Overall Thermal-Hydraulic Performance of GRIPMetal

Karim Alrefaey[a], John Swift[b], Roger Kempers[a*]

[a]Department of Mechanical Engineering, York University, Toronto, Canada
[b]NUCAP Energy, Toronto, Canada

The enhancement in heat transfer achieved by adding fins to a surface is typically accompanied by a significant increase in pressure drop [1]. To address this, the thermal enhancement factor (η_o), proposed by Webb and Eckert [2], is usually used in describing the enhancement in heat transfer while taking the pressure drop penalty into consideration. η_o is calculated at equal pumping power for both finned and unfinned surfaces, and it can be formulated as

$$\eta_o = \frac{Nu}{Nu_o^*} \tag{1}$$

where Nu and Nu^*_o are the Nusselt numbers for the finned and smooth surfaces, respectively. Nu^*_o is evaluated at an equivalent Reynolds number, Re^*_o, which is expressed as

$$Re_o^* = \left(\frac{f}{f_o^*}\right)^{\frac{1}{3}} Re \tag{2}$$

where Re is the Reynolds number for the finned surface and f^*_o is the friction factor for the smooth surface evaluated at Re^*_o.

GRIPMetal array geometry is described by streamwise spacing between the hooks within each group (S_L), spanwise spacing between each group set (S_T), and spanwise spacing between the hooks within each group (C_h), hook width (W_h), hook length (L_h), groove length (L_g), and hook height (h), as shown in Fig. 1. The numerical values for these geometrical features are summarized in Table 1.

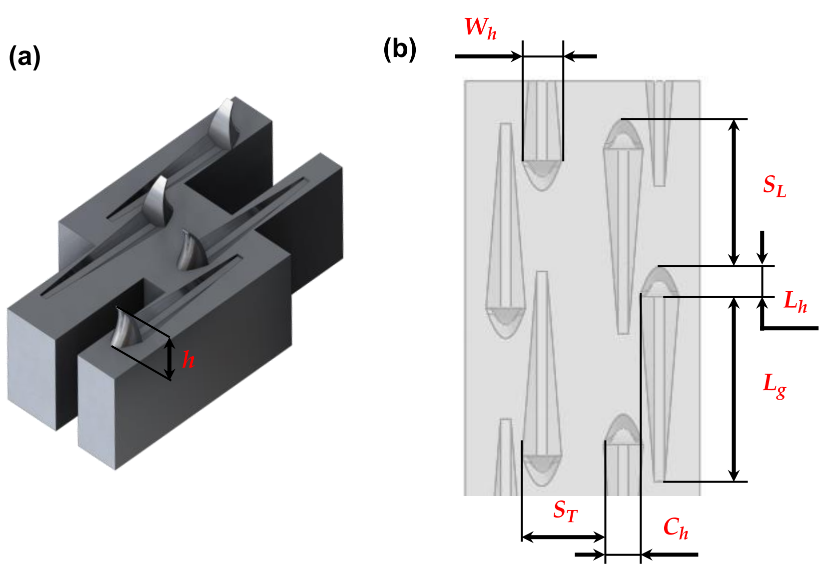

Fig. 1. Schematic of the GRIPMetal arrays: (a) a magnified unit cell and (b) geometrical parameters of the array with its orientation in the test channel.

Table 1. Geometrical parameters of the GRIPMetal arrays.							
Array Type	*h*	S_L	S_T	C_h	W_h	L_h	L_g
	(mm)						
Mini	1.00	2.50	1.33	1.00	1.00	0.830	3.60
Standard	1.50	4.00	2.24	1.00	1.00	0.825	5.10
Heavy	2.25	4.00	3.80	1.00	1.60	1.51	7.50

To evaluate the relative overall performance of the GRIPMetal arrays, their thermal hydraulic performance is compared with that of surface enhancement techniques previously investigated in the literature (see *Fig. 2*). These studies used arrays with geometrical features similar in size to those in the present study. Several factors were considered, including fin height, inter-fin spacing, hydraulic diameter, and Reynolds number. The comparison was based on several similar parameters, including the hydraulic diameter of the test channel (D_h), feature diameter (f_d), transverse pitch (f_p), feature height (f_h), and height-to-diameter ratio (f_h/f_d). For GRIPMetal arrays, hook width was taken as f_d, the average spanwise spacing between the hooks was considered equivalent to f_p, and hook height was taken as f_h. Detailed geometric similarities between the GRIPMetal arrays and those from the literature are shown in *Table 2*.

Table 2. Geometric similarities between GRIPMetal arrays and other geometries from the literature.						
Study	Case Number	Geometry	Equivalent GRIPMetal Array*	Parameter	Geometry Parameter Value	GRIPMetal Parameter Value
Bi et al. [3]	1	Hemispherical dimple	Mini	D_h	1.0 mm	2.0 mm
				f_d	0.96 mm	1.0 mm
			Standard	D_h	1.0 mm	3.2 mm
				f_d	0.96 mm	1.0 mm
Bi et al. [3]	2	Hemispherical dimple	Mini	D_h	1.0 mm	2.0 mm
				f_d	1.1 mm	1.2 mm
Xie et al. [4]	3	Teardrop dimple	Same as case 1			
	4	Teardrop protrusion				
Sun et al. [5]	5	Winglet delta pairs	Mini	f_h	0.60 mm	1.0 mm
	6	Winglet delta pairs with elliptical cylinder	Heavy	f_h	2.0 mm	2.2 mm
Zhou et al. [6]	7	Circular micropillar	Mini	f_h / f_d	1.2	1.0
Alam et al. [7]	8	Triangular pin fins	Heavy	f_h	2.5 mm	2.2 mm
				f_d	2.0 mm	1.6 mm
			Mini	f_h / f_d	1.2	1.0
* Performance of GRIPMetal arrays used in the comparison is based on zero or smallest tip clearance.						

Overall, *Fig. 2* shows that the mini and standard arrays outperformed the hemispherical dimples investigated by Bi et al. [3], with their performance being, on average, 32% and 91% higher than that of the dimples, respectively. This demonstrates the enhancing effect of the hooks on the GRIPMetal dimples, where they improve thermal performance without significantly increasing the pressure drop. The teardrop protrusions and dimples studied by Xie et al. [4] exhibited better performance compared with the hemispherical ones, but still fell short of the performance of the GRIPMetal arrays. The mini arrays were, on average, 13% and 18% higher in performance than the protrusions and dimples, respectively, while the standard arrays were 69% and 77% higher.

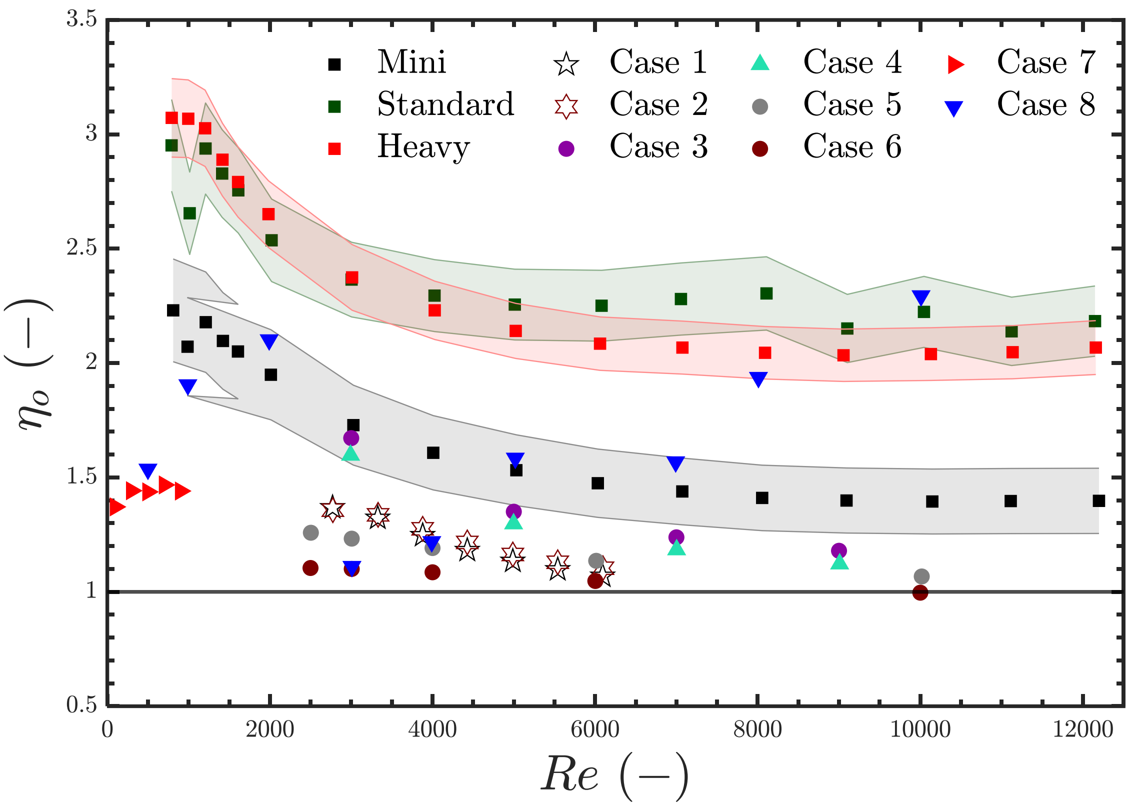

Fig. 2. Comparison between the overall performance of the GRIPMetal arrays with that of other surface enhancement techniques previously investigated in the literature. The highlighted regions indicate the uncertainty in performance of the GRIPMetal arrays.

The winglet delta pairs with elliptical cylinder investigated by Sun et al. [5] showed relatively low performance compared with the heavy arrays, with its performance being about 91% lower. However, the winglet delta pairs alone performed slightly better, with its performance being 51% lower than that of the mini arrays.

The micropillars studied by Zhou et al. [6] had significantly lower performance compared with the mini arrays. The triangular pins of Alam et al. [7], on the other hand, exhibited a rapidly changing performance compared with the other geometries investigated. Initially, their performance was 9% lower than that of the mini arrays; then, it increased to become 7% higher at $Re \approx$ 2,000. However, the performance dropped rapidly, reaching a turning point at $Re \approx$ 3,000, after which it increased again, reaching a peak performance at $Re \approx$ 10,000 that was 39% higher than the mini arrays. The heavy arrays, on the other hand, showed significantly better performance compared with the triangular pins at lower *Re*, though their performance degraded as *Re* increased.

Overall, the GRIPMetal arrays demonstrated significantly better thermal-hydraulic performance compared with the geometries investigated, highlighting their enhanced thermal and hydraulic efficiency. Because of their relatively inexpensive and simple manufacturing process, the GRIPMetal arrays represent a promising alternative to conventional heat transfer enhancement techniques.

References

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