The Novel Undulated Parabolic Trough Receiver: Performance Enhancement, Reduction in the Size and Cost of the Collector Fields

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Abstract

One of the main options to drive the cost of parabolic trough collectors (PTCs) technology down is to reduce the size of the solar field. This work proposes a novel receiver longitudinally undulated as a replacement for the conventional straight tube and investigates the effects on the size of absorbers, PTC modules and entire solar field. For this purpose, the developed method based on the similitude analysis should provide tools for drawing a comparison between the various designs of the absorber and should give useful measures of the scenario of their commissioning. Undulated absorber in service and without added supplementary mechanical components; the size of a solar collector field should reduce about ~29.5% consequence of the reduced size of the solar collector module and the absorber. The increase of the pressure drops through the novel absorber pipe should be re-balanced by the reduction in its size.

Keywords: Parabolic trough, undulated receiver, similitude analysis, size reduction of the solar field.

1. Introduction

The PTC large scale technology has proved its capacity to produce power with the lower cost as possible. PTC plants consist mainly of four loops, a large solar collector field, a steam generation system, a turbine/generator cycle and an optional thermal storage. One of the main options to drive the cost of PTC technology down is to reduce the size of the solar field (Price et al. 2002). The first way of reaching this purpose is to increase the parabolic mirrors reflectance and/or the absorber absorptance of the direct solar irradiance. The latter can be achieved through adding a secondary non-imaging reflector on the receiver (McIntire, 1980, Gee et al. 2002).

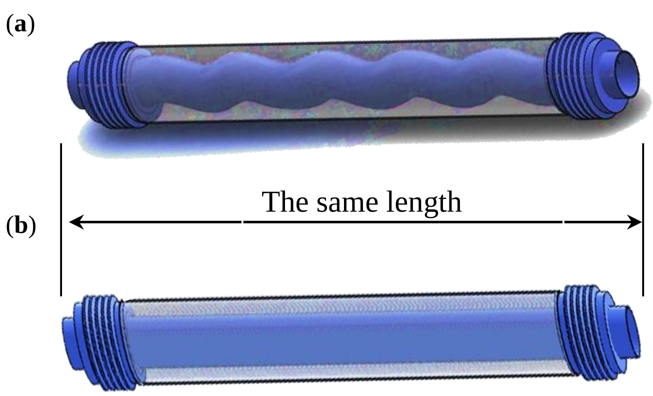

Fig. 1: (a) The novel PTC undulated absorber. (b) The conventional PTC absorber.

The second way is to improve thermal performances with a minimum pressure loss penalty as possible, which cannot be achieved by the passive techniques that add supplementary mechanical components to the absorber,

doi:10.18086/swc.2017.04.03 Available at http://proceedings.ises.org

the increase of the pressure losses is too important and the cost rise dramatically. In 2015, (Demagh et al. , 2015) introduce the possible use of longitudinal curved receiver in PTCs. The novel design (Fig. 1(a)) allows better characteristics of the outer heat flux due to its 3D distribution, with regard to the 2D nature of the conventional straight one (Fig. 1(b)). The focus of this study is to set up a general-purpose methodology to quantify effects of any heat exchanger enhancement technique on the reduction in the size of devices. The particular case of the newly designed undulated PTC absorber pipe will be the subject evaluation of the method.

2. Similitude analysis

It would be very interesting to be able to quantify the advantages of the heat transfer improvement on the reduction in the size of such exchangers. In a general-purpose, the methodology leads to develop expressions that could set up a comparison between two different pipe exchangers. Assuming steady-state conditions, the mean heat flow rate $\dot{Q}$ throughout the pipe can be defined as,

$$\dot{Q} = \rho \bar{c} u_{in} \left(\pi D_i^2 / 4 \right) \left(\bar{T}_{out} - \bar{T}_{in} \right) = h \left(\pi D_i L \right) \left(\bar{T}_w - \bar{T}_m \right) \quad \text{(eq. 1)}$$

u_{in} , ρ and $\bar{c}$ being the convective heat transfer fluid (HTF) inlet velocity, density and specific heat at the HTF mean temperature $\bar{T}_m$, respectively. D_i , h and L being the inner diameter, inner heat transfer coefficient and equivalent length, respectively. $\bar{T}_{in}$ and $\bar{T}_{out}$ being the inlet and outlet HTF bulk temperatures, respectively.

The ratio of equations resulting from the expression (1) when it is applied to a first configuration (subscript 1) and to a second configuration (subscript 2) leads to, after the rearrangement,

$$\left(\frac{L_1}{L_2} \right) = \frac{St_2}{St_1} \frac{\left(\bar{T}_{out} - \bar{T}_{in} \right)_1}{\left(\bar{T}_{out} - \bar{T}_{in} \right)_2} \frac{\left(\bar{T}_w - \bar{T}_m \right)_2}{\left(\bar{T}_w - \bar{T}_m \right)_1} \frac{\left(D_i \right)_1}{\left(D_i \right)_2} \quad \text{(eq. 2)}$$

$St = h / \rho u_{in} \bar{c}$ being the Stanton number. This result is extremely useful; it suggests that the comparison between the heat exchange rates of various exchangers may be modelled by an equality that introduces dimensionless groups which quantifying the dynamic and thermal behaviour

2.1. The novel undulated absorber: Thermal enhancement

3D steady-turbulent simulations are carried out to predict the flow fields using the CFD code (FLUENT 6.3). The k–ω based Shear-Stress-Transport (SST) model was used in the simulations. Exploiting the established 3D heat flux density distribution on the outer wall of the undulated PTC absorber pipe (Fig. 1(a)) (Demagh et al., 2015), a UDF was established and compiled in the commercial code Fluent. Numerical results for the turbulent heat transfer coefficient and the pressure drop obtained with Syltherm 800 flowing through the undulated PTC absorber are reported in Fig. 2. It is obvious that the average heat transfer coefficient of the undulated absorber is greater than that of the conventional straight absorber obtained by Gnielinski’s correlation (Incropera et al., 2007), up to 63% increase, in addition to an increasing of the pressure drops, less than 60%.

2.2. The novel undulated absorber: Dimensional analysis and size reduction

- Without any enhancements, assuming the same pipe diameters and the similar operating conditions, it follows from expressions (2) that $L_2 / L_1 = 1$.
- In the particular case of this study, exchangers would be the conventional PTC straight absorber pipe and the novel undulated PTC absorber, respectively subscript 1 and 2, with the same inner diameter. To reach the similar rise of the HTF temperature (i.e. $\left(\bar{T}_{out} - \bar{T}_{in} \right)_2 = \left(\bar{T}_{out} - \bar{T}_{in} \right)_1$), when it is assumed the similar HTF inlet temperature (i.e., the similar HTF properties), the $\left(\bar{T}_w - \bar{T}_m \right)_1 = \left(\bar{T}_w - \bar{T}_m \right)_2$, the same flow regime (i.e., $\left(u_{in} D_i \right)_2 = \left(u_{in} D_i \right)_1$) and since $h_2 \geq h_1$, equation (2) becomes $L_1 / L_2 = h_2 / h_1 \geq 1$. Taking into account the results of Fig. 2, the trend of the equation (2) while varying the flow regime is

shown in Fig. 3. Until $\mathrm{Re} = 71000$ the trend is decreasing from $L_1/L_2 \simeq 1.63$ to $\simeq 1.41$; from this location it increases a little and becomes relatively flat, about $\simeq 1.45$. To achieve the same HTF temperature increase of the classic straight absorber, the equivalent length of the novel absorber will be significantly reduced, consequence of the heat transfer improvement. With a mean equivalent length of $L_2 = L_1/1.63$, the area size of the solar collector field should reduce about $\simeq 0.39$ %, consequence of the reduction in the size of solar PTC units. It is clear that the cost will be lower.

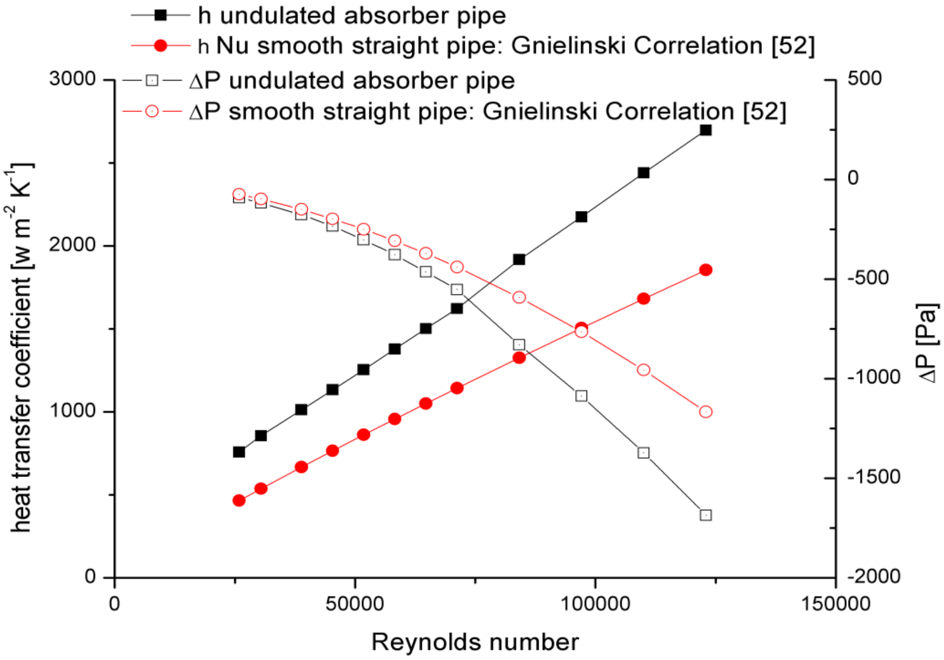

Fig. 2: The convective heat transfer coefficient and the pressure drops through the undulated pipe against Re, for $\overline{T}_{in} = 450$ K. Correlations refer to (Incropera et al., 2007)

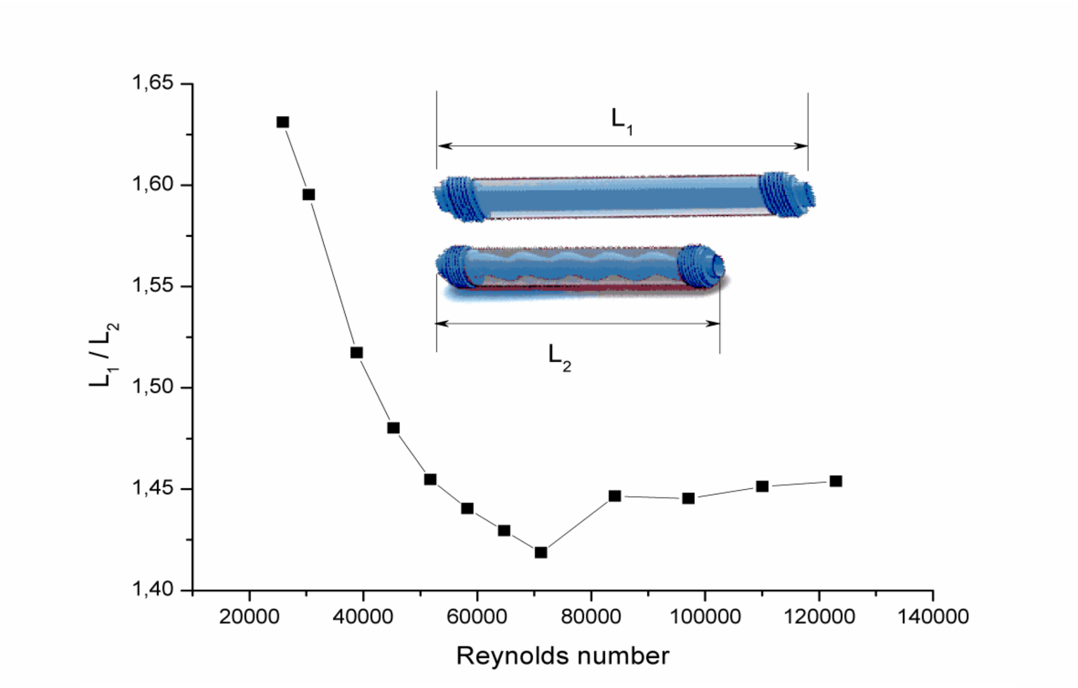

Fig. 3: The reduction in the size of the newly designed undulated PTC absorber

- Taking into account the reduction in the size of the novel absorber (with the length L_2), the pressure drop penalty $\Delta P|_{L1}$, shown in Fig. 2, for the length L_1, should be reconsidered as $\Delta P|_{L2} = \Delta P|_{L1} \cdot (L_2/L_1)$, and decreases as shown in Fig. 4.

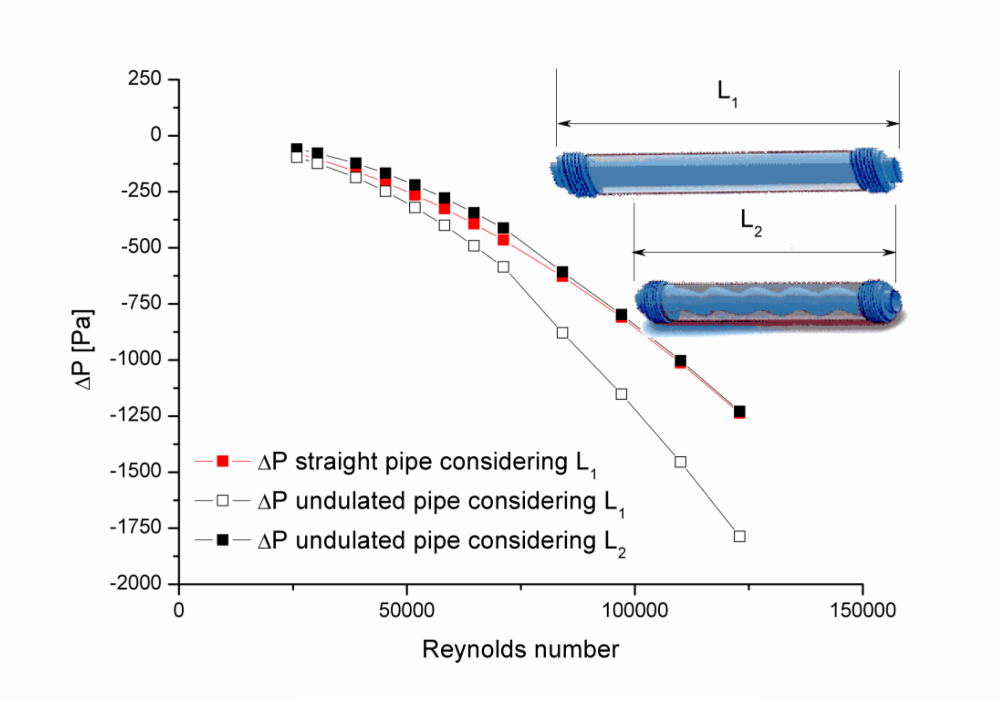

Fig. 4: The re-balancing of the pressure drops.

3. Conclusion

Following a similitude analysis developed in this study, the sizes of the absorber, solar collector modules and solar collector field should reduce about $\simeq 0.39\%$ by using of the novel undulated absorber. The increase of the pressure drop penalty of the novel solar absorber pipe is shown to be re-balanced by the reduction in its length. The manufacturing cost diminishes and the know-how remains unchanged with regard to the conventional absorbers, while the performance increases; the (performance/cost) ratio should be higher, what reduces drastically the kWh cost of the solar power.

4. References

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