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COLD PLATE DESIGNS: A COMPARISON OF EVALUATION METRICS - CONSTRUCTAL SVELTENESS AND GLOBAL RESISTANCE

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Cold plates are heat transfer devices used in various industries such as aerospace, automotive, and telecommunications primarily to prevent overheating and ensure efficient operation of electronics and power electronics components. They are compact, flat heat exchangers designed mainly by dissipate heat to a liquid coolant. The present paper compares the thermal performance of three serpentine arrangements using a global resistance metric that accounts for thermal resistance and pumping power. Then, various Svelteness definitions that differ in the external length scale are investigated. All the designs hold the same five degrees of freedom: plate area, plate weight, pipe diameter, pipe bend radius ratio, and plate length ratio, but only the two latter ones are investigated here. Results show that the simple "S" shape performs better regarding the global resistance metric, mainly for configurations with low values of the ratio between the bend curvature radius and the pipe diameter (*R/d*). The three variants of Svelteness capture the general thermal performance very well, particularly the R/d effect and the impact of the plate aspect ratio (*W/d*). However, none of the Svelteness definitions considered could completely capture the performance differences among the different arrangements measured with the global resistance metric.

Keywords: Cold plates; Conduction; Convection; Internal flow; Svelteness.

1. INTRODUCTION

Power electronic components require an efficient thermal management system to maintain their performance and longevity [1]. Thermal management can be achieved through active or passive means. Active thermal management utilizes forced convection, employing fans or pumps to circulate a fluid coolant. In contrast, passive cooling methods rely on heat sinks and fins, utilizing free convection [2]. An example of indirect active cooling, whose design can benefit from results developed in relation with the Constructal Law, is the cold plate, which consists of a plate with attached or internal pipes for coolant flow.

Investigations considering various pipe shapes for heat-transferring devices were found in the literature [3-7] and motivated the present study. This work compares three internal pipe shapes for cold plates with the same degrees of freedom. The novelty here is in proposing two modified S-type serpentine shapes and investigating their performance according to a proposed non-dimensional global thermal resistance and three Svelteness definitions that differ in the external length [7].

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2. METHODOLOGY

Computational fluid dynamics simulations were performed in OpenFOAM considering steady-state solution and incompressible flow with constant thermophysical properties. Turbulence modeling was obtained with the Reynolds Average Navier-Stokes (RANS) method, and the $\kappa - \varepsilon$ model was used to close the system of equations. At the pipe inlet, the fluid temperature and speed were specified, while a heat transfer rate was prescribed on one of the plane surfaces of the cold plate, with the remaining surfaces being treated as adiabatic.

Figure 1 shows the three serpentine shapes and the variables that define the geometries. The geometrical relationships are determined by the expressions in Eq. 1 and the variable listed in Table 1.

$$R = R/d \cdot d,\ \ W = \left(A_p \cdot W/D\right)^{0.5},\ \ D = \frac{A_p}{W}, S_1 = 2R,\ \ S_2 = \frac{D-2S_1}{2} \tag{1}$$

Table 1

Variables

Parameters	Decision variables		Dependent variables
	R/d	***W/D***	
d = 0.004 m	2.0	1.2	H
A_p = 0.20 m²	6.0	1.6	$\dot{m}$
T_i = 298.15 K	10.0	2.0	T_o
Q = 1000 W			*T-field*
Δp = 0.25 bar			
m_p = 2.50 kg			

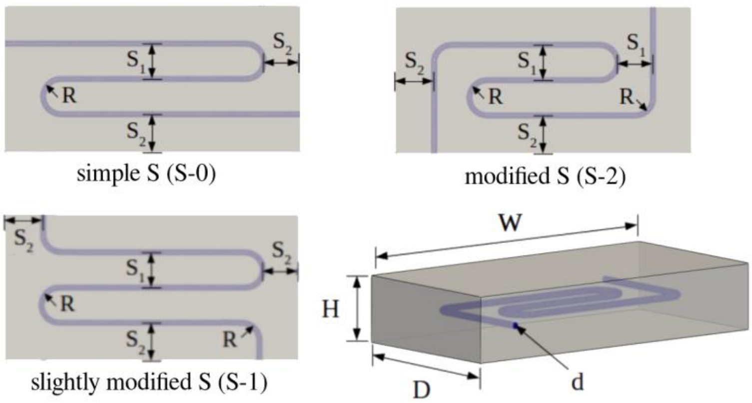

Fig. 1 – Serpentine shapes.

Three values are explored for each of the two degrees of freedom and for each of the three serpentine shapes, totaling 27 configurations.

3. RESULTS AND DISCUSSION

Results indicate that design S-0 provides a better temperature distribution, particularly for lower values of *R/d* and *W/D* (Fig. 2). When analyzing the non-dimensional global thermal resistance (defined here as the product of global thermal resistance and pumping power divided by fluid inlet temperature), S-0 exhibits significantly lower values, especially for lower *R/d* and *W/D* (Fig. 3).

To correlate the thermal performance with potential geometric shape advantages, three Svelteness definitions were examined in Figs. 4, 5 and 6. These definitions (see figures insets) differ in the external length scale (numerator of the equations), while the internal length scale consistently depends only on the serpentine volume (v).

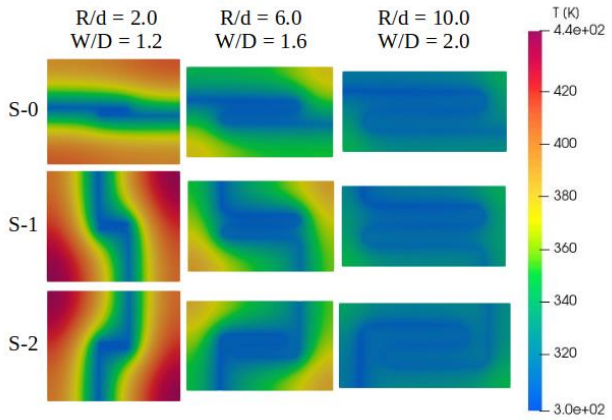

Fig. 2 – Temperature fields.

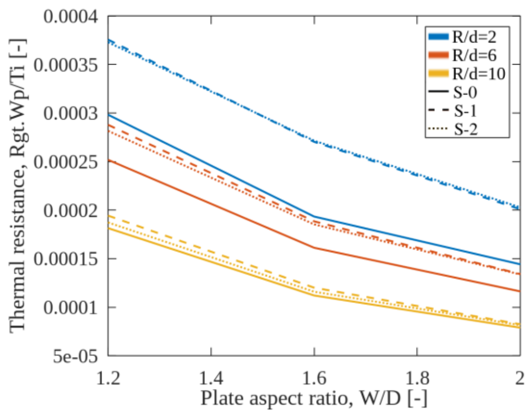

Fig. 3 – Non-dimensional global resistance.

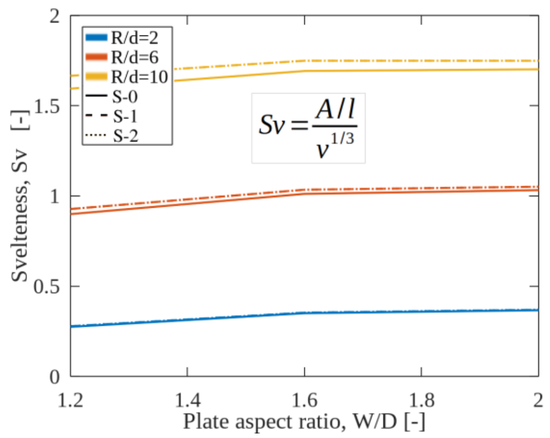

Fig. 4 – Svelteness by definition “a”.

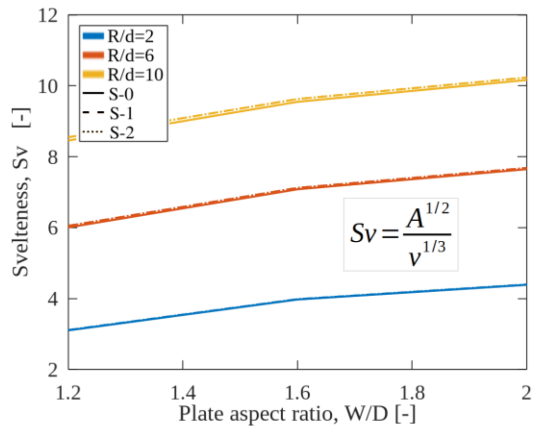

Fig. 5 – Svelteness by definition “b”.

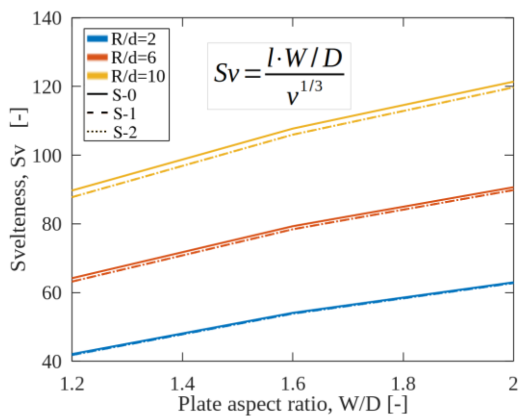

Fig. 6 – Svelteness by definition “c”.

Consider *A* as the area available to mount heat-dissipating devices and *l* as the serpentine length. Although the Svelteness definitions used do not capture the superiority of the S-0 design for *R/d* values of 2 and 6 (suggested by Fig.3), all the Svelteness definitions capture the general thermal performance, particularly concerning *R/d*. The impact of *W/D* is more strongly seen in Svelteness "c" (Fig. 6). Note that the current simulations assumed rough wall pipe and are for turbulent flow in all the cases.

REFERENCES

1. Ordonez J.C., Sailabada C., Chalfant J., Chryssostomidis C., Li C., Luo K., Santi E., Tian B., Biglo A., Rajagopal N., Stewart J., DiMarino C., Thermal Management for Ship Electrification-Approaches for Power Electronic Building Blocks and Power Corridors, *IEEE Transactions on Transportation Electrification*, 2024.
2. Yoon Y., Hyeon S., Kim D.R., Lee K.-S., Minimizing thermal interference effects of multiple heat sources for effective cooling of power conversion electronics, *Energy Conversion and Management*, **174**, pp. 218–226 (2018).
3. Kobayashi H., Lorente S., Anderson R., Bejan A., Serpentine thermal coupling between a stream and a conducting body, *Journal of Applied Physics*, **111**, *2*, p. 044911 (2012).
4. Almerbati A., Lorente S., Bejan A., The evolutionary design of cooling a plate with one stream, *International Journal of Heat and Mass Transfer*, **116**, pp. 9–15 (2018).
5. Mosa M., Labat M., Lorente S., Role of flow architectures on the design of radiant cooling panels, a constructal approach, *Applied Thermal Engineering*, **150**, pp. 1345–1352 (2019).
6. He L., Hu X., Zhang L., Xing T., Jin Z., Performance evaluation and optimization of series flow channel water-cooled plate for IGBT modules, *Energies*, **16**, *13* (2023).
7. Clemente M.R., Panão M.R.O., On the Svelteness as an Engineering Tool in Constructal Design: A Critical Review, *Applied Sciences*, **12**, *23*, p. 12053 (2022).