heat sink exchange area *S*. Data are obtained after fitting a second order polynomial fit to P_{net}. For example, for the case shown in Fig. 6, $P_{net,max}$ = 1.99 W for v = 2.67 m s^{-1}.

As expected, the maximum net output power increases with *S*. For a fixed heat sink exchange area *S* (i.e., same number of fins), the heat sinks with thicker fins correspond to those with the highest net power. Since the number of fins and the base area are the same, an increase in the fins thickness leads to small gaps between them (smaller fin to fin distances, see Table I). This reduction in cross-sectional area increases the air velocity, thereby enhancing the heat transfer in comparison with heat sinks with larger fin to fin distances. The improvement in the heat transfer leads to a better performance of the TEG.

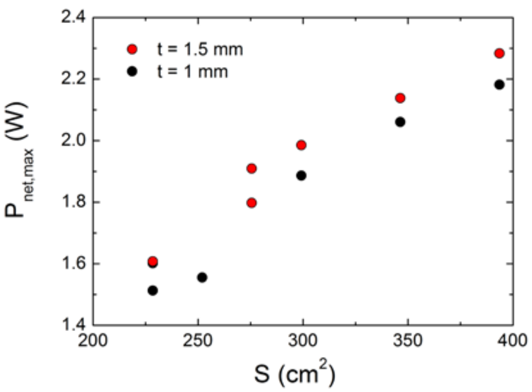

Fig. 7. Maximum net power as a function of the heat sink exchange area for the cases listed in Table I (t = fin thickness).

However, an increase in the air flow velocity that circulates through the fins also implies an increase in the pressure head losses. This effect reduces the net power since it increases the fan power requirements. All in all, the overall effect of increasing the fin thickness, with the same value of the heat sink exchange area, is to increase the net power output that is reached at lower fluid flow velocities.

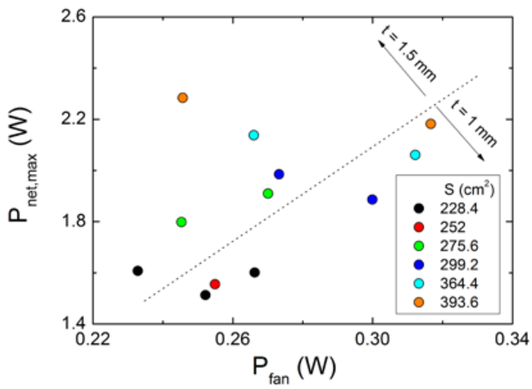

Fig. 8. Maximum net power as a function of the fan power requirement (t = fin thickness; S = exchange surface area of the heat sink).

Figure 8 shows the maximum net power output as a function of the fan power, the latter being proportional to v^3. For clarity, the exchange surface area *S* for each case is also shown. Results can be clearly divided into two regions depending on the fin thickness *t*. Higher values of fin thickness generate more net power with low fan power requirements.

The increase in the performance of thicker fins may lead to values of net output power similar to those obtained with heat sinks with more but thinner fins (compare, e.g., case *S* = 364.4 cm^2 and *t* = 1.5 mm with case *S* = 393.6 cm^2 and *t* = 1 mm in Fig. 8). In addition, heat sinks with thicker fins have the advantage of requiring less fan power for reaching the maximum output point. This may lead to more economical fan devices and, consequently, more economical TEG systems.

6. Conclusions

The effect of changing the geometry of air cooled finned heat sinks on the performance of a TEG system has been analysed. Experimental data obtained in the laboratory have been used for validating a numerical model. The model uses ANSYS-CFX and includes heat transfer mechanisms between solid and fluid regions. The TEG has been modelled as a solid element whose transport coefficients are determined following the methodology found in [3].

Simulations of several heat sinks are performed in order to evaluate the available net power (TEG production minus fan consumption). The results indicate that: 1) the TEG performance improves when increasing the exchange surface area of the heat sink (as expected) and 2) for a fixed exchange surface area, thicker fins provide better results since generate more net power with low fan power.

This last result implies that economical extrusion-based aluminium heat sinks are very good options for air cooled finned heat sinks in TEG applications.

Acknowledgement

This work has been partially funded by the University of Girona under grant MPCUdG2016-4. Sergi Saus and Jordi Vicens provided very helpful technical assistance.

References

[1] E. Massaguer, A. Massaguer, T. Pujol, J.R. Gonzalez, L. Montoro, “Modelling and analysis of longitudinal thermoelectric energy harvesters considering series-parallel interconnection effect”, in Energy, 2017, Vol. 129, pp. 59-69.

[2] M. Karvonen, R. Kapoor, A. Uusitalo, V. Ojanen, “Technology competition in the internal combustion engine waste heat recovery: a patent landscape analysis”, in Journal of Cleaner Production, 2016, Vol. 112, pp. 3735-3743..

[3] I. Ruiz, M. Borrelli, T. Pujol, N. Luo, L. Pacheco, A. Massaguer, L. Montoro, “Effective thermal conductance of thermoelectric generator modules”, in Renewable Energy and Power Quality Journal, 2017, Vol. 1, pp. 545-550.

[4] I. Tosun, D. Uner and C Ozgen, “Critical Reynolds number for newtonian flow in rectangular ducts”, in Industrial and Engineering Chemistry Research, 1988, Vol. 27, pp. 1955-1957.

[5] ANSYS-CFX Solver Theory Guide. ANSYS, Inc, 2015.