Performance Evaluation of Heat Transfer Enhancement in Plate-fin Heat Exchangers with Offset Strip Fins

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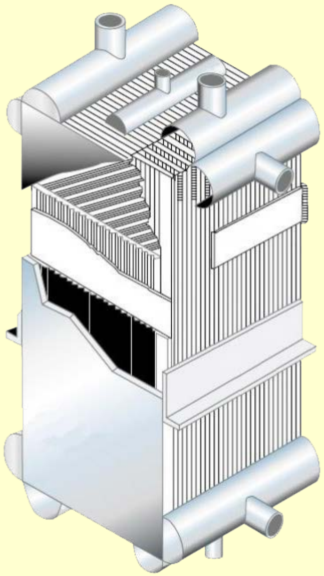
Outline

- Background
- Physical model and entropy generation
- A new evaluation method
- Effects of the geometrical parameters
- Conclusions

Plate-fin heat exchanger



Aerospace

Gases

Automobile

Application

Plate-fin surface

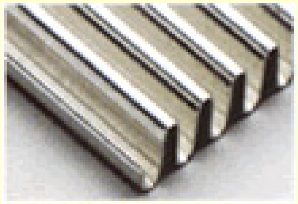
Plain fin

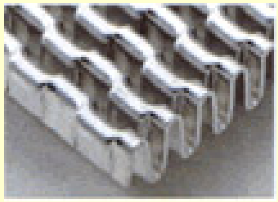
Perforated fin

Offset strip fin

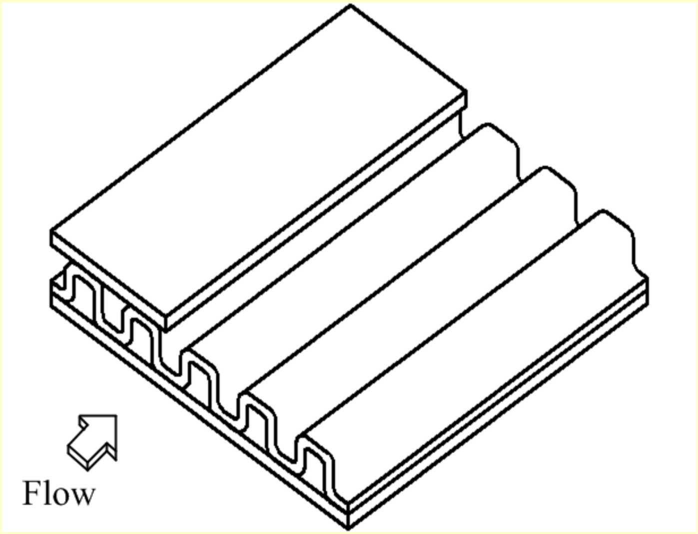
Wavy fin

Louvered fin





Offset Strip Fin (OSF)

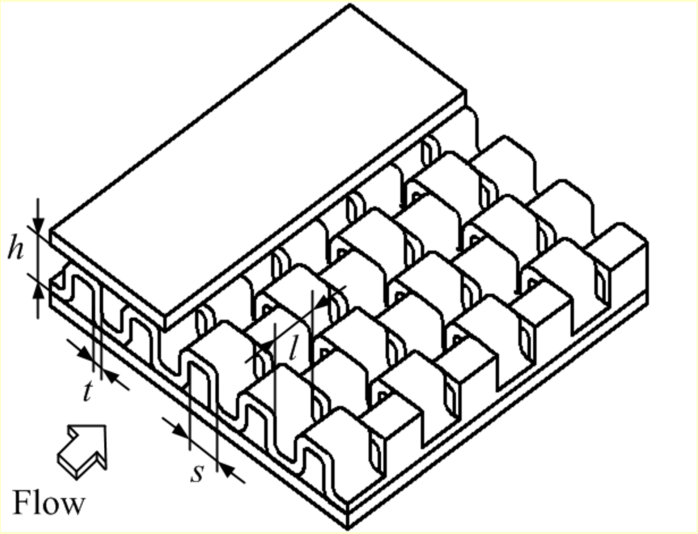


Heat transfer

Pressure drop

Enhanced heat transfer

Increased pressure drop



Non-dimensional parameters:

The fin thickness-to-height ratio $\alpha = (t/h)$

Fin density $\gamma = (t/s)$

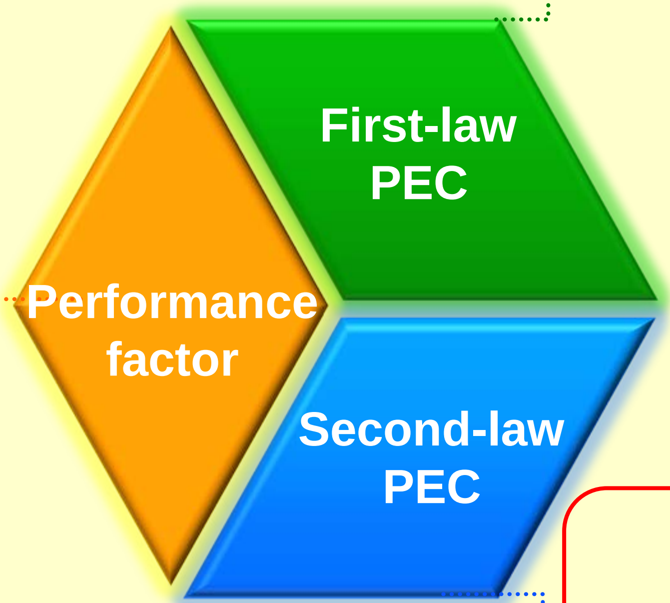
The fin thickness-to-length ratio $\delta = (t/l)$

Performance evaluation criteria (PEC)

1

***JF* factor**

$$JF = \frac{j_a / j_o}{(f_a / f_o)^{1/3}}$$



2

The performance objectives

- reducing surface area;
- increasing heat duty;
- reducing pumping power.

3

Relative comparison of entropy generation

Khoshvaght-Aliabadi M, Hormozi F and Zamzamian A, *Int J Therm Sci* 2014, 79:183-93.
Webb RL, *Int J Heat Mass Tran* 1981, 24:715-26.

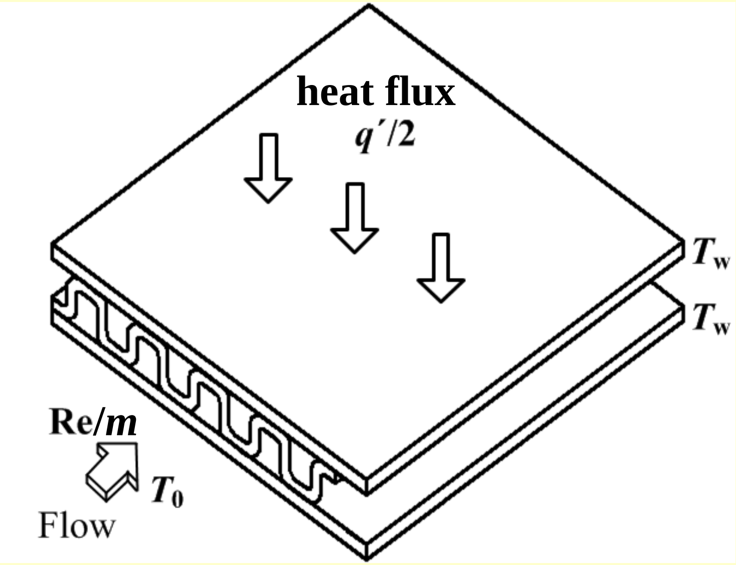
Physical model and entropy generation

Boundary condition:

Constant wall temperature

Assumptions:

The thermo-physical properties of the fluid are constant.



Entropy Generation:

$$\frac{dS_{gen}}{dx} = -mC_p \frac{T - T_w}{TT_w}\frac{dT}{dx} + \frac{m}{\rho T}\left(-\frac{dp}{dx}\right)$$

$$\theta = \theta_0 \exp\left(-\frac{h}{\rho u C_p}\frac{4x}{D_h}\right)$$

$$\Rightarrow S_{gen} = mC_p\left\{\tau_0\varepsilon + \ln\left[\frac{1+\tau_0(1-\varepsilon)}{1+\tau_0}\right]\right\} + \frac{f}{2j}\frac{m^3 \Pr^{2/3}}{\rho^2 A_c^2 T_w}\ln\left[\frac{1+\tau_0(1-\varepsilon)}{(1+\tau_0)(1-\varepsilon)}\right]$$

Important parameters:

Relative temperature difference $\tau_0 = \dfrac{T_0 - T_w}{T_w}$ **Reynolds number** $\mathrm{Re}_a = \dfrac{D_{h,a}}{D_{h,o}}\mathrm{Re}_o$

Prasad RC, Shen J. *Int J Heat Mass Tran* 1993; 36:4193-7.

The second-law PEC

Augmentation entropy generation number

$\boldsymbol{N_{s,a}}$ ($N_{s,a}$ <1 is desirable)

$$N_{s,a} = \frac{S_{gen,a}}{S_{gen,o}} = \frac{S_{gen,a,\Delta T} + S_{gen,a,\Delta p}}{S_{gen,o,\Delta T} + S_{gen,o,\Delta p}}$$

Entropy generation distribution factor

$\boldsymbol{\psi}$ (ψ >1 is desirable)

$$\psi = \frac{S_{gen,o,\Delta T} - S_{gen,a,\Delta T}}{S_{gen,a,\Delta p} - S_{gen,o,\Delta p}}$$

Bejan A and Pfister JPA, *Lett Heat Mass Transfer* 1980; 7:97-106.
Manglik RM and Fang PP. *in: Proceedings of the IHTC10*, Brighton, England, 1994, 67-72.

The second-law PEC

The dimensionless entropy generation

$$S_{gen} \Rightarrow N_{s1} = \frac{T_w \cdot S_{gen}}{Q}$$

The irreversibility distribution ratio

$$\phi_0 = \frac{N_{s1,o,\Delta p}}{N_{s1,o,\Delta T}}$$

$$N_{s,a} = \frac{S_{gen,a}}{S_{gen,o}} = \frac{S_{gen,a,\Delta T} + S_{gen,a,\Delta p}}{S_{gen,o,\Delta T} + S_{gen,o,\Delta p}}$$

$$\Downarrow$$

$$N_{s1}^{*} = \frac{N_{s1,a}}{N_{s1,o}} = \frac{N_{s1,a,\Delta T} + N_{s1,a,\Delta p}}{N_{s1,o,\Delta T} + N_{s1,o,\Delta p}} = \frac{N_{s1,\Delta T}^{*} + \phi_0 N_{s1,\Delta p}^{*}}{1 + \phi_0}$$

N^{*}_{s1} <1 is desirable

$$\psi = \frac{S_{gen,o,\Delta T} - S_{gen,a,\Delta T}}{S_{gen,a,\Delta p} - S_{gen,o,\Delta p}}$$

$$\Downarrow$$

$$\Psi = \frac{N_{s1,o,\Delta T} - N_{s1,a,\Delta T}}{N_{s1,a,\Delta p} - N_{s1,o,\Delta p}} = \frac{1}{\phi_0}\frac{1 - N_{s1,\Delta T}^{*}}{N_{s1,\Delta p}^{*} - 1}$$

Ψ >1 is desirable

Hesselgreaves JE. *Int J Heat Mass Tran* 2000; 43:4189-204.

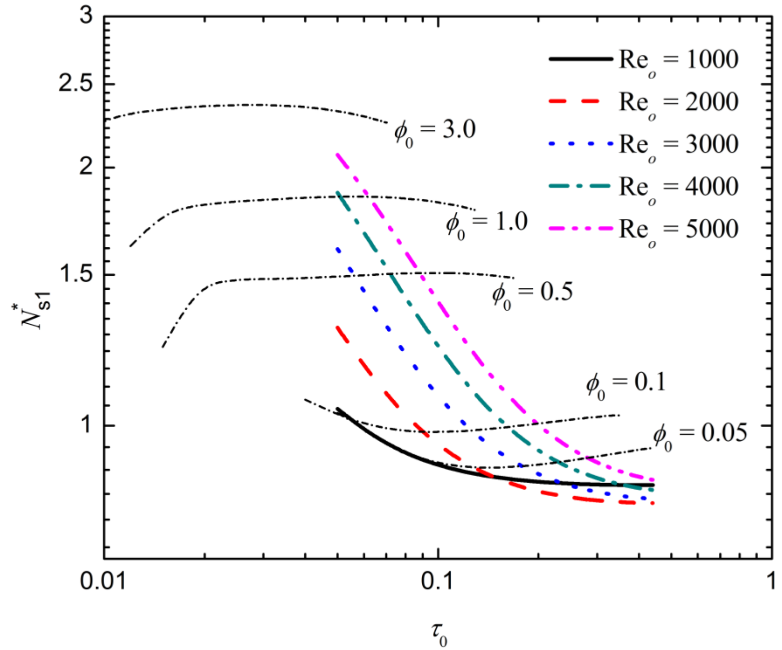
The second-law PEC

Relative temperature difference $\tau_0 = \dfrac{T_0 - T_w}{T_w}$

The irreversibility distribution ratio $\phi_0 = \dfrac{N_{s1,o,\Delta p}}{N_{s1,o,\Delta T}}$

- **Fig. 1 N^*_{s1} vs. τ_0**
- **It is more advantageous to use OSFs under larger temperature difference.**

1



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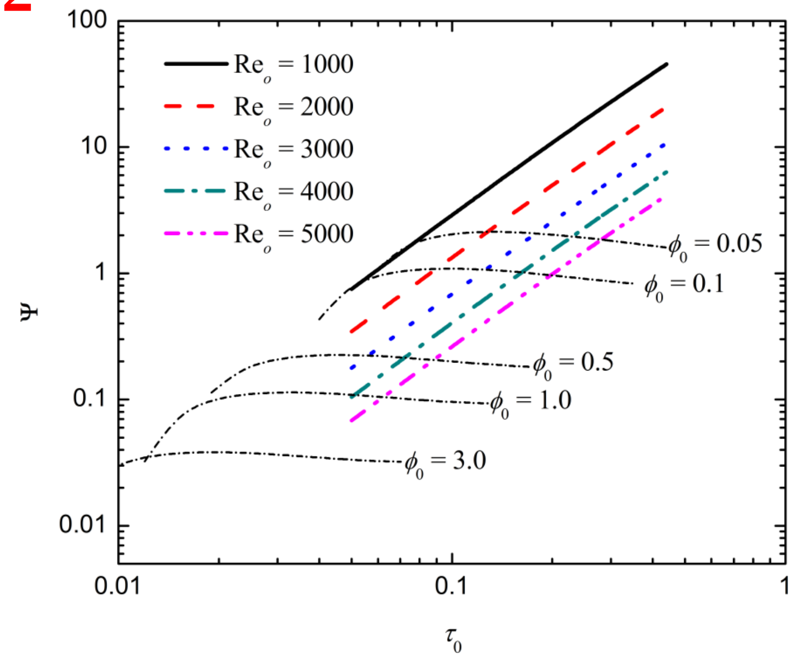


- **Fig. 2 Ψ vs. τ_0**
- **The conditions with high irreversibility of heat transfer are desirable.**

A New evaluation method

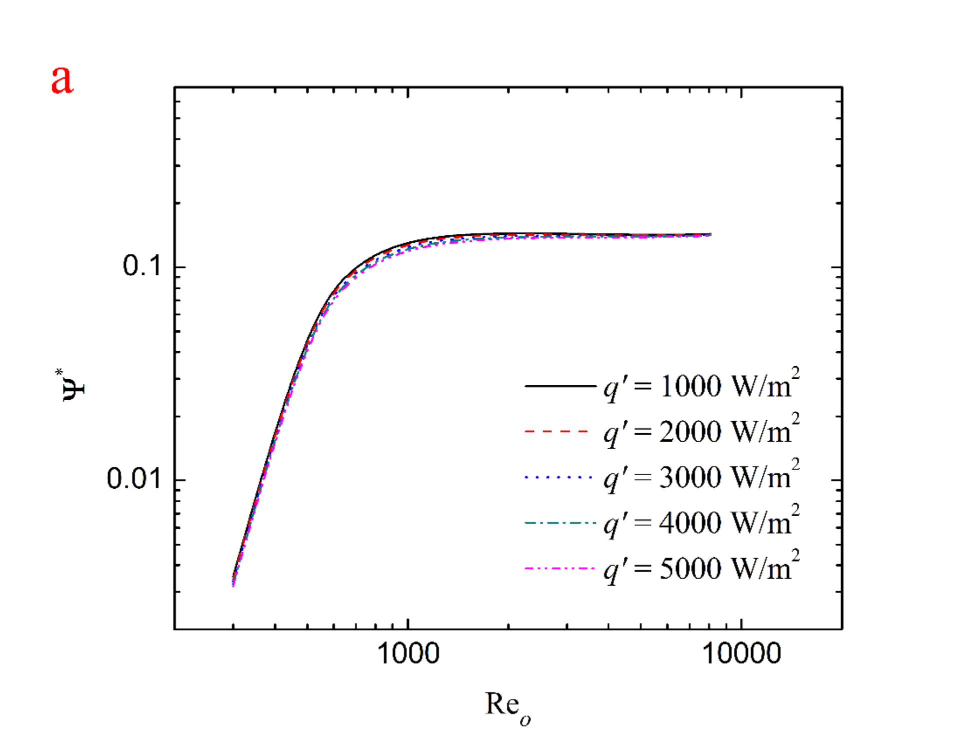
Relative entropy generation distribution factor, Ψ^*

$$\Psi^* = \frac{\left(N_{s1,o,\Delta T} - N_{s1,a,\Delta T}\right) / N_{s1,o,\Delta T}}{\left(N_{s1,a,\Delta p} - N_{s1,o,\Delta p}\right) / N_{s1,o,\Delta p}} = \frac{1 - N^*_{s1,\Delta T}}{N^*_{s1,\Delta p} - 1}$$

The higher the Ψ^* value, the higher the degree of the heat transfer enhancement.

The evaluation results of Ψ^*

- Fig. a Ψ^* vs. Re_o with heat flux q' as a parameter



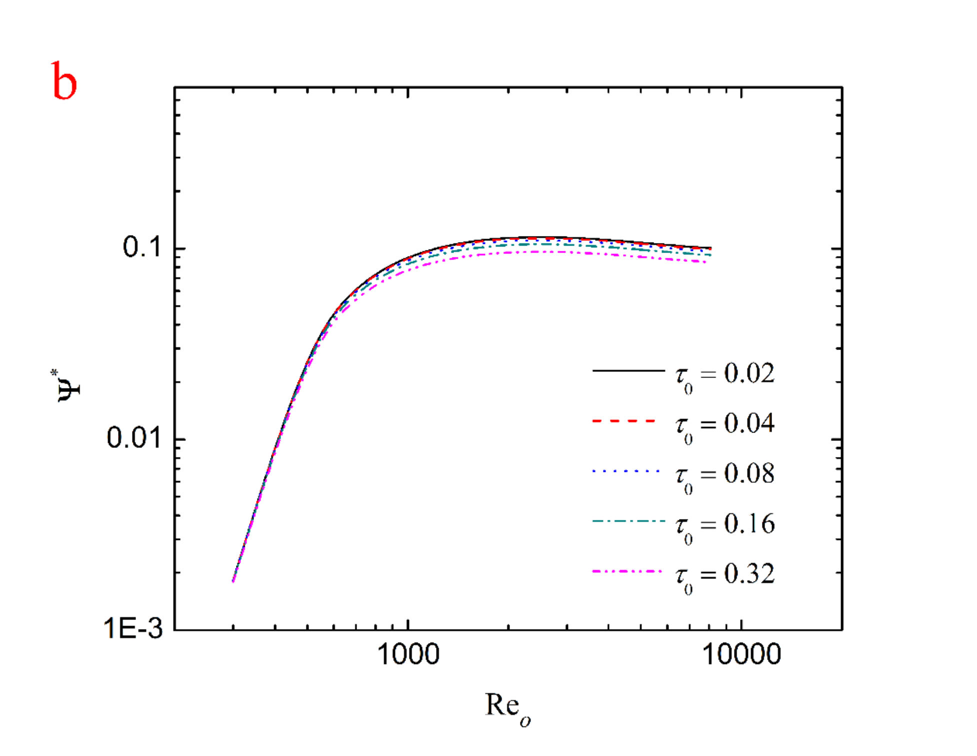
- The q' has little influence on Ψ^*
- Ψ^* is a strong function of Re_o

The evaluation results of Ψ^*

Relative temperature difference on the inlet $\tau_0 = \frac{T_0 - T_w}{T_w}$

- **Fig. b Ψ^* vs. Re_o with τ_0 as a parameter.**

- **The performance of heat transfer enhancement of OSF fin degrades as τ_0 is increased.**

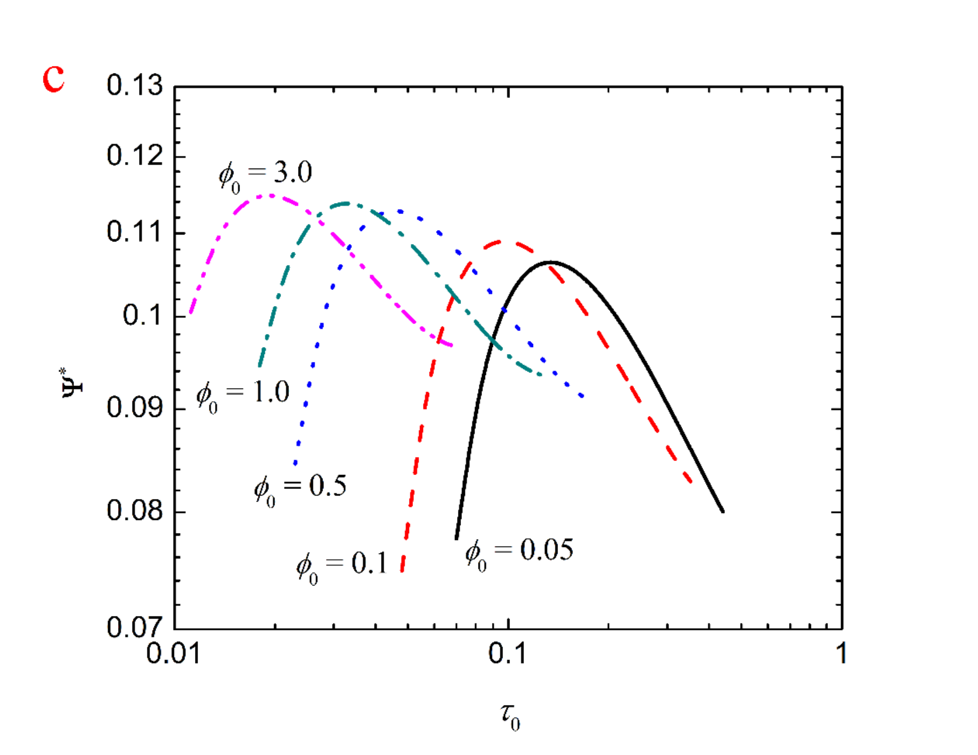


The evaluation results of Ψ^*

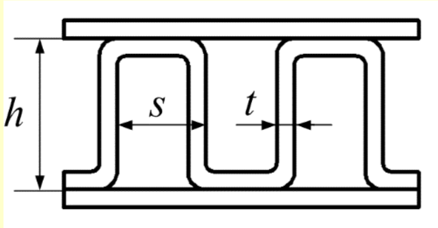
The irreversibility distribution ratio $$\phi_0 = \frac{N_{s1,o,\Delta p}}{N_{s1,o,\Delta T}}$$

- **Fig. c Ψ^* vs. τ_0 with ϕ_0 as a parameter.**

- **For a particular ϕ_0, there exists optimum condition of τ_0 and Re_o which corresponds to the maximum Ψ^*.**



Effects of the geometric parameters

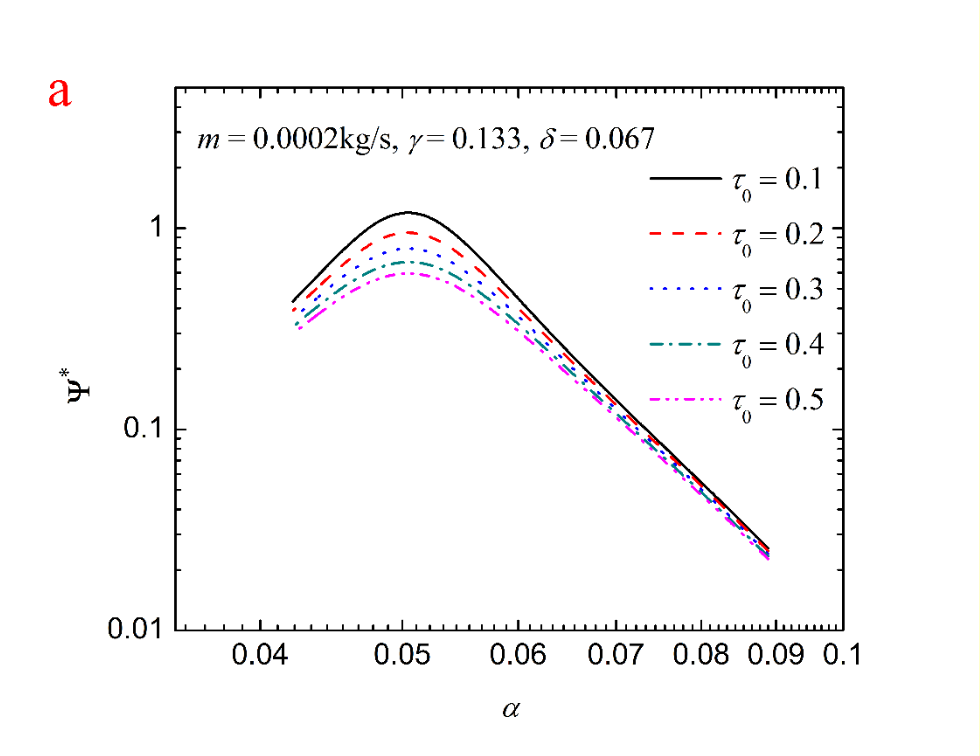


The fin thickness-to-height ratio $\alpha = (t/h)$

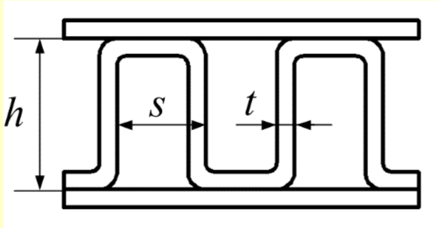
- Fig. a Ψ^* vs. α with τ_0 as a parameter.

- Range: α = 0.042-0.089.

- The optimum α = 0.051.



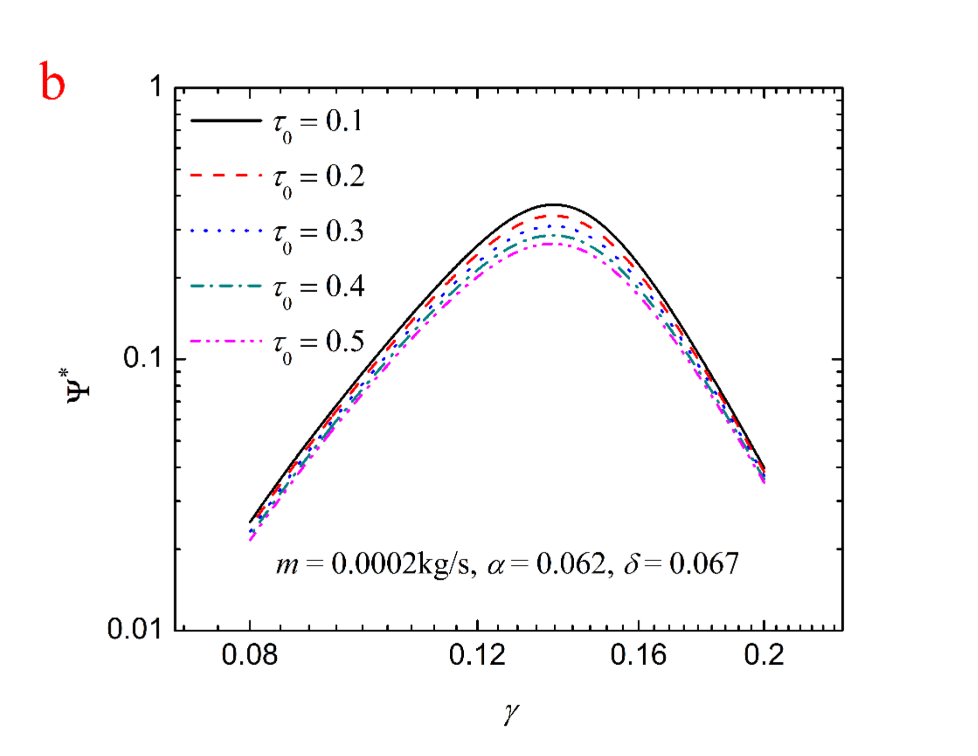
Effects of the geometric parameters



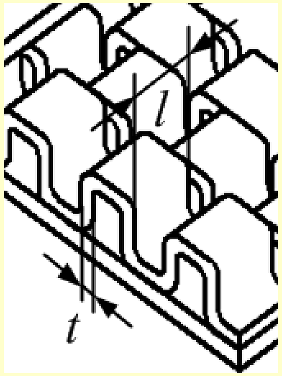
Fin density $\gamma = (t/s)$

- Fig. b Ψ^* vs. γ with τ_0 as a parameter.

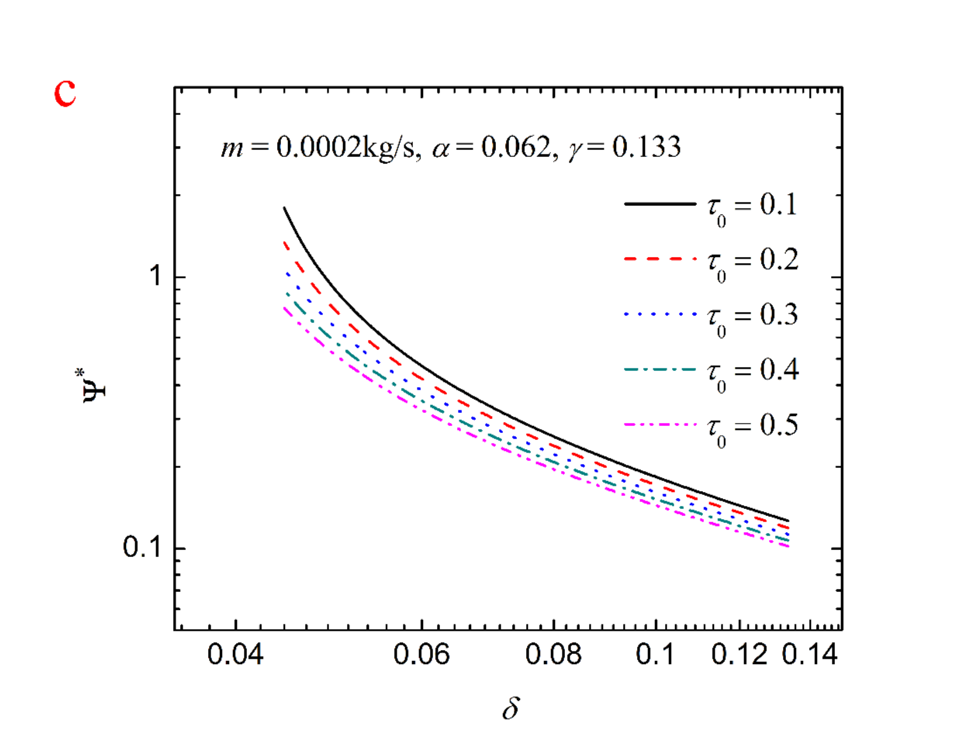
- Range: γ = 0.08-0.2.
- The optimum γ = 0.138.



Effects of the geometric parameters



The fin thickness-to-length ratio $\delta = (t/l)$



- **Fig. c Ψ^* vs. δ with τ_0 as a parameter**
- **Range: δ = 0.04-0.133.**
- **Smaller δ is desirable.**

Conclusion

- **A new evaluation method is proposed to evaluate the performance of heat transfer enhancement of OSFs.**
- **The proposed method provides rational evaluations under different operating conditions.**
- **There exist the optimum geometric parameters that maximize the degree of heat transfer enhancement of OSFs.**

Thanks for your attention !

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