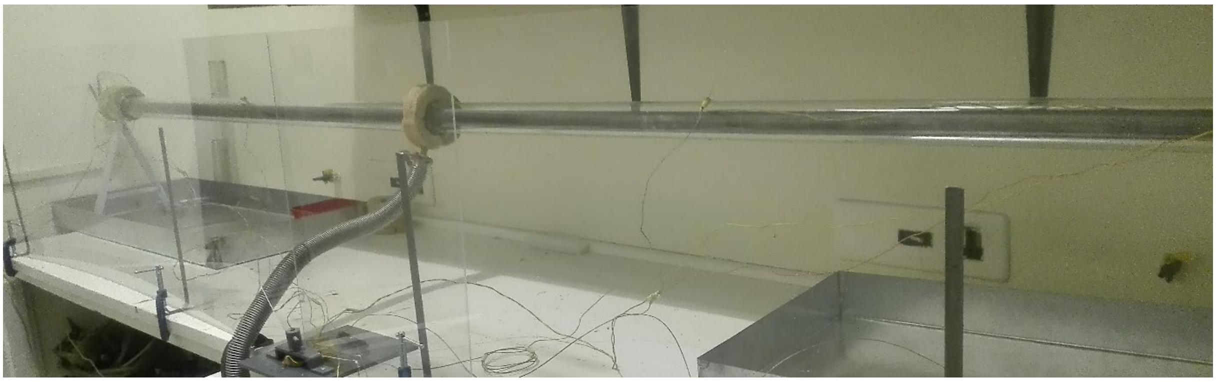

Figure 2: The receiver unit set up in the laboratory.

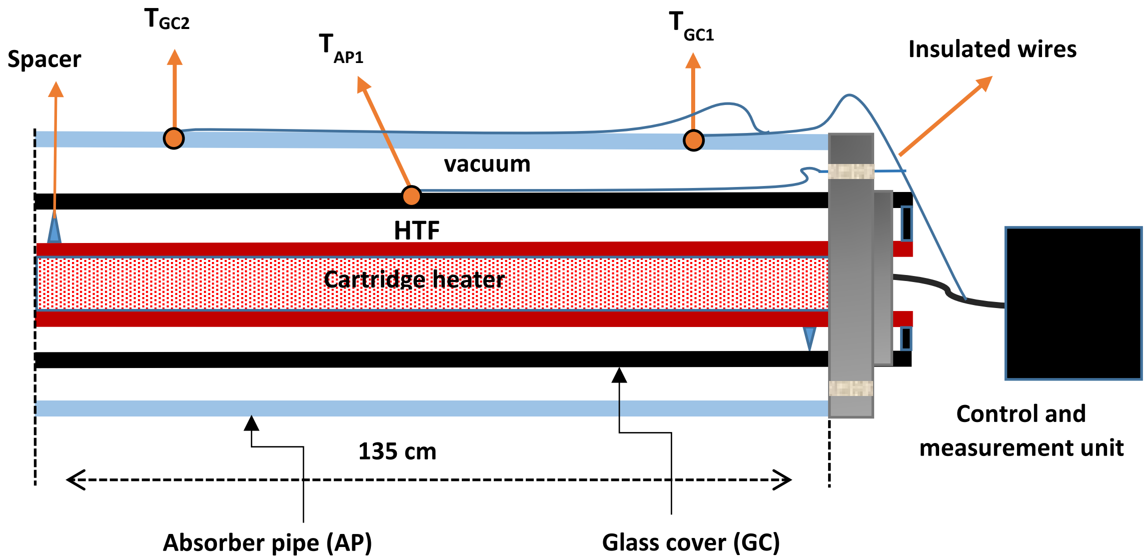

Figure 3: The right one-half of RU. T represents the thermocouple position.

3. Theory and simulation study

The source of the thermal energy is an electrical resistance heater wire with a constant rate of heat generation and can be modified by a variac. Fig. 3 shows the total heat transfer of the system and the interactions between its components. The physical basis of our model starts with a comprehensive description of the thermal interaction. Under steady operating conditions, the absorber pipe and the glass cover reach a different stagnation temperature. In addition, the heat loss and the heat gain of each element in the RU must equal the total rate of heat generation of the heating elements $\dot{E}_{gen}$

$$\dot{q}_{GC,amb} = \dot{q}_{GC,cond} = \dot{q}_{AP,GC} = \dot{q}_{AP,cond} = \dot{E}_{gen},$$

where $\dot{q}_{GC,amb}$ is the rate of the heat transfer from the glass cover (GC) to the surroundings, $\dot{q}_{GC,cond}$ is the conduction through the GC layer, $\dot{q}_{AP,GC}$ is the heat transfer from AP to GC, and $\dot{q}_{AP,cond}$ is the conduction through the AP.

The calculations start from the heat loss to the ambient because the ambient temperature is always known. We initially guess the unknown outer GC surface temperature $T_{g,o}$ iteratively, until the steady operating condition at which $\dot{q}_{GC,amb} = \dot{E}_{gen}$ is fulfilled. The heat rate $\dot{q}_{GC,amb}$ consists of natural convection and radiation heat transfer from the glass cover to the ambient.

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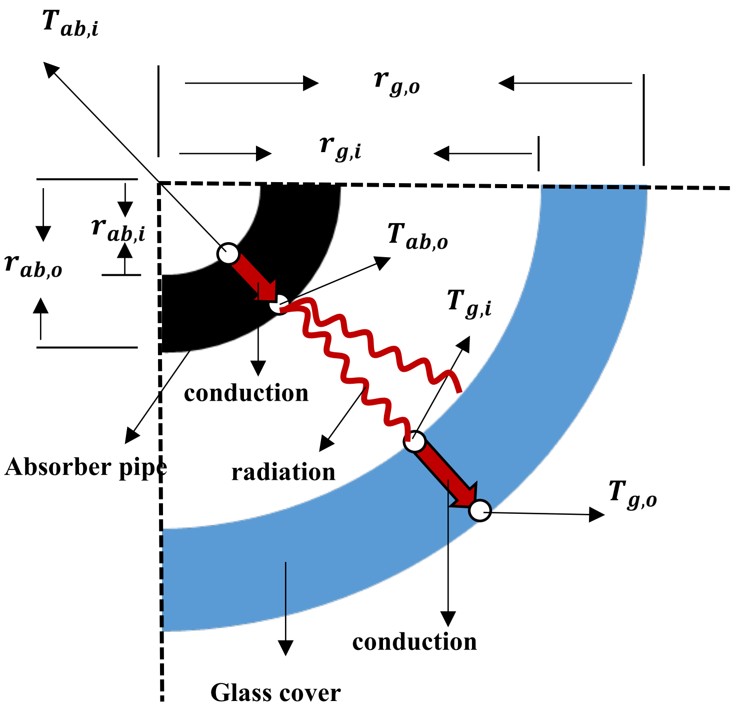

Figure 4: Receiver unit cross section.

The air properties during the calculation were selected at $T_{avg} = \frac{T_{g,o}+T_{amb}}{2}$. We could then evaluate $T_{g,i}$ at which the rate of heat loss due to the conduction through GC equal $\dot{E}_{gen}$. In the same way, $T_{ab,o}$ is evaluated through iteration until fulfilling $\dot{q}_{AP,GC} = \dot{E}_{gen}$, where $\dot{q}_{AP,GC}$ consists of the rate of the heat transfer between the AP and GC by convection and radiation. The convection heat transfer inside the evacuated annulus was ignored. Finally, $T_{ab,i}$ was evaluated such that the conduction heat loss through the AP equaled $\dot{E}_{gen}$. This simulation code was implemented using Python and is shown in Fig. 5.

4. Results

The initial experimental results tested for a normal RU reference unit without any coating. The aim was to validate our theoretical framework and simulation using experimental results. Two experiments were performed testing the thermal behaviour of the RU; 1) with air inside the annulus, and 2) with the annulus evacuated. The simulation predicted differing temperature readings for them, which we wanted to verify experimentally. The tested RU is shown in Fig. 2

In Fig. 6 and 7, the heat loss per meter of the RU length is depicted as a function of the absorber pipe and glass cover temperatures respectively. In the figures, "Sim" indicates simulation and "Exp" indicates experimental. In Fig. 6, the discrepancy between the simulation and experimental work in both cases vacuum and air in the annulus are 2% and 5.6% respectively.

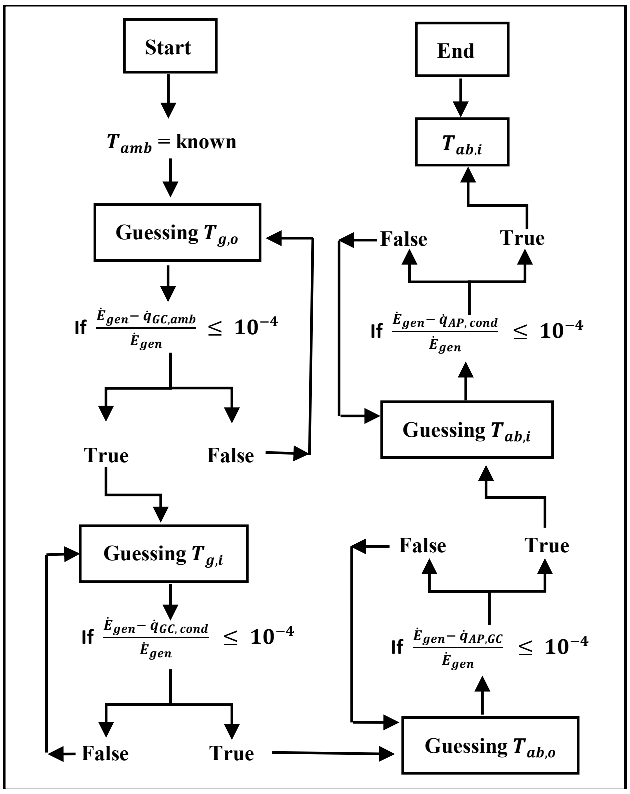

Figure 5: Algorithm for simulation code

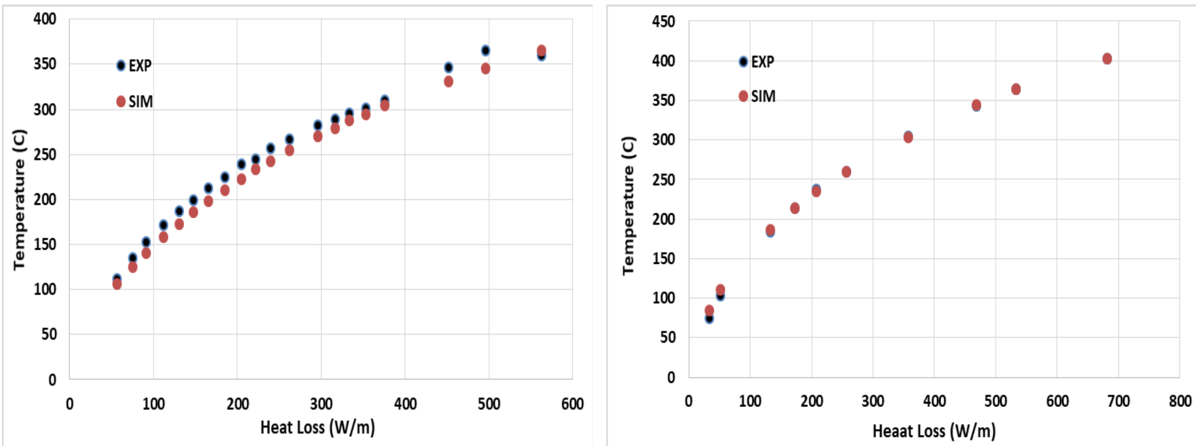

Figure 6: a) Heat loss versus AP temperature (Air in the annulus). b) Heat loss versus AP temperature (Vacuum in the annulus).

The simulation predicted a higher AP temperature for the vacuum system, since there the convective heat transfer has been eliminated, and the only for heat to escape is via radiation. This is clearly shown in the experimental results, where the AP temperature is measurably higher in the vacuum case.
In all cases the simulation seems to predict a greater heat loss. This seems to suggest that some of the material property values need to be re-evaluated. Further, the edge heat loss effects need to be incorporated.

In Fig. 7, the simulation predicts that the GC temperature for the case of vacuum and air in the annulus is the same at a fixed value of the heat power generation, since the heat dissipation mechanism from the

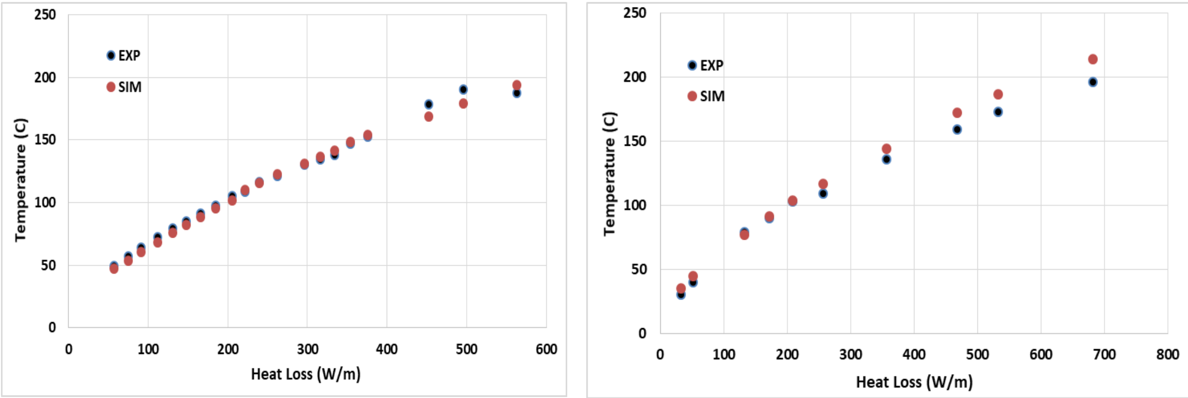

Figure 7: a) Heat loss versus GC temperature (Air in the annulus). b) Heat loss versus GC temperature (Vacuum in the annulus).

GC to the ambient is similar. Further, the discrepancy between the simulation and experimental work in both cases vacuum and air in the annulus are 6% and 3% respectively.

5. Conclusion

We tested a receiver unit (RU) of the parabolic trough collector indoor, in order to validate our theoretical and numerical framework. Two experiments were performed, for which the simulation predicted different results. Experimental data verified the results of the simulation to within 2 % and 6% discrepancy for the absorber pipe temperature in the case of vacuum and air in the annulus respectively. Also, a discrepancy of 6% and 3% for the glass cover in the case of vacuum and air in the annulus respectively. This successful set of validations encourages us to continue testing our proposed designs using this experimental setup.

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