CEEE CENTER *for* ENVIRONMENTAL ENERGY ENGINEERING

CFD-Based Correlation Development for Air Side Performance of Wavy Fin Tube Heat Exchangers using 2mm-5mm Tube Diameters

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Introduction

- Wavy fin and round tube heat exchangers are suitable for applications such as heat pumps in cold climates
  - Lower performance degradation compared to louvered and slit fins (Silva et al., 2011; Huang et al., 2014)
- Small tube diameters (below 5.0mm) result in more compact surfaces and better thermal performance (Bacellar et al. 2014, 2015, 2016)

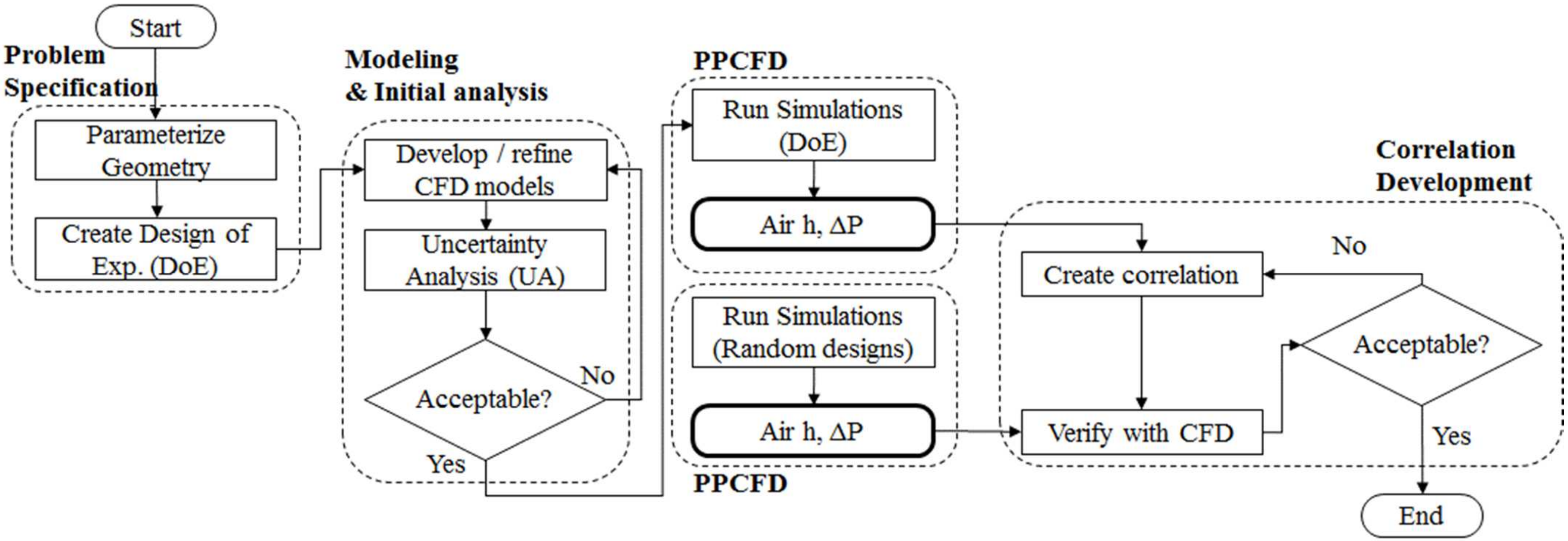
Objectives

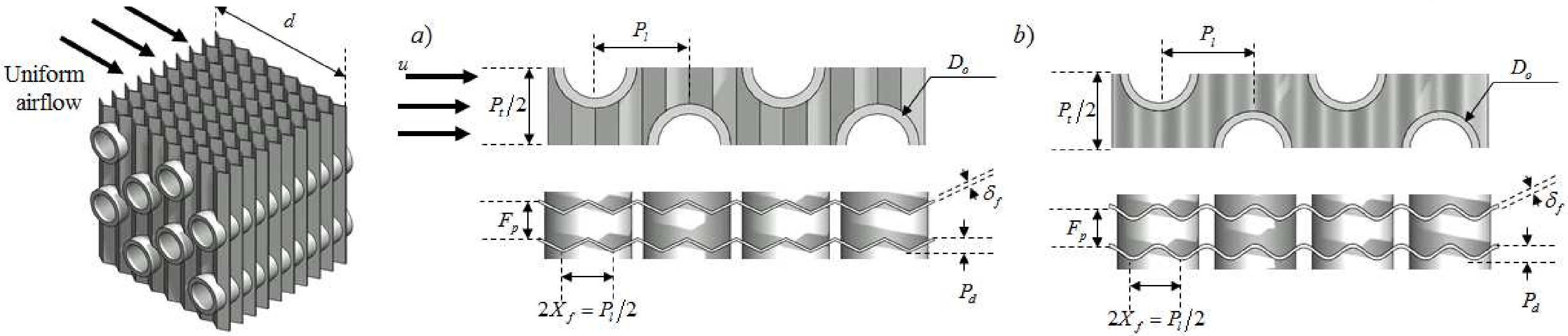
- Leverage automated CFD simulations to investigate a large Design of Experiments
- Present new set of equations for airside heat transfer and friction characteristics of wavy (smooth and Herringbone) fin and round tubes for diameters ranging between 2.0mm-5.0mm
- Show how they compare to existing correlations for such surfaces

Literature Survey

Author	Fin type	Tube arrangement	Application range	Accuracy (staggered only)
(Webb, 1990)	Flat and wavy	Staggered	9.5mm≤Dc≤12.7mm 2≤N≤6	Nu : 10%(96% of data)
(Kim et al., 1997)	Wavy Herringbone	In-line / Staggered	9.5mm≤Dc≤12.7mm 1≤N≤8	j : 10%(92% of data) f: 15% (91% of data)
(Wang et al., 1997)	Wavy Herringbone	In-line / Staggered	Dc=10.3mm 1≤N≤4	j : 10%(94% of data) f: 15% (95% of data)
(Wang et al., 1999)	Wavy Herringbone	Staggered	7.7mm≤Dc≤16.4mm 1≤N≤6	j : 15%(95.1% of data) f: 15% (97.3% of data)
(Wang et al., 2002)	Wavy Herringbone	Staggered	8.6mm≤Dc≤10.4mm 1≤N≤6	j : 15%(91% of data) f: 15% (85% of data)
(Bacellar et al., 2015)	Wavy Smooth	Staggered	2.0mm≤Dc≤5.0mm 2≤N≤10	j : 20%(64% of data) f: 20% (66% of data)
(Bacellar et al., 2016)	**Wavy Herringbone**	**Staggered**	**2.0mm≤D_o≤5.0mm 2≤N≤20**	**Nu: 15%(96% of data) C_f: 15%(94% of data)**
	Wavy Smooth			**Nu: 15%(94% of data) C_f: 15%(93% of data)**

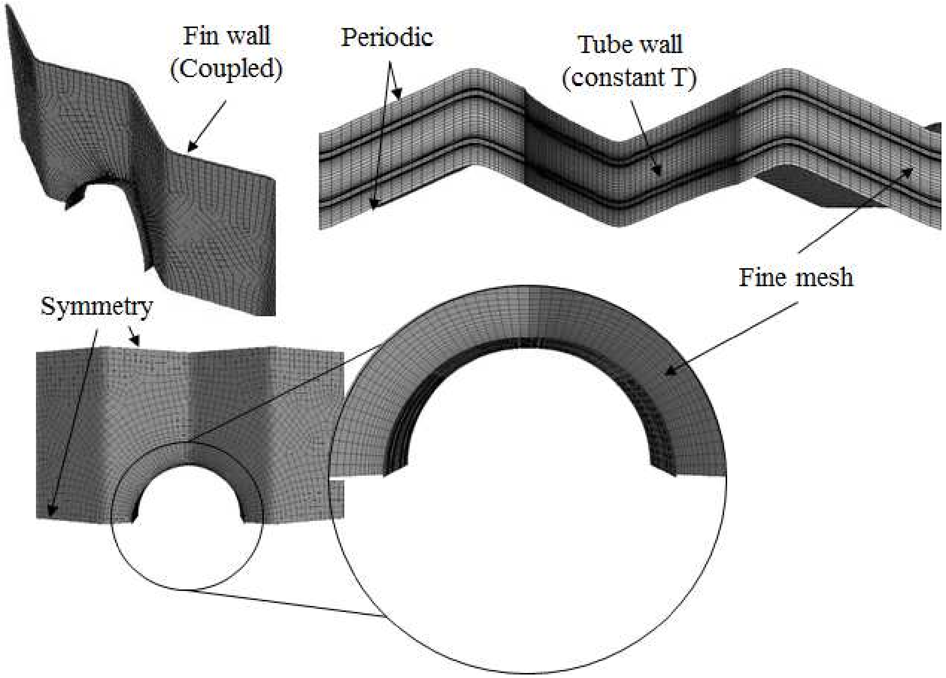
Methodology

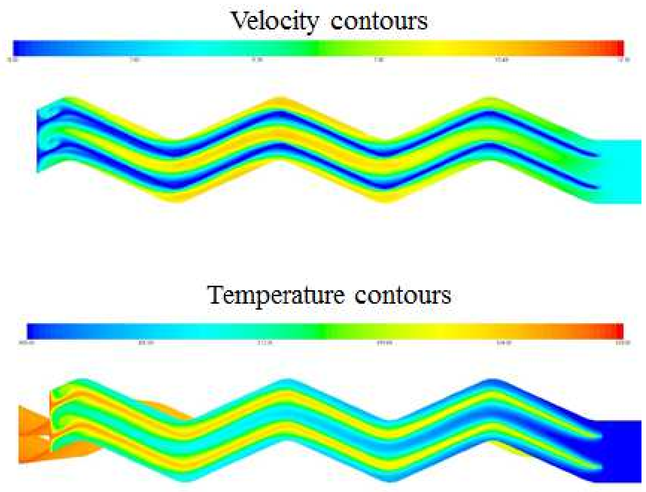




D_o (mm)	P_l/D_o (-)	P_t/D_o (-)	F_p (mm)	P_d/X_f (-)	δ_f (mm)	N (-)	u (m/s)
2.0 - 5.0	1.25 – 4.0	1.25 – 4.0	0.5 – 2.5	0.088 – 0.84	0.05 – 0.1	2 - 20	0.5 – 7.0

CFD Modeling and Simulation

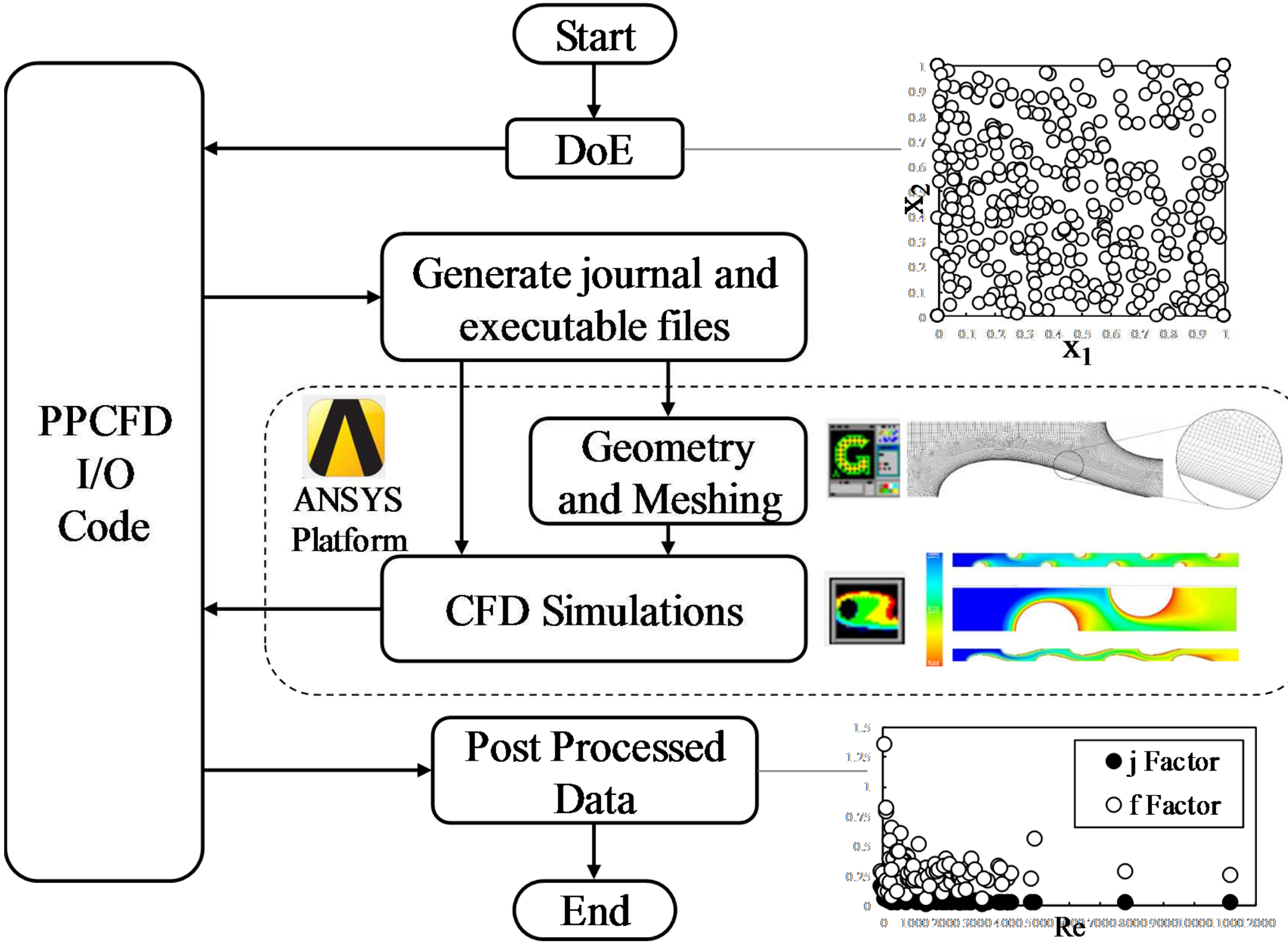




Settings: Ideal gas (density), polynomial curve fit (other thermophysical properties) and k-ε Realizable for turbulence

Post Processing: UA-LMTD method, iterative fin efficiency (Schmidt, 1949)

Parallel Parameterized CFD



Proposed Equations

$$\phi(\underset{\sim}{x}) = \sum_{i=1}^{n_{Rows}} c_i \cdot \left(\prod_{j=1}^{n_{Columns}} x_j^{M_{i,j}} \right), M_{n_{Rows} X n_{Columns}} : \text{Parameters power matrix, } \underset{\sim}{c}_{n_{Rows}} : \text{ Coefficients array}$$

$$\phi_h = \ln\left(Nu_{Dh}\right), \phi_{\Delta P} = \ln\left(C_f\right)$$

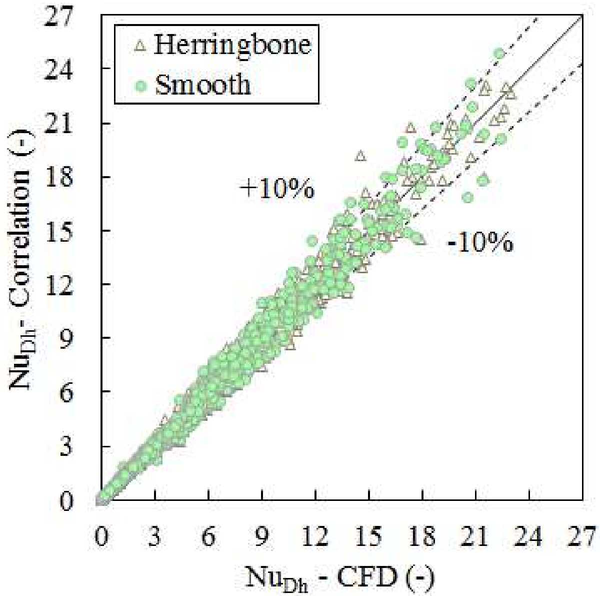
$$\underset{\sim}{x} = \left[\ln\left(F_p / D_o\right), \ln\left(P_l / D_o\right), \ln\left(P_t / D_o\right), \ln\left(P_d / X_f\right), \ln\left(\delta_f / F_p\right), \ln\left(N\right), \ln\left(\mathrm{Re}_{D_o, u_c}\right) \right]$$

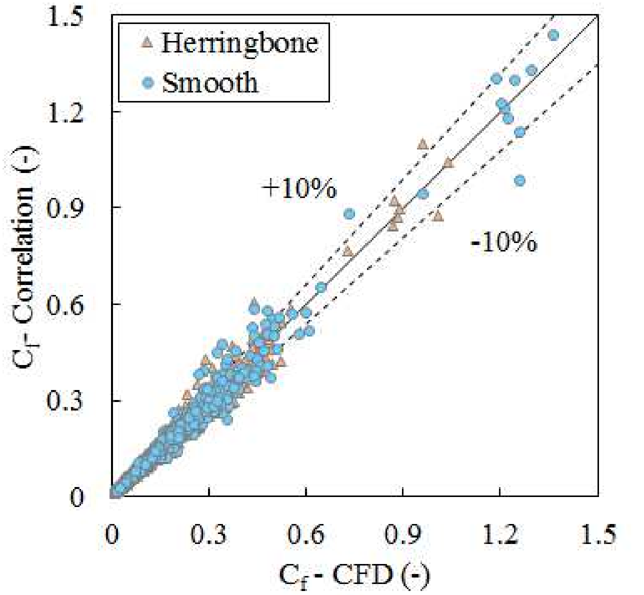
$$Nu_{Dh} = hD_h / k \qquad C_f = \Delta P \Big/ \left(0.5 \rho u_c^2\right) \cdot D_h \Big/ \left(4d\right)$$

$$D_h = 4 A_c d / A_o \qquad \mathrm{Re}_{D_o, u_c} = \rho u_c D_o / \mu$$

T (K)	P (kPa)	ρ (kg/m³)	μ (Pa.s)	k (W/m.K)	c_p (J/kg.K)
300	101.325	1.177	1.86E-05	2.57E-02	1005

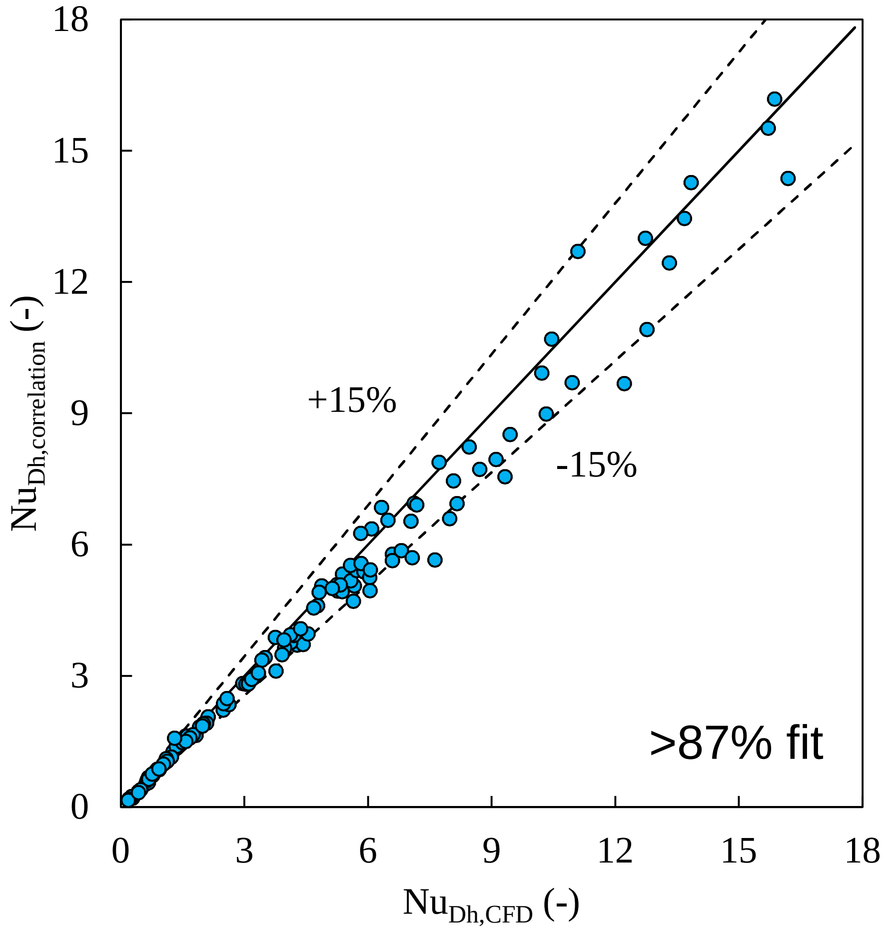
Fitness to Source Data

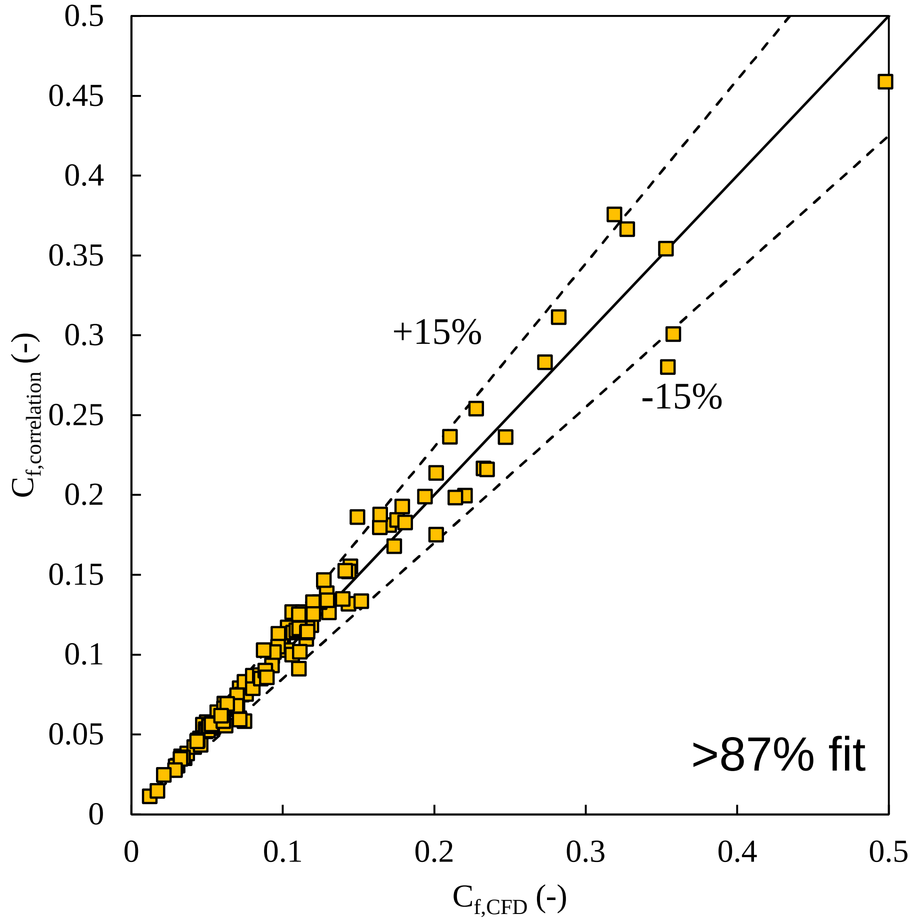




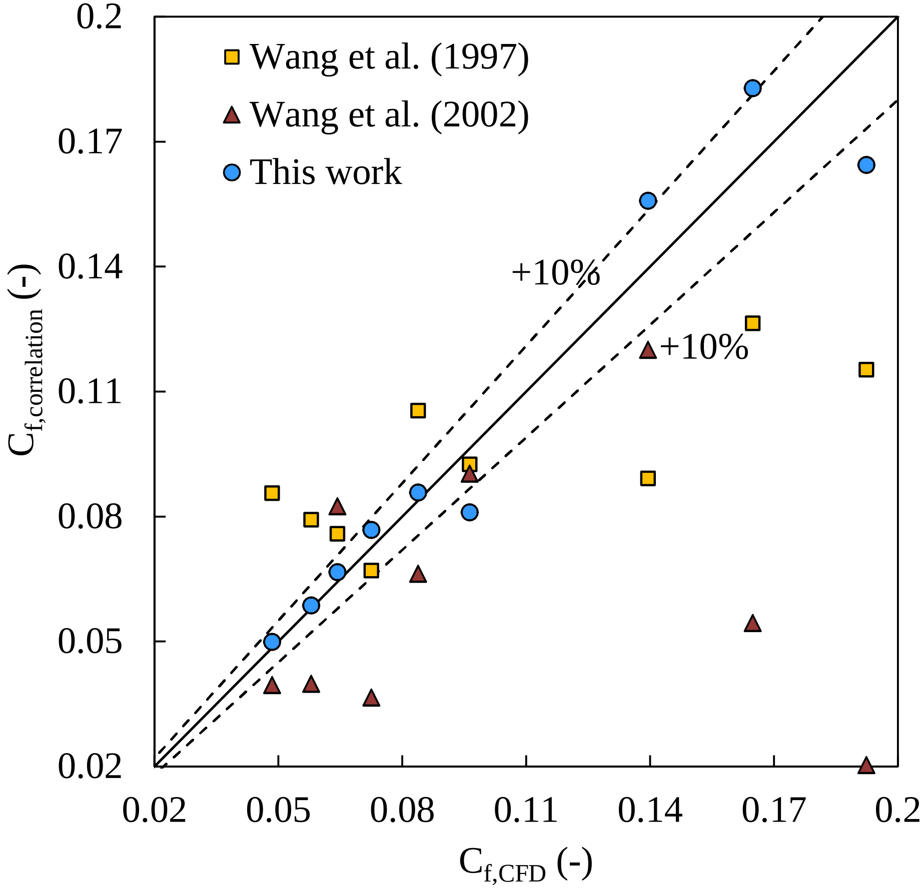
Fin Type	Herringbone		Smooth	
Metric	Nu_{Dh}	C_f	Nu_{Dh}	C_f
Predicted data (e=10.0%)	84.73%	83.92%	80.84%	81.88%
Predicted data (e=12.5%)	92.63%	91.22%	88.95%	89.43%
Predicted data (e=15.0%)	**96.17%**	**94.54%**	**94.28%**	**93.48%**
Predicted data (e=20.0%)	99.04%	98.08%	98.97%	97.62%
Predicted data (e=25.0%)	99.56%	99.04%	99.60%	98.97%
R^2	0.9937	0.9881	0.9927	0.9889
Mean Absolute Relative Error	5.344%	5.665%	5.747%	6.038%
Median Absolute Relative Error	3.940%	4.288%	4.253%	4.750%

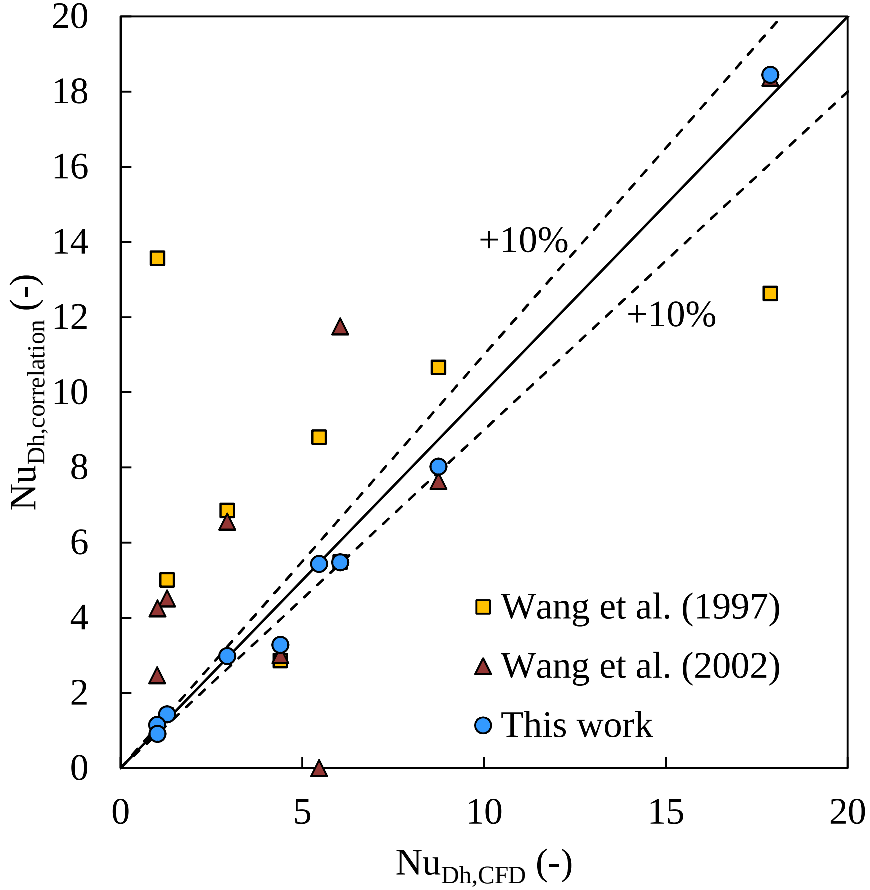
120 Random Samples





Comparison - Existing Correlations





Conclusions

- Presented novel CFD-based correlations for smooth and Herringbone wavy fin and tube heat exchangers, in staggered arrangement
- Filled the literature gap by including a large and not well investigated design space: D_o = 2.0-5.0mm, P_l/D_o and P_t/D_o = 1.25-4.0, N = 2-20, F_p = 0.5-2.5mm, P_d = 0.088-0.84, δ_f = 0.05-0.1mm, u=0.5-7.0m/s
- Equations showed good fitness to source data (more than 93% within 15% deviation) and similar fitness to random samples (consistent CFD models)
- Existing equations prediction analysis suggest they are applicable to this design space, but also they are not even consistent with themselves

Acknowledgements

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THANK YOU!