Integrated nonimaging optical design for evacuated tube solar thermal collector

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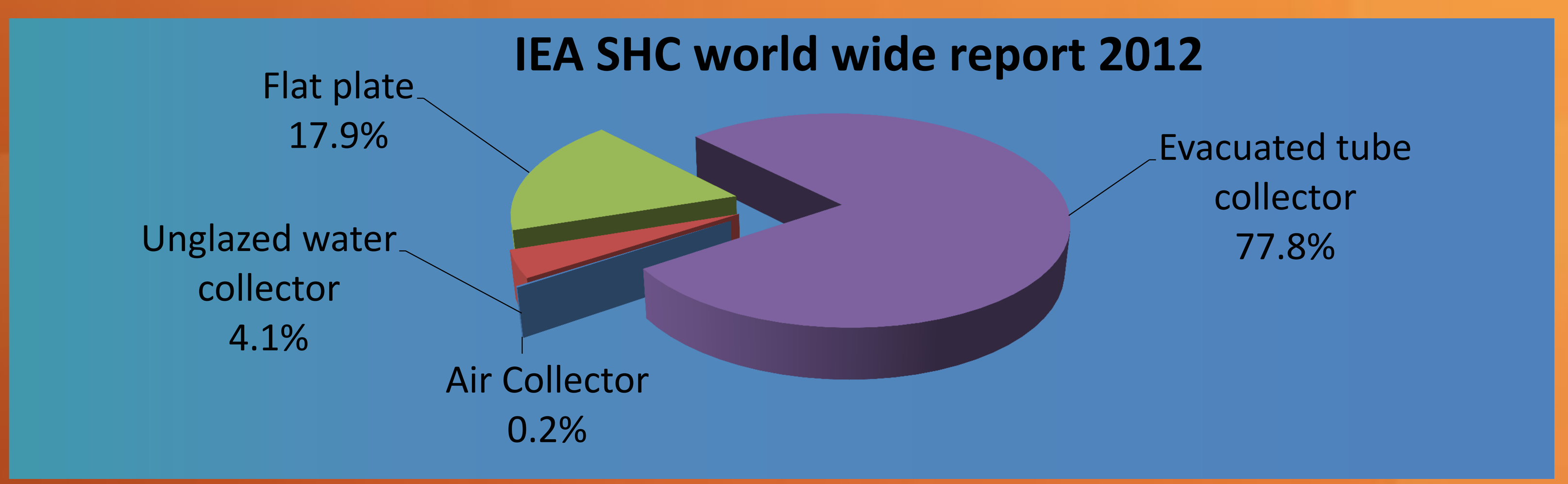
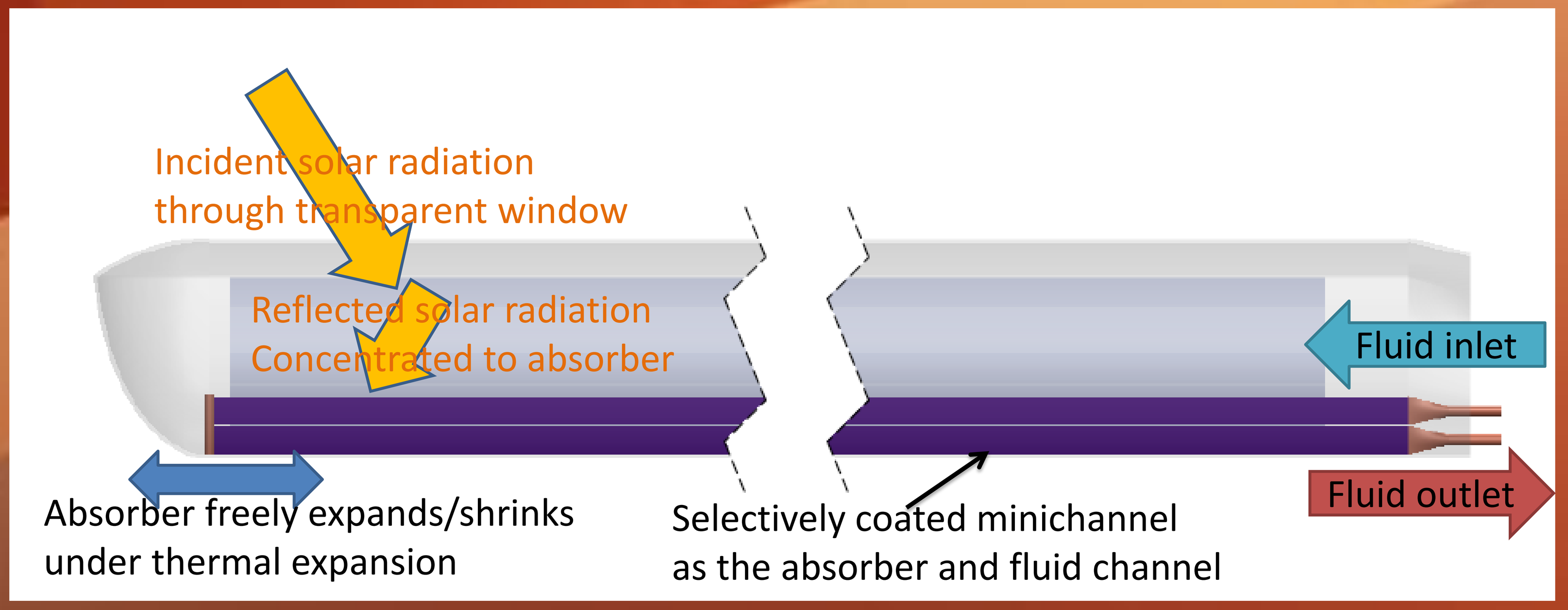
Background and the problem

Solar thermal has penetrated the energy market at a rate much higher than photovoltaic (PV). The low temperature solar hot water heater has reached historical total capacity of 245 GW(thermal) compared to 67.4GW (electricity) PV in year 2011. Compared to the high adoption rate of solar thermal collector operating below 100 Celsius, the development of solar thermal technology for applications above 100 Celsius for thermal processing has been challenging researchers for the last two decades. The potential for this kind of medium temperature collectors is promising: the temperature range of 100 to 250 Celsius accounts for 1/3 of the industrial thermal processing heat; the double effect LiBr absorption cooler used for large scale space cooling utilizes 140 to 155 Celsius heat. The general solar approach for these applications have been to use tracking devices with high concentration ratio. However, the maintenance of the tracker is not usually economically sustainable without subsidies. On the other hand, lower temperature, non tracking collectors such as evacuated tubes can not reach such temperatures without substantial change of the design. The prototype demonstrated in this poster utilizes the most widely adopted evacuated tube technology and improves its efficiency to enable non-tracking solar thermal technology to enter the medium temperature solar thermal applications



Working principle

The collector is positioned with its axis along east-west. The glass tube is shaped with a cross section of a nonimaging concentrator designed for 34 degrees half acceptance angle to accommodate the seasonal change of the sun. The incident solar radiation passes through the transparent upper part of the glass tube. Then it is concentrated by the lower part of the tube which is coated with reflective material and concentrates onto the absorber. As the working fluid (Duratherm 600) passes through the minichannel absorber, it heats up and carries away the thermal power generated by the device. The tube is evacuated and therefore very small amount of conduction or convection heat loss exists. The radiation loss is kept low by selective coating and relatively smaller absorber area due to concentration.



Challenges and solutions

- **Affordable/cost effective**

The general industrial payback time for implementing alternative energy sources tend to be 1 to 2 years. Using solar to compete with other energy sources within such a short time frame is sometimes prohibitive because solar collector investment is typically its system life time, which ranges from 20 to 30 years.

- Evacuated tubes are a proven mature technology that has 3 years payback time without subsidies, which resulted in their large scale implementation and mass production.

- **Efficient at higher temperatures**

As the working temperature rises for the solar thermal collector, the efficiency drops. Maintaining the efficiency above 40% despite of the higher working temperature is necessary for solar thermal to be comparable with other forms of energy.

- Although without tracking, the nonimaging wide angle concentration ratio is still able to achieve 1.1 to 1.8 as well as utilizing both the front and back of the absorber. Therefore 40% efficiency at 250 Celsius is achievable with the current prototype of the device.

- **Easy to install and maintain**

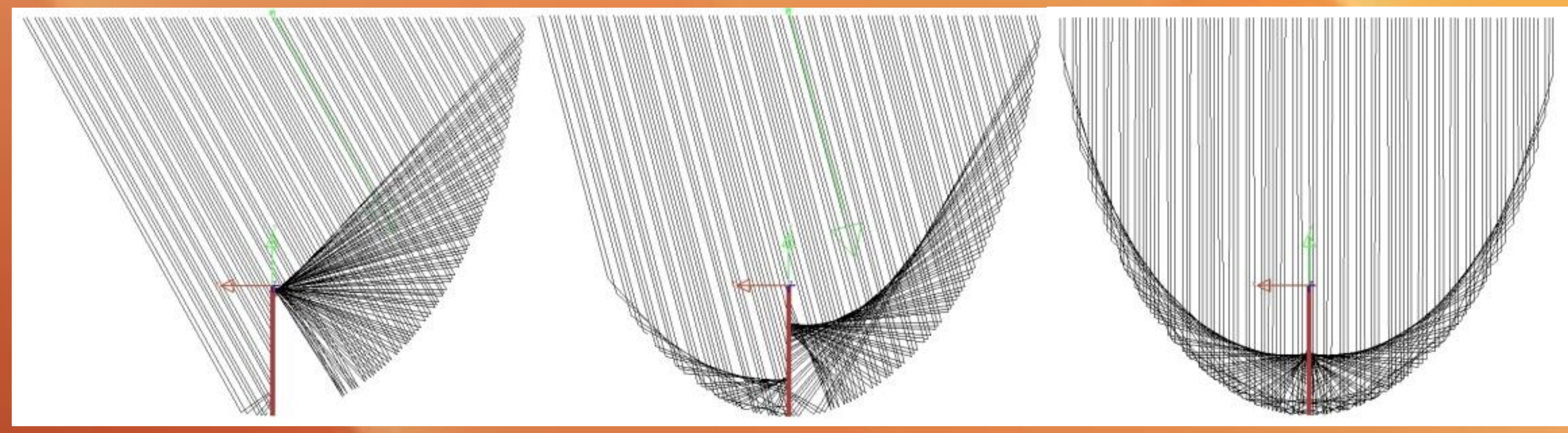
Many technologies (LFC, PTR), originally designed for higher (>300 Celsius) applications such as driving steam turbine to produce electricity, have been sized down to be optimized for the medium temperature application. All of them require tracking which means higher cost of installation and maintenance.

- Non-tracking device installation is well established in the market and almost as simple as plug and play. No poles have to be put down, therefore rooftop installation is also possible with a small amount of labor. Without any moving parts except pumps and fluids, the maintenance is also low.

- **Durable**

Many solar thermal devices which utilize concentrators face the problem of degradation of the reflective layer over time.

- The vacuum inside of the evacuated tube collectors have been proven to last more than 25 years, the reflective coating for the design is encapsulated in the vacuum inside of the tube, which will not degrade until the vacuum is lost.



Ray tracing according to different seasonal sun position

Solar Concentrator and efficiency

The efficiency of a solar collector is simply the energy extracted by the solar collector divided by the radiation energy received by the collector.

$$\eta_{collector} = \frac{Q_{collect}}{Q_{in}} < 1$$

Here the heat loss from the collector to the ambience reduces $Q_{collect}$:

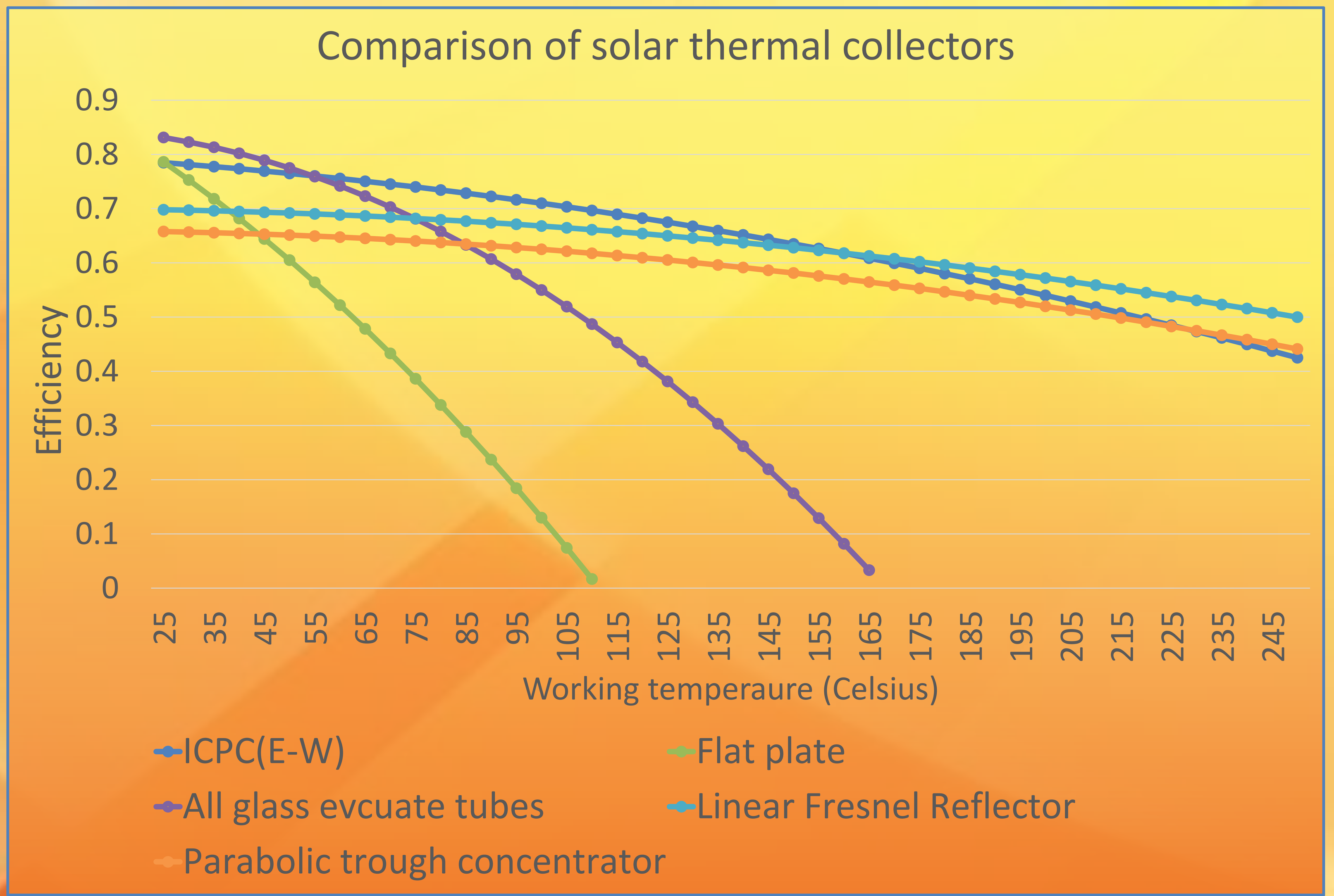
$$\eta_{collector} = 1 - \frac{Q_{loss}}{Q_{in}} = 1 - \eta_{loss}$$

Therefore increasing $\eta_{collector}$ can be achieved by effectively reducing η_{loss}. Heat loss can be divided into radiative, convection and conduction heat losses. Radiative heat loss plays a bigger role in higher temperature solar collector designs because it rises according to the fourth order of the working temperature according to the Stefan-Boltzmann law, while as the other two kinds of heat loss rises linearly according to the working temperature.

$$Q_{loss} \sim Q_{radiLoss} = \sigma\epsilon A_{absorber}({T_{work}}^4 - {T_{amb}}^4)$$

$$\eta_{loss} \sim \frac{Q_{radiLoss}}{Q_{in}} = \frac{\sigma\epsilon A_{absorber}({T_{work}}^4 - {T_{amb}}^4)}{G_{incident}\, A_{aperture}} = \frac{\sigma\epsilon\,({T_{work}}^4 - {T_{amb}}^4)}{G_{incident}\, C}$$

Where C is the concentration ratio: $C = A_{aperture}/A_{absorber}$. Given the working temperature T_{work}, certain solar resource $G_{incident}$, in order to achieve higher efficiency at higher working temperature, the collector design seeks to lower the emissivity ϵ and increase the concentration ratio C. The state of the art commercially available selective coating is 5.6% for ϵ at T_{work} of 200˚C. The heat loss in this case is still $200W/m^2$ and Q_{in} is typically $600W/m^2$ to $800W/m^2$ during summer in California. Therefore, all parameters for determining η_{loss} are fixed except for C. Increasing C with non-tracking concentrators will thus increase the efficiency of non-tracking solar thermal collectors by reducing the radiation loss percentage. Enabling such a concentration technology to be implemented in evacuated tubes provides an independent method for increasing the efficiency as well as improving the selective coating by lowering the emissivity (ϵ).



Calculated efficiency drop according to working temperature