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UNIVERSITÉ LAVAL

CANCAM 99

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Experimental Thermal Characterization of a Counterflow Heat Exchanger with Phase Change.

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Outline

- *Introduction*
- *"Projet Échangeur"*
- *Objectives*
- *Experimental apparatus*
- *Results*
- *Conclusions and further developments*

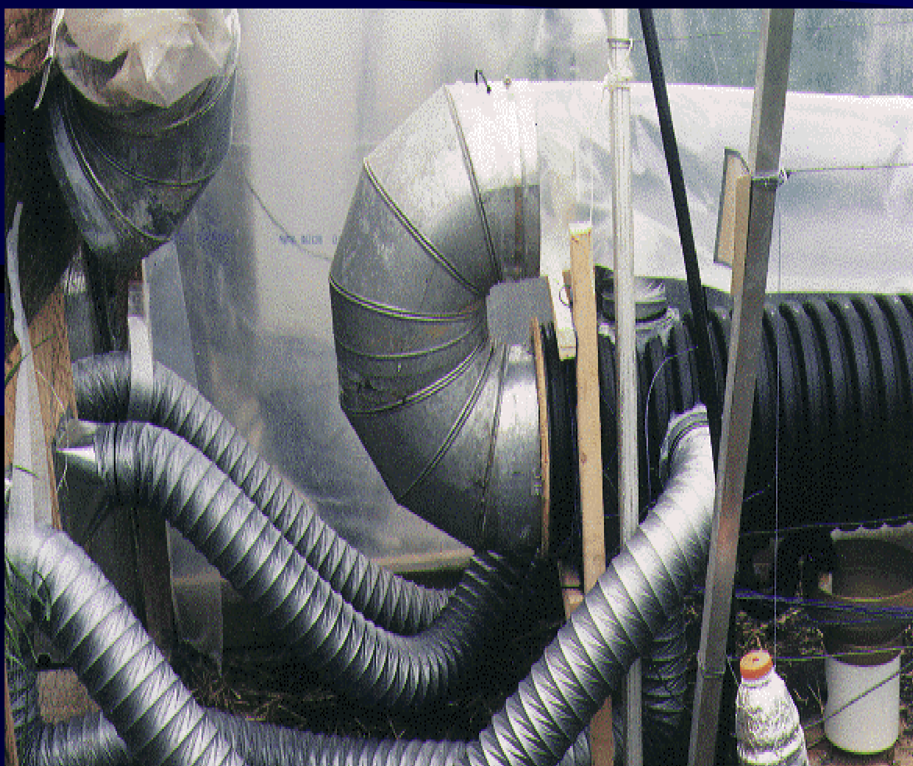
Introduction

- Humidity control in greenhouses
  - Conventional method : Heating/ventilating
  - Air-air heat exchangers

- *"Projet Échangeur""*
  - CIDES, *Center for Info & Exp. Dev. In Greenhouses*
  - MAPAQ, *Food, Fisheries, and Agriculture Ministry*
  - Université Laval, *Energy Research Group*

"Projet Échangeur"

- A first prototype, 1996

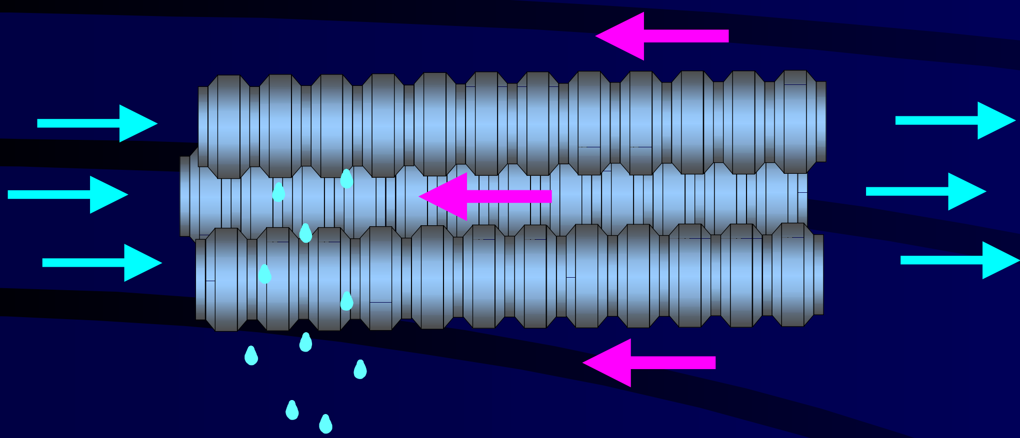


“Projet Échangeur”

- Other heat exchanger prototypes, 1997-1998

"Projet Échangeur"

- Heat exchanger thermal analysis



Sieder – Tate

$$h_i = \frac{k_i}{D_i} Re_i^{0.8} \, \mathrm{Pr}_i^{1/3} \left(\frac{\mu}{\mu_p} \right)_i^{0.14}$$

Nusselt

$$h_o = 0.729 \left[\frac{g \rho_l (\rho_l - \rho_g) k_l^3 h'_{lg}}{N D_o \mu_l (T_{sat} - T_p)} \right]^{1/4}$$

Sieder – Tate

$$h_o = \frac{k_o}{D_o} Re_o^{0.8} \, \mathrm{Pr}_o^{1/3} \left(\frac{\mu}{\mu_p} \right)_o^{0.14}$$

Objectives

- *Determine the condensation profiles on the external wall of the inner tube;*
- *Evaluate the effects of friction on internal heat transfer;*
- *Estimate the effects of corrugations, air mass fraction and velocity on external heat transfer;*
- *Find the empiric correlation that best fits the experimental results.*

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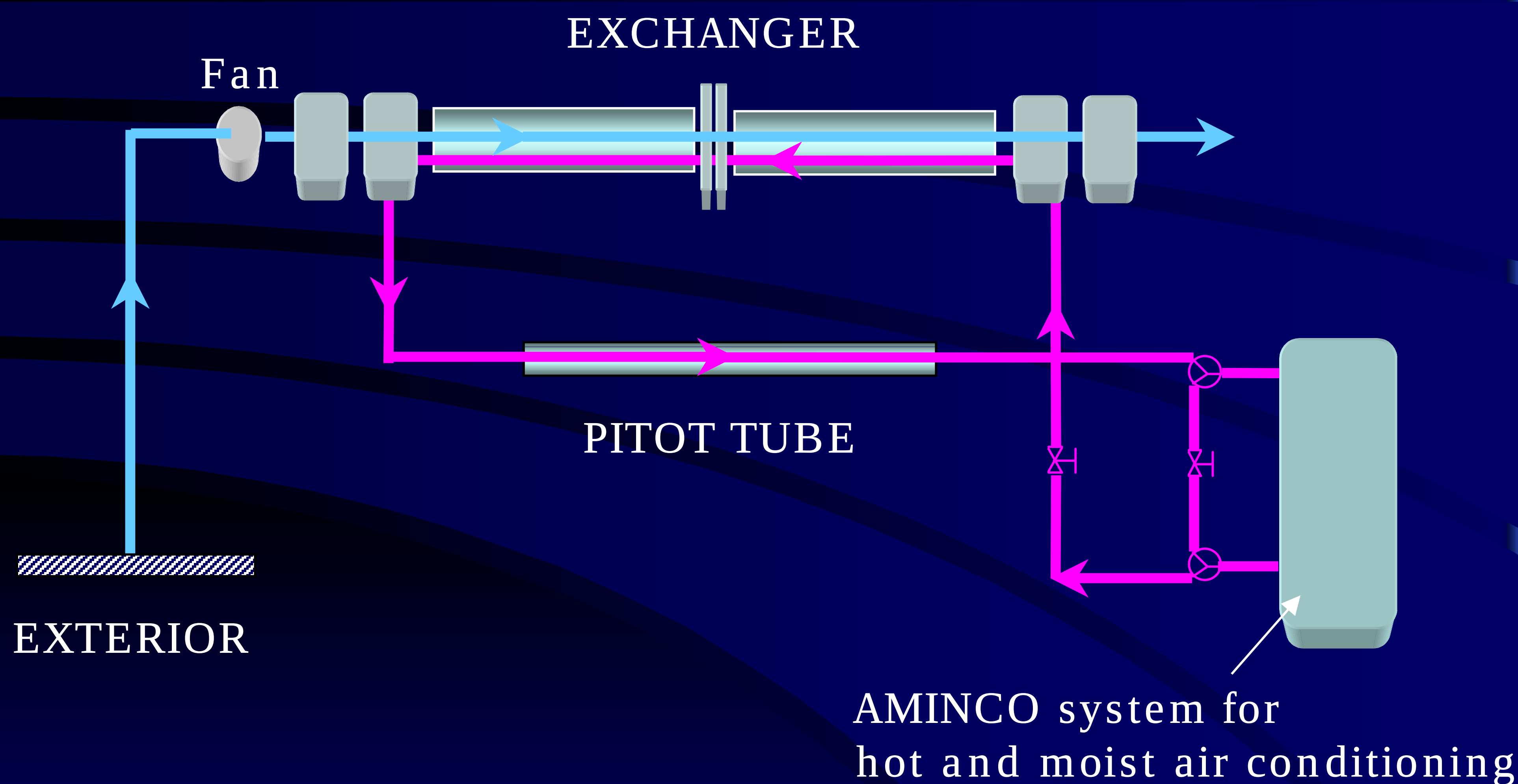
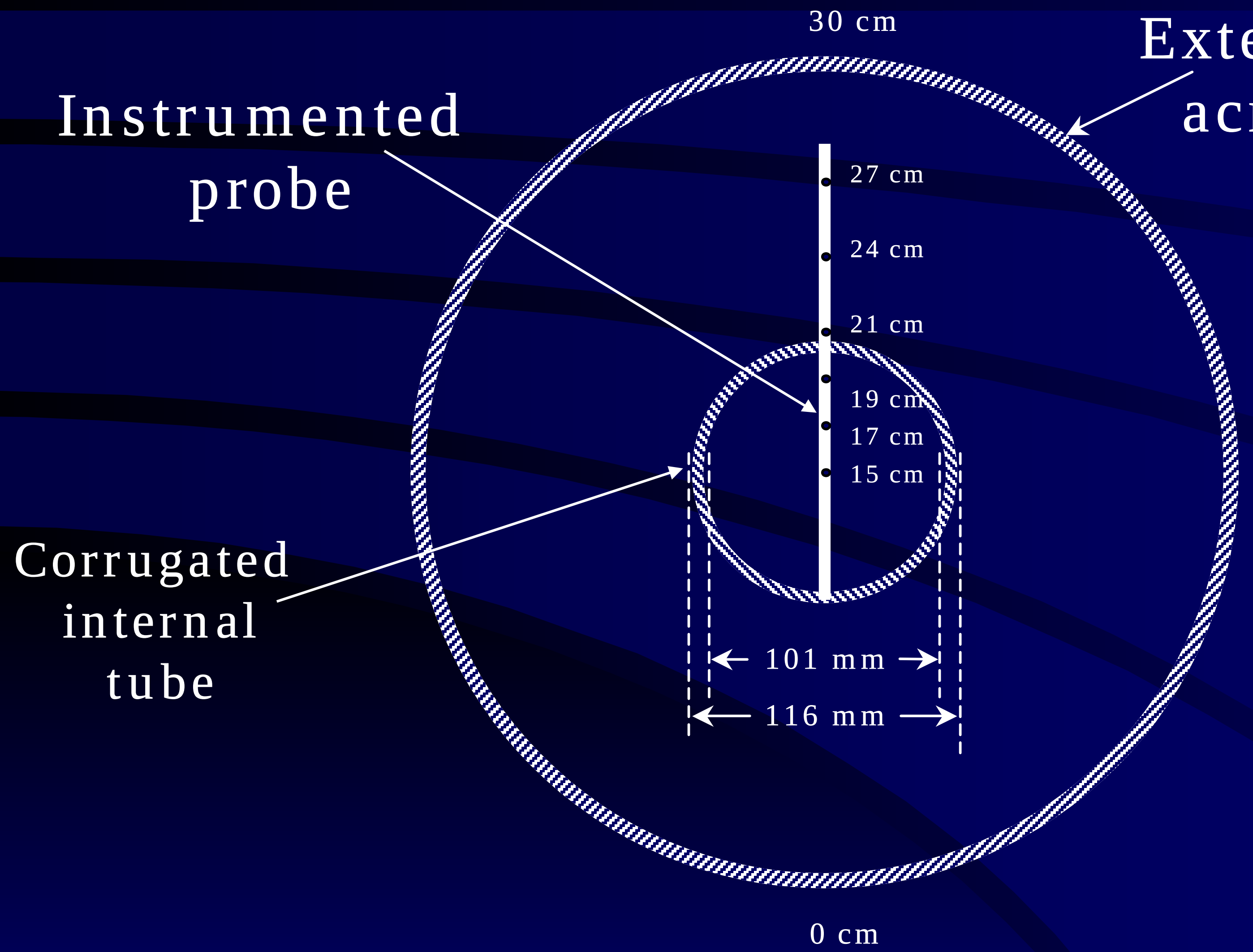
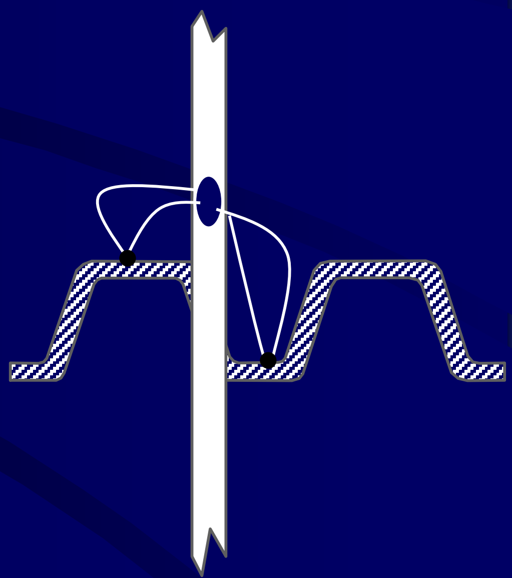
Experimental apparatus



Experimental apparatus

Experimental apparatus





Data analysis

① Direct calculation of h.

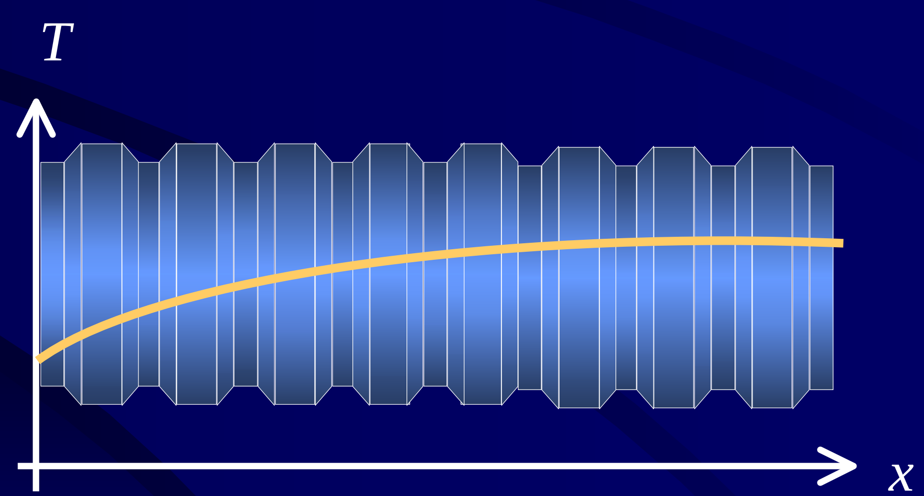
Energy balance

$$q_i'' dA = \dot{m}_c c_{P,c} dT_c$$

Newton's Law of Cooling

$$q_i'' = h_i \left(T_{w,i} - T_c\right)$$

$$h_i = \frac{\dot{m}_c c_{P,c}}{\pi D_i \left(T_{w,i} - T_c\right)} \frac{dT_c}{dx}$$

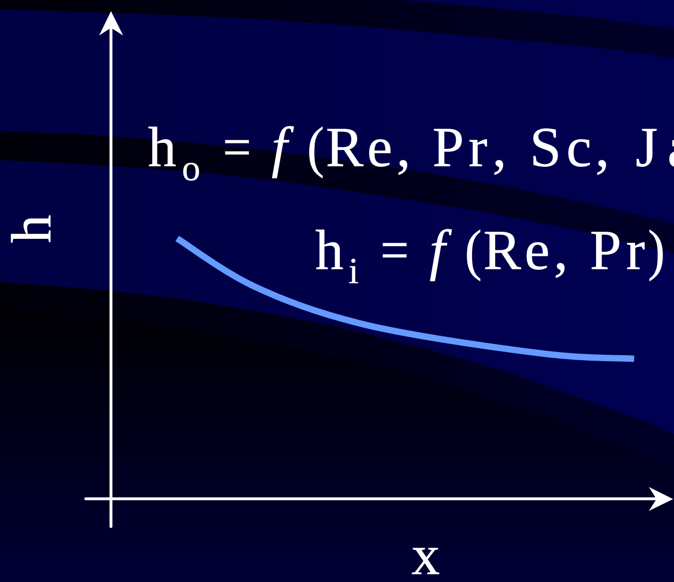


Data analysis

② *Experimental data correlation*

$h_o = f\,(Re, Pr, Sc, Ja, x_a)$

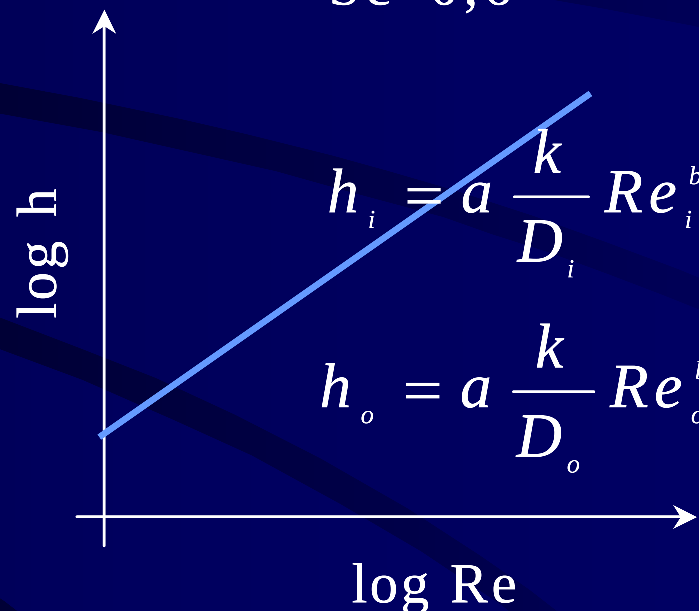
$h_i = f\,(Re, Pr)$



Pr = 0,69
Sc=0,6

$$h_i = a\,\frac{k}{D_i}\,Re_i^{\,b}$$

$$h_o = a\,\frac{k}{D_o}\,Re_o^{\,b}\,Ja^{c}\,x_{air}^{\,d}$$



Data analysis

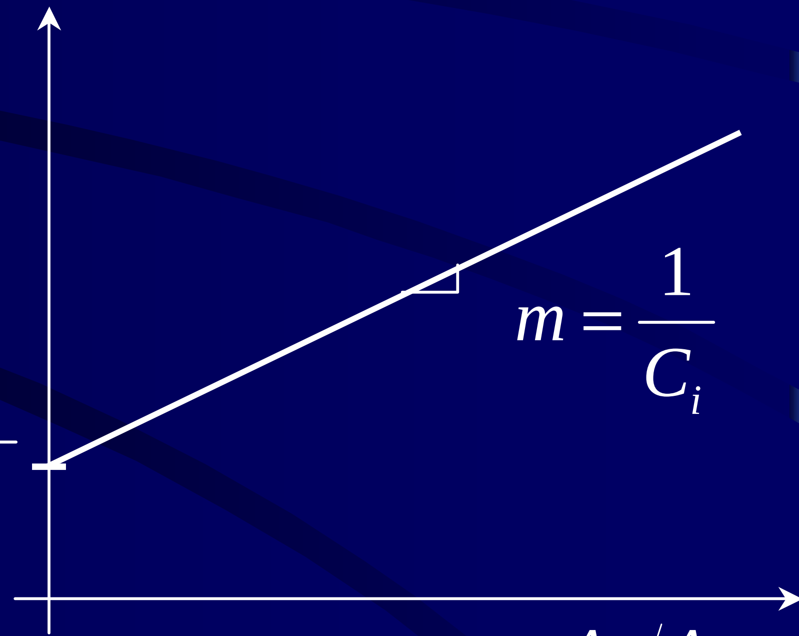
③ Wilson Plot Technique

$$\frac{1}{UA} = \frac{1}{h_i A_i} + R_{eq} + \frac{1}{h_o A_o}$$

$$\left(\frac{1}{U_o} - A_o R_{eq} \right) = \frac{A_o / A_i}{C_i h_i} + \frac{1}{C_o h_o}$$

$$\left(\frac{1}{U_o} - A_o R_{éq} \right) h_o = \frac{A_o / A_i}{C_i h_i} h_o + \frac{1}{C_o}$$

$$y = \left(\frac{1}{U_o} - R_{eq} A_o \right) h_o$$



$$b = \frac{1}{C_o}$$

$$m = \frac{1}{C_i}$$

$$x = \frac{A_o / A_i}{h_i / h_o}$$

Results

- Condensation profiles

①dry-dry regime

②dry-drops regime

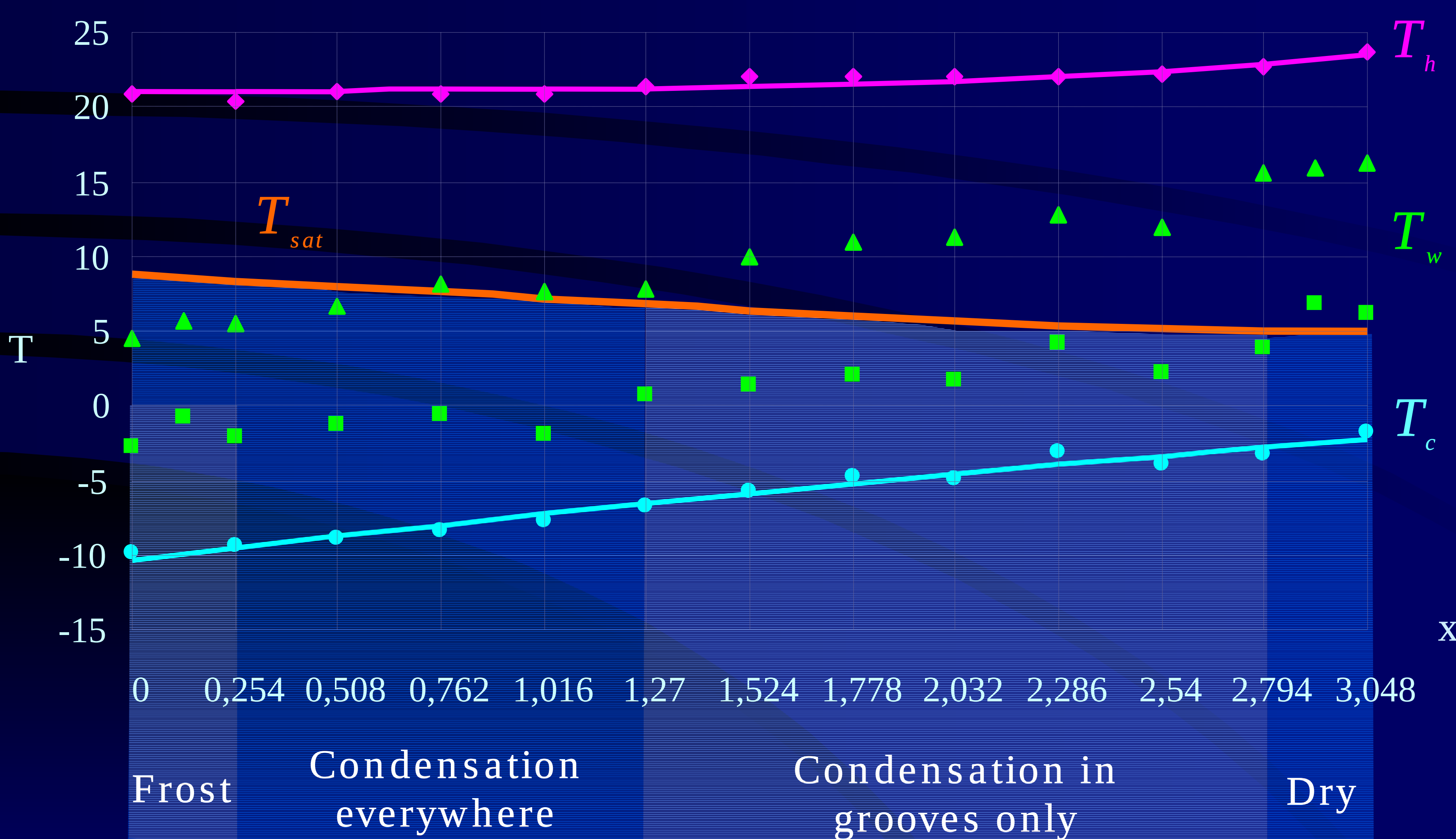
③drops-film regime

④film-film regime

⑤film-frost regime

Results

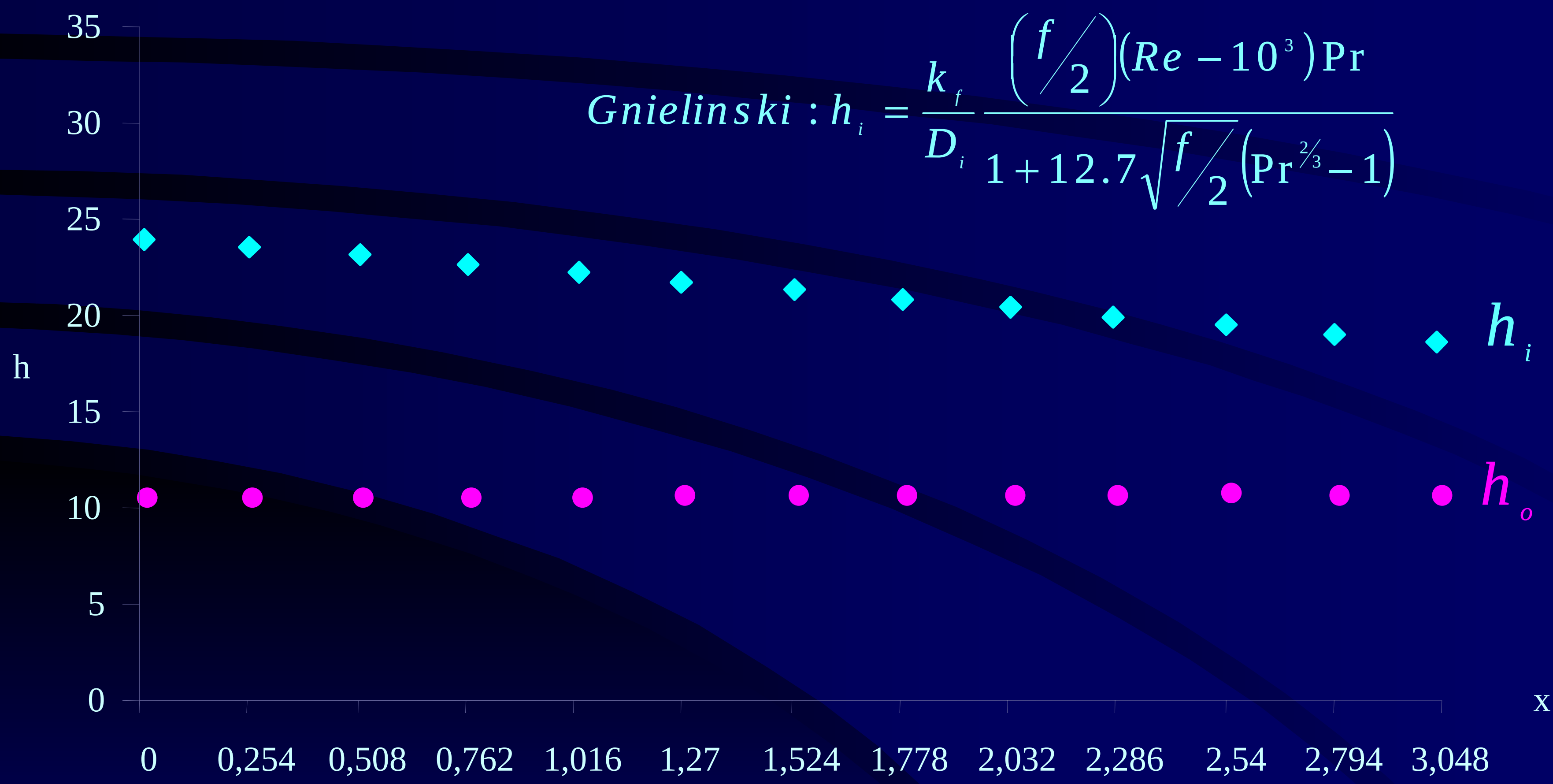
- Temperature profiles



Results

- Heat transfer coefficients

$$Gnielinski: h_i = \frac{k_f}{D_i}\frac{\left(f/2\right)\left(Re-10^3\right)Pr}{1+12.7\sqrt{f/2}\left(Pr^{2/3}-1\right)}$$



Conclusions and further developments

- ✓ *Five condensation regimes established.*
- ✓ *Temperature profiles obtained.*
- ✓ *Experimental heat transfer coefficient estimated.*
- ⚒ *Need for a correlation for the internal and external transfer.*
- ⚒ *Transpose the results for tube banks.*

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Acknowledgments

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by

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"Projet Échangeur"

- Objectives and design limitations
  - Cost < 2000 $CAN; Payback 3 years;
  - Easy to assemble;
  - Low maintenance and repairs;
  - Resistant to corrosion and rot;
  - Good performance under frost conditions.

Temperature profiles

$$T_f(x) = A - B \exp(-Cx)$$

$$T_{p,o}(x) = A + B\,x$$

$$T_c(x) = A + B \exp(Cx)$$

$$T_{p,i} = T_{p,o} - \frac{q_i''}{2\pi\,k}\ln\left(\frac{r_o}{r_i}\right)$$

Empiric relations

$$Sieder-Tate: h_i = \frac{k_i}{D_i} Re_i^{0.8}\, \mathrm{Pr}_i^{1/3} \left(\frac{\mu}{\mu_p}\right)_i^{0.14}$$

$$Gnielinski: h_i = \frac{k_f}{D_i} \frac{\left(f/2\right)\left(Re-10^3\right)\mathrm{Pr}}{1+12.7\sqrt{f/2}\left(\mathrm{Pr}^{2/3}-1\right)}$$

$$Nusselt: h_o = 0.729\left[\frac{g\rho_l\left(\rho_l-\rho_g\right)k_l^3 h'_{lg}}{ND_o\mu_l\left(T_{sat}-T_p\right)}\right]^{1/4}$$

$$Shekriladze-Gomelauri: \bar{h}_o = 0.64\frac{k}{D} Re^{1/2}\left[1+\left(1+1.69\frac{gh'_{lg}\mu_l D}{U_\infty^2 k_l\left(T_{sat}-T_s\right)}\right)^{1/2}\right]^{1/2}$$