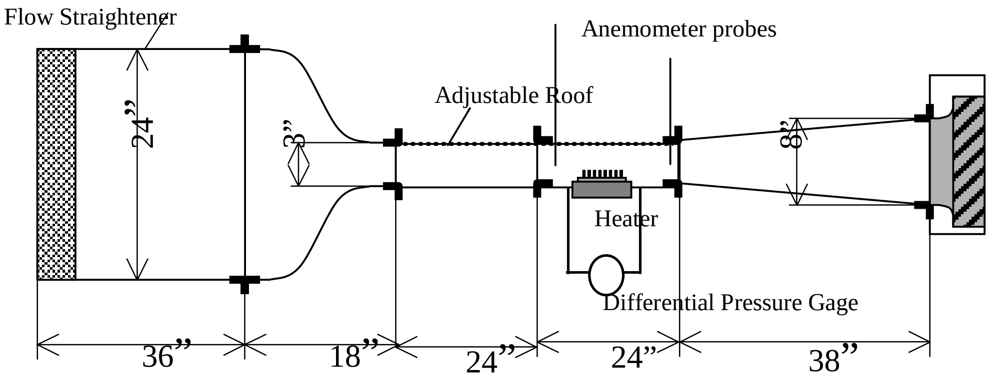


Based on optimal porosity

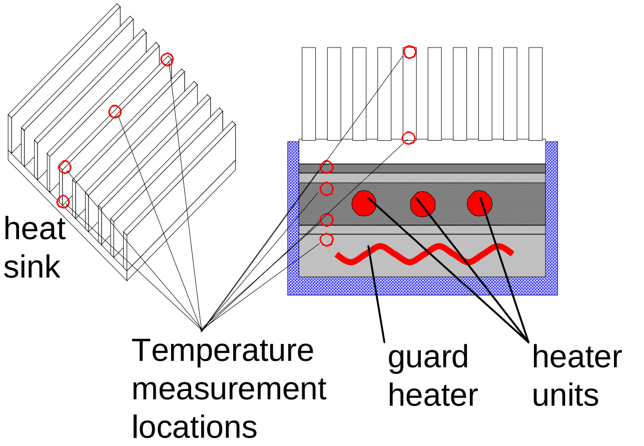
Fiber-optic LDV system overview



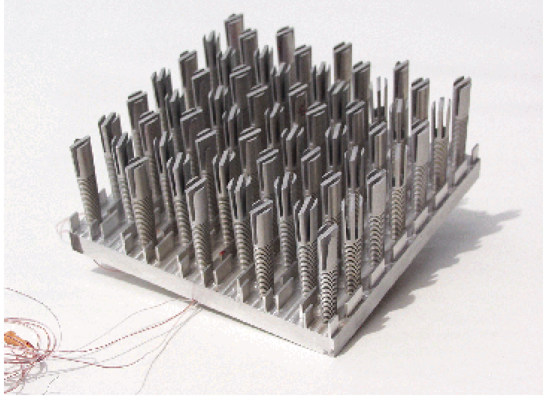
Experimental Test Apparatus

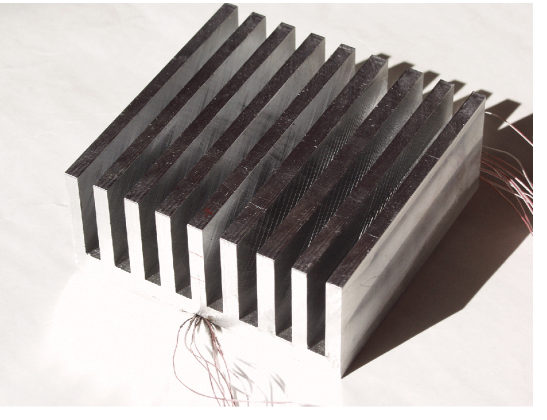


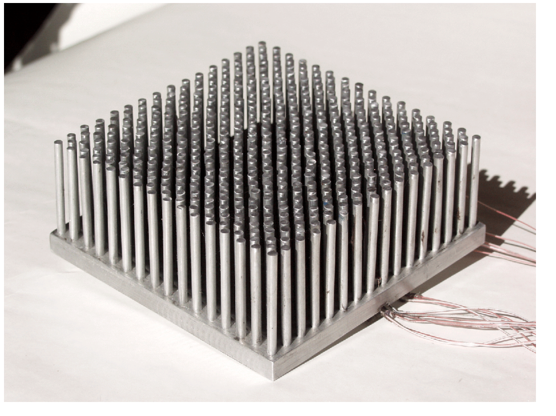
Heat rejection measurement



Tested Heat Transfer Surfaces

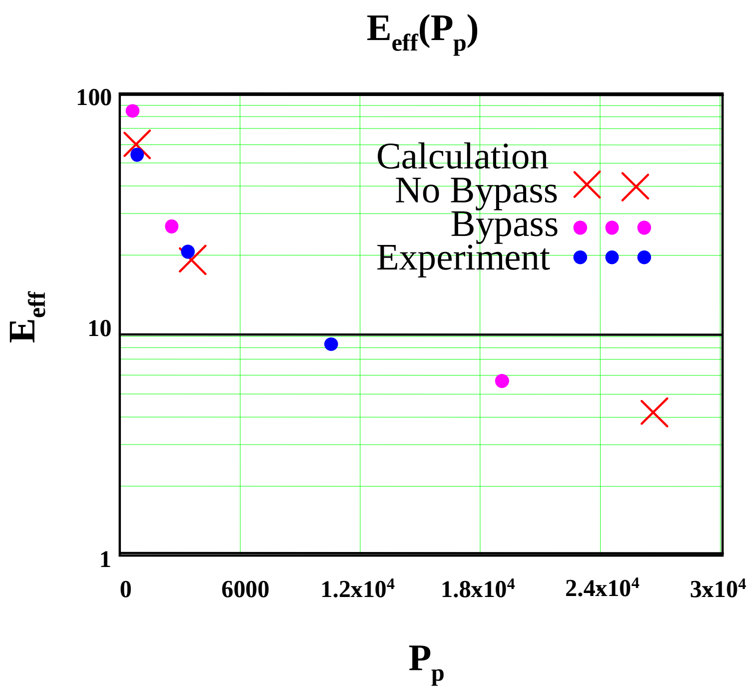




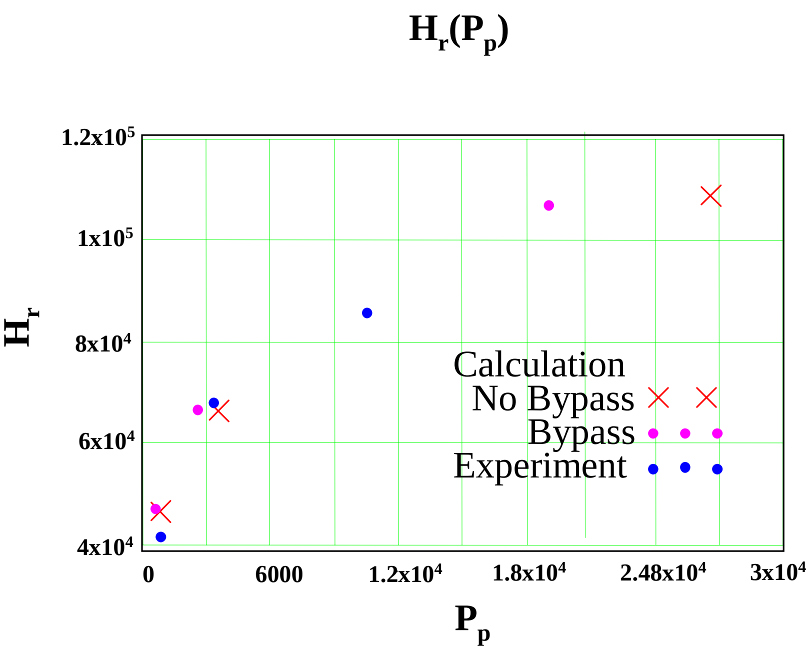


Experimental Investigation

Comparison between numerical simulation and experiment.

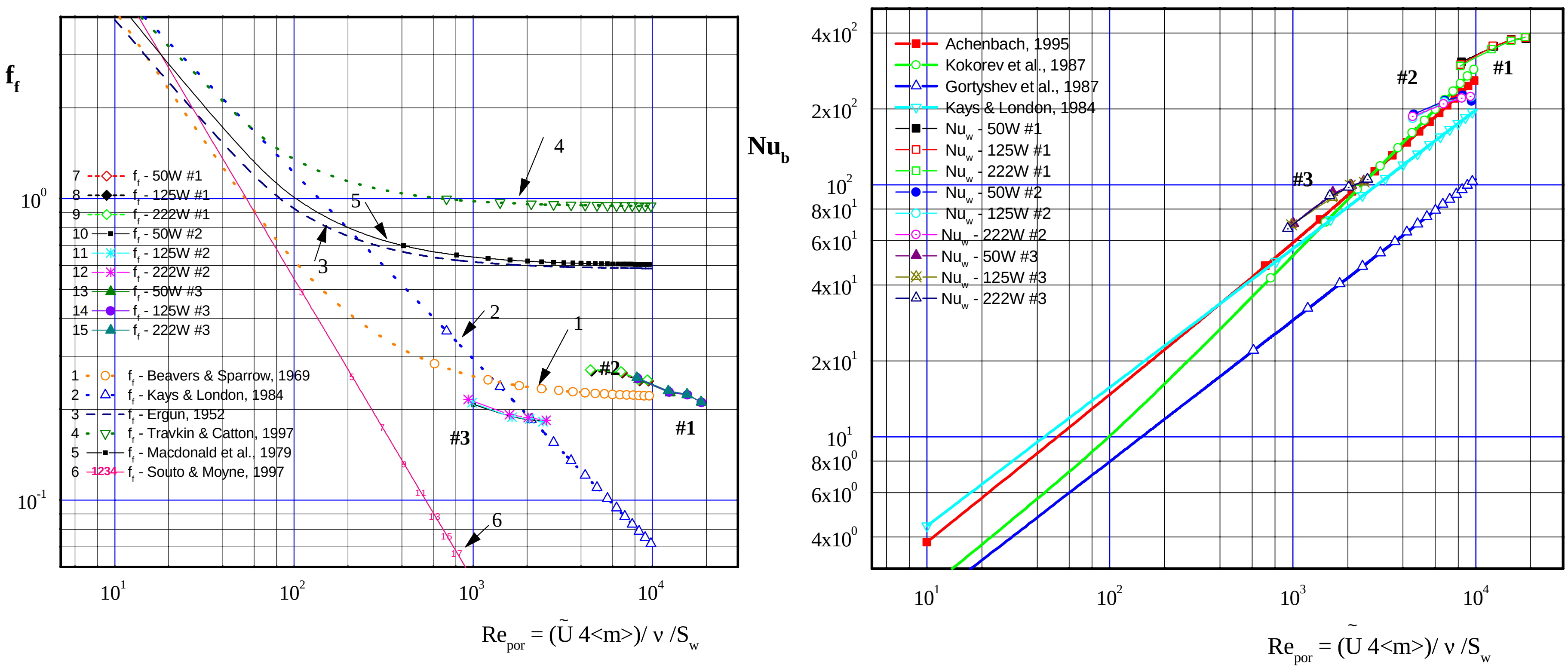


Heterogeneous effectiveness versus power for straight fin heat sink.



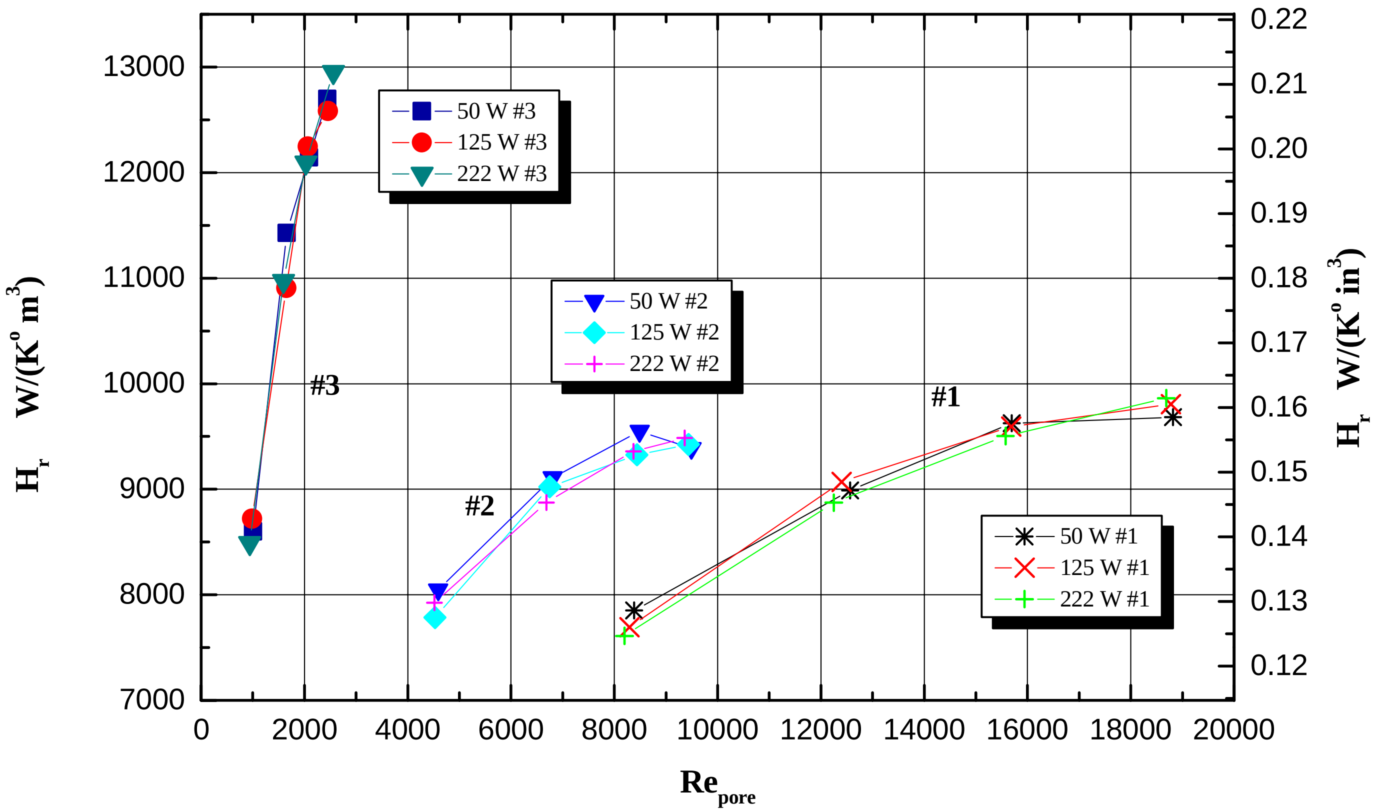
Heat transfer rate versus power for straight fin heat sink.

Experimental Investigation (Cont.)



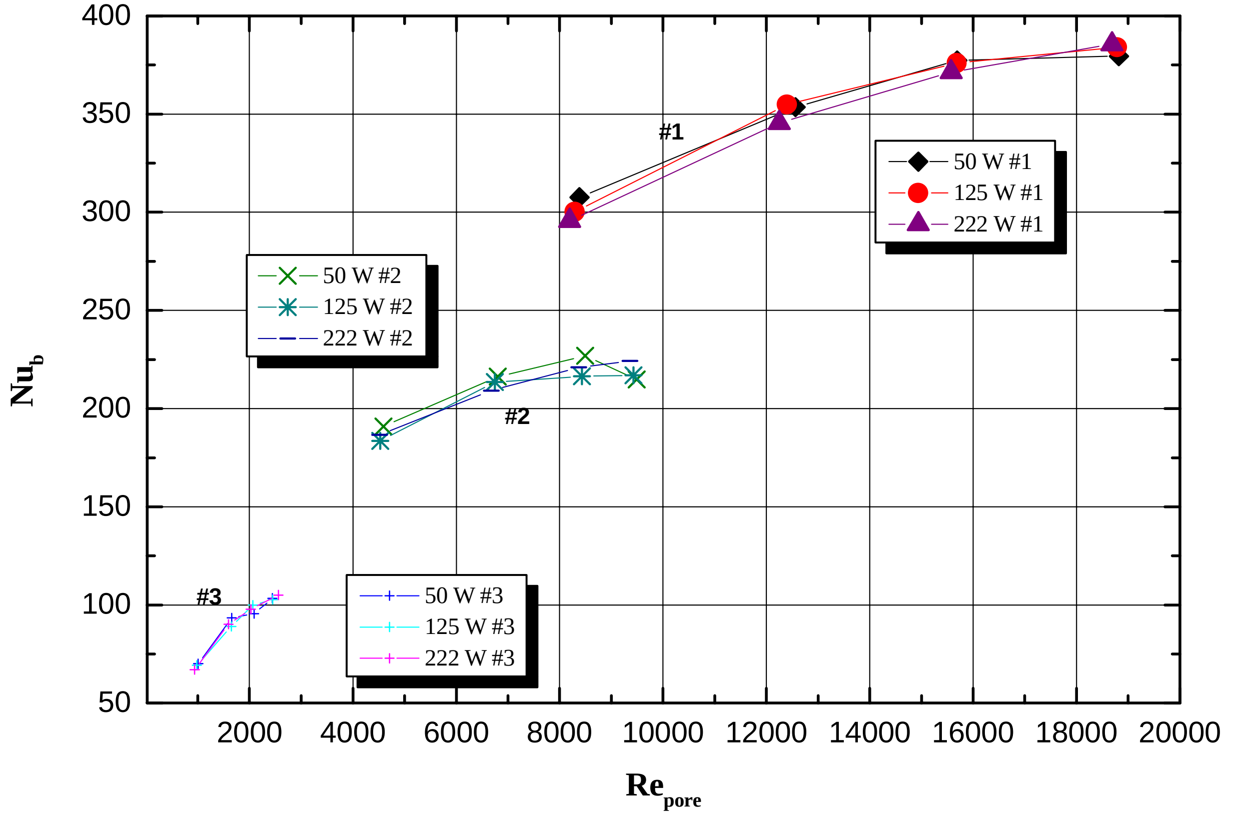
Comparison of *Nu* and f_f for heat sink experimental investigation

Experimental Investigation (Cont.)



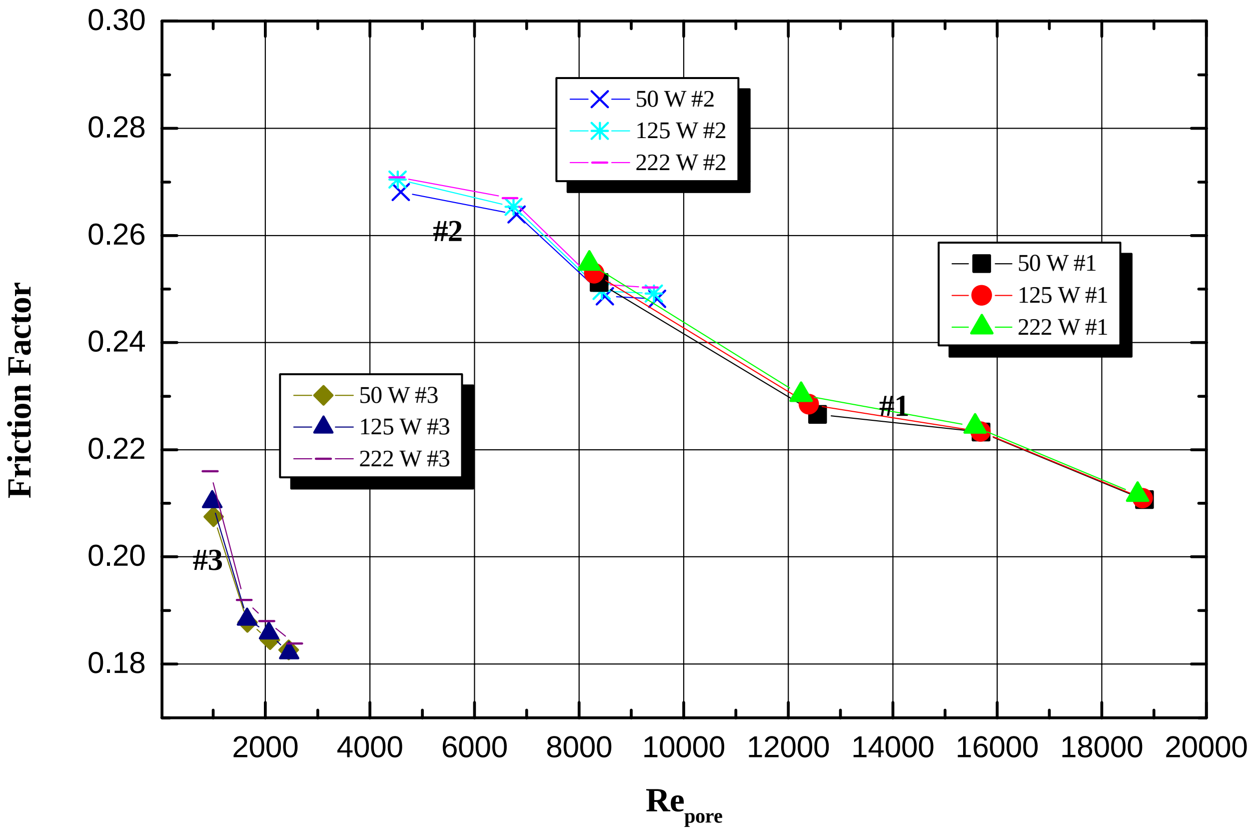
Heat sink heat transfer rate per unit volume per unit temperature difference

Experimental Investigation (Cont.)



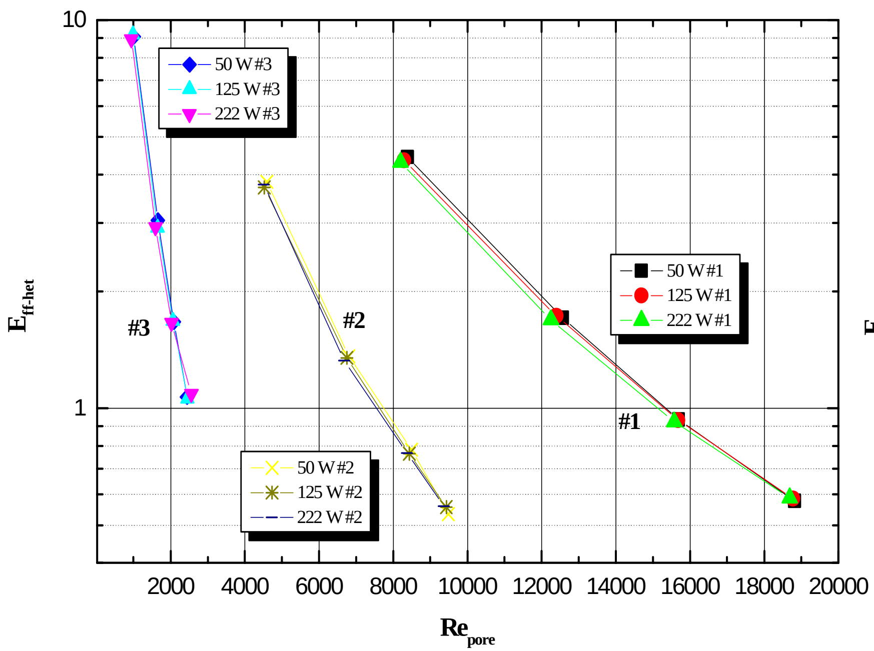
Heat sink conjugate wall Nusselt number

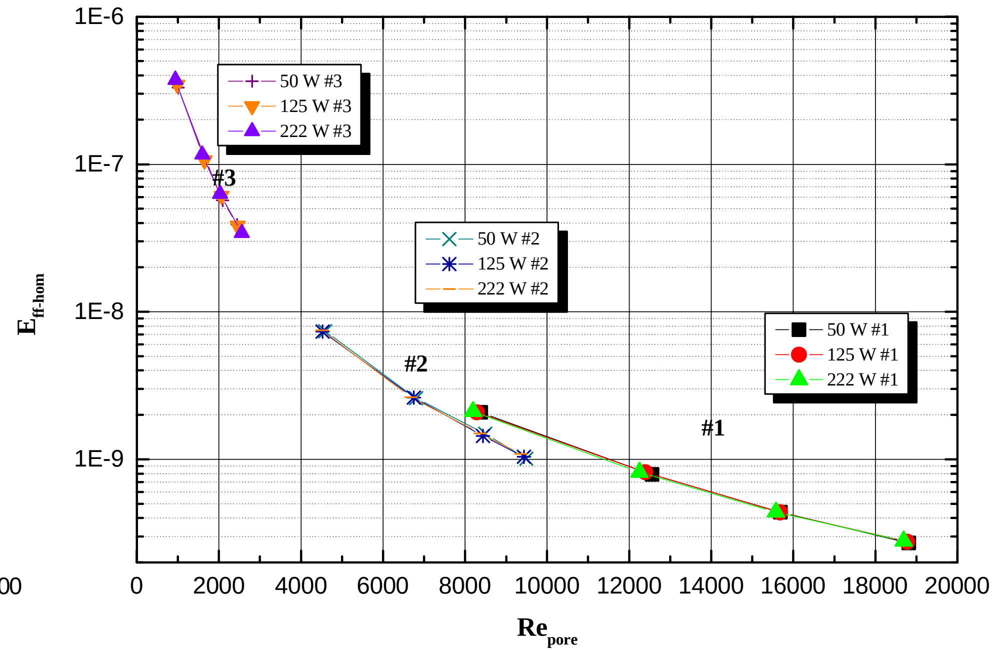
Experimental Investigation (Cont.)



Heat sink friction factor

Experimental Investigation (Cont.)





$$E_{eff-het} = \frac{H_r}{P_p} = \left[\frac{Nu_w}{f_f \, Re_{por}^3} \left(32 \frac{S_b^*}{\langle m_{yz} \rangle} \frac{\langle m \rangle^3}{S_{all}^{*\,3}} \right) \frac{k_f \rho_f^2}{\mu^3} \right], \quad \left[\frac{1}{K} \right],$$

$$E_{eff-\mathrm{hom}} = \left[\frac{Nu_w}{f_f \, Re_{por}^3} \right]$$

Heat sink heterogeneous and homogeneous effectiveness

Concluding Remarks

Accomplishments:

- **Constructed tunnel for augmented surface testing.**
- **Tested base case surfaces.**
- **Developed and demonstrated method for surface optimization.**
- **Selected initial geometric surface characteristics.**
- **Designed and tested new kind of heat sinks.**