STERG

SOLAR THERMAL ENERGY RESEARCH GROUP

Design Process and Optimization of Helically Twisted Tapes as a Suitable Insert for Heat Transfer Enhancement in Solar Receiver Tubes

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Introduction

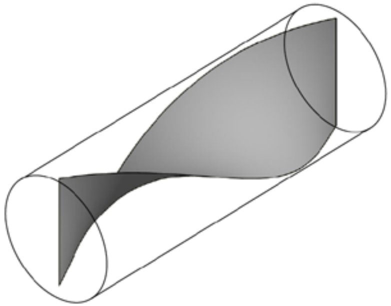
- Air as a HTF for a Brayton cycle.
- Advantages
  - Free and readily available
  - Environmentally friendly
- Disadvantages
  - Unfavourable heat transfer characteristics
- Passively enhance heat transfer with minimal pressure drop
- Use of twisted tapes

Twisted tapes

- Use of twisted tapes to break up thermal boundary layer and enhance heat transfer
- Pressure drop as a consequence
- Maximize thermal enhancement factor

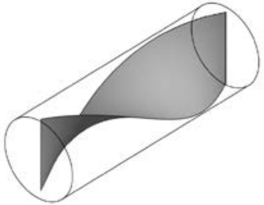
$$\eta = \frac{\frac{\mathrm{Nu}_e}{\mathrm{Nu}_p}}{\left(\frac{f_e}{f_p}\right)^{1/3}}$$

- Advantages
  - Cheap
  - Ease of fabrication
  - Simple insert
  - Reliable

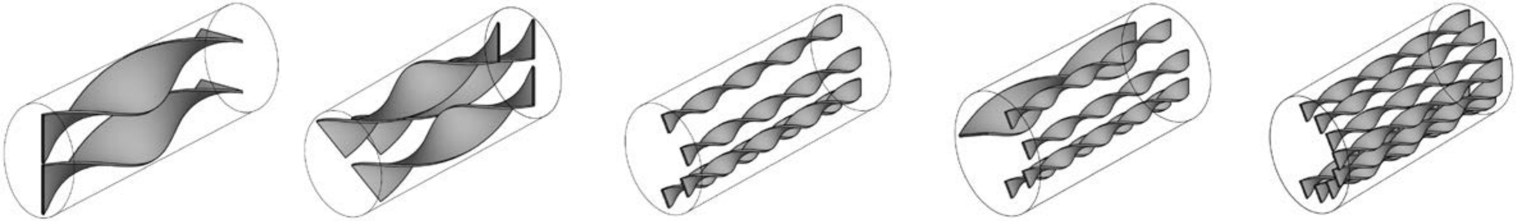


Twisted tapes

- Simple twisted tape



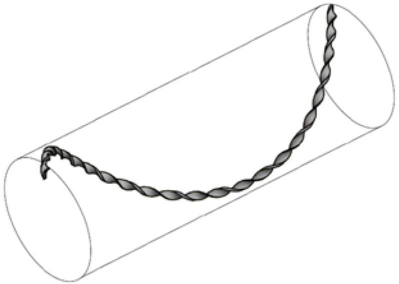
- Various combinations of twisted tapes simulated on FLUENT



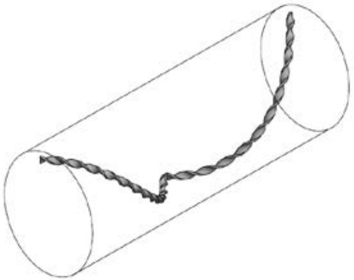
- Very high pressure drop due to a large surface area

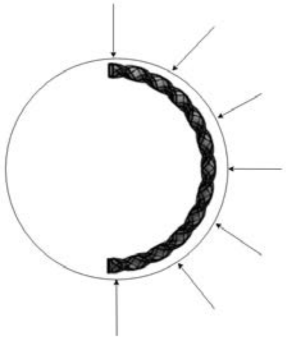
Helically twisted tapes (HTT)

- Very thin twisted tape wound in a coil form



- Modify HTT to be in the region of applied heat flux





CFD

- Menters SST $k - \omega$ model
- Simulation performed at Re = 20000
- Incompressible air with constant thermodynamic properties
- $T_{in} = 300\mathrm{K}$
- $q = 10000 \frac{\mathrm{W}}{\mathrm{m}^2}$ on one side of tube

Optimization

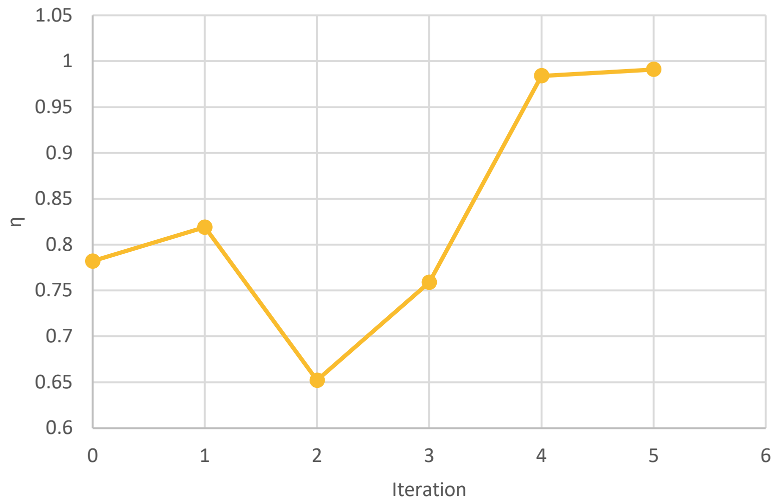
- Design vector: $\mathbf{x} = \{P, H, W, y, D, \delta\}^T$
- Maximization problem: $\max \eta(\mathbf{x}) = -\min \eta(\mathbf{x})$
- Subject to constraints:
  - $g_1(\mathbf{x}) = -\frac{P}{H} + 0.75 \leq 0$
  - $g_2(\mathbf{x}) = -\frac{W}{y} + 0.75 \leq 0$
  - $g_3(\mathbf{x}) = -\frac{y}{\delta} + 4 \leq 0$
  - $g_4(\mathbf{x}) = -D + H + 2t \leq 0$
  - $g_5(\mathbf{x}) = -P \leq 0$
  - $g_6(\mathbf{x}) = -H \leq 0$
  - $g_7(\mathbf{x}) = -W \leq 0$
- For
  - $12 \text{ mm} \leq D \leq 60 \text{ mm}$
  - $0.4 \text{ mm} \leq \delta \leq 1.5 \text{ mm}$
  - $y \geq 3 \text{ mm}$

Optimization

- Algorithm: Spherical Quadratic Steepest Descent (SQSD) method
  - $\boldsymbol{x}_{k+1} = \boldsymbol{x}_k - \frac{\nabla f(\boldsymbol{x}_k)}{C_k}$
  - $C_k = \frac{2[f(x_{k-1}) - f(x_k) - \nabla^T f(x_k)\{x_{k-1} - x_k\}]}{\|x_{k-1} - x_k\|^2}$
- Penalty function is used to convert a constrained optimization problem to an unconstrained optimization problem
  - Penalty parameter: $\mu = 1000$
- Initial design vector
  - $\boldsymbol{x}_o = (P_0, H_0, W_0, y_0, D_0, \delta_0) = (76\text{ mm}, 38\text{ mm}, 12\text{ mm}, 3\text{ mm}, 40\text{ mm}, 0.5\text{ mm})$
- Convergence criteria: $|\eta_k - \eta_{k-1}| \leq 1\%$

Optimization

- Five iterations to converge



Iteration	η
0	0,782
1	0,819
2	0,652
3	0,759
4	0,984
5	0,991

- Final design vector:
  - $x_5 = (P_5, H_5, W_5, y_5, D_5, \delta_5) = (360\ \text{mm}, 58\ \text{mm}, 54\ \text{mm}, 3\ \text{mm}, 60\ \text{mm}, 0.4\ \text{mm})$

Conclusion

- Obtained a good efficiency factor
- Current work:
  - Perform on a range of Reynolds numbers
  - Compressible flow with temperature dependent properties at elevated temperatures and pressure
  - Apply a variable heat flux: $q(y) = q_{max} \cos\left(\frac{\pi}{2}\frac{y}{r_{max}}\right)$

Thank you

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