Novel Design of an East-West XCPC for Solar Thermal Applications

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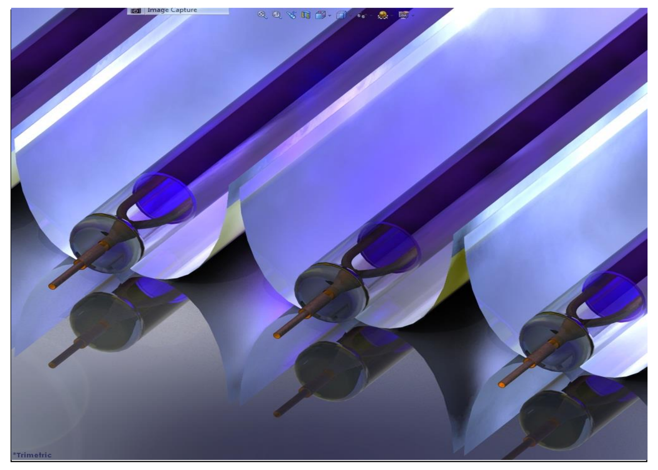
Background

Typical solar thermal collectors fall into tow major categories. First low temperature flat plate collectors and second high temperature concentrating collectors. Flat plate collectors are simple in that they don't require any motion tracking, but they are limited in temperature range, only reaching around 100ºC. The high temperature concentrating collectors are able to reach temperatures above 400ºC, but they require large complicated solar tracking systems which are energy intensive and difficult to maintain. Our goal is to develop a medium temperature range system that can concentrate sunlight without the need to track. Using the principles of Non-Imaging Optics a solar concentrator was developed to collect sunlight onto a uniquely shaped collector. Design and testing resulted in a new External Compound Parabolic Concentrator (XCPC) which can operate at temperature at or above 200ºC.

Fig. 1 - Early generation design of the North-South XCPC



Early Iterations

The first versions of the XCPC consisted of a Non-Imaging Optics designed collector which would concentrate sunlight to a cylindrical receiver placed inside a vacuum tube without tracking. These XCPCs were designed with a solar concentration ratio of C=1.15 and an acceptance half angle of 60º. With these parameters the first XCPC collectors were oriented in a North-South aligned configuration to accept sunlight for approximately 8 hours of the day. From testing, the North-South XCPCs were found to operate at relatively high efficiencies at operating temperatures below 180ºC. When reaching temperatures above 200ºC however, the efficiency of the collectors began to drop. A new design was needed to breach the 200ºC barrier while still operating at a high efficiency.

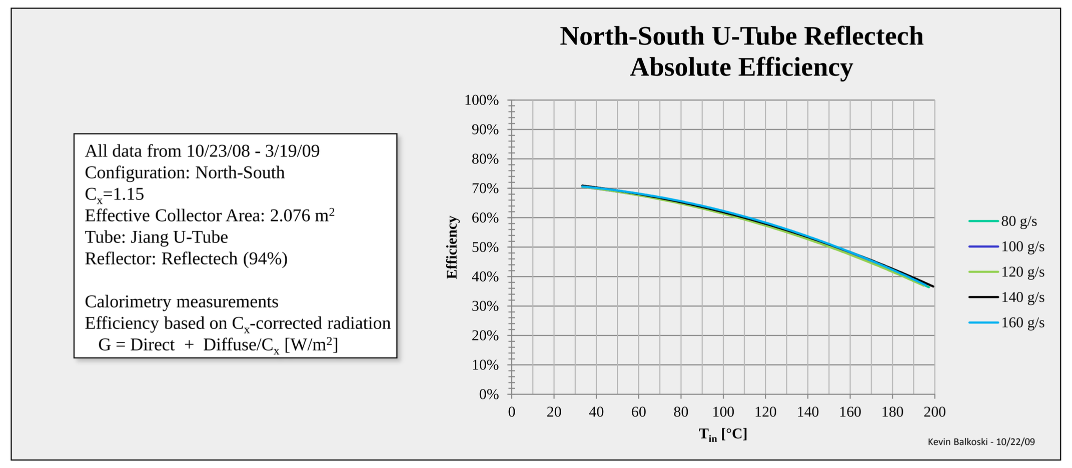


Fig. 2 - North-South XCPC Efficiencies

Design

The original design of the XCPC had the restrictions of seeing only a limited portion of the sky and could only reach around 180ºC at 40% efficiency. Our goal was to modify and improve the XCPC design to:

- Operate for a longer period of the day
- Reach an operating temperature above 200ºC
- Maintain an operating efficiency at or above 40% at 200ºC

To achieve these parameters a new Non-Imaging Optics collector was designed with a higher concentration ratio of C=1.5 and an acceptance half angle of 40º. The smaller acceptance half angle of the collectors meant they needed to be oriented in an East-West direction. This East-West orientation allowed the collectors to see the sun throughout the entire day, while following its seasonal variation above the horizon.

Secondly a new pentagonal shaped receiver was designed to more readily conduct heat to the heat transfer fluid. After many iterations it was found that a diamond or **"Superman"** shaped pentagon was the most effective for heat transfer, and collector design, as well as the simplest to manufacture. Simulations were done using LightTools software, Figures 3 and 4, to verify that our collector and receiver shape would effectively capture the majority of the input solar radiation.

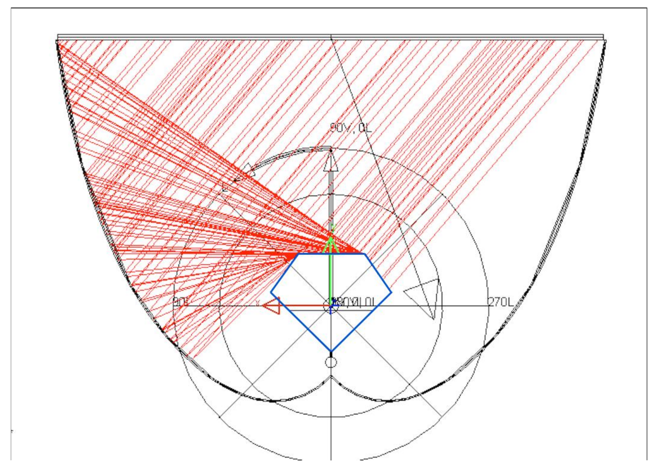


Fig. 3 - Light Ray Tracing of the XCPC collector profile and "Superman" receiver.

Fig. 4 - Light Tools simulation results of collector performance throughout seasonal change in sunlight angle.

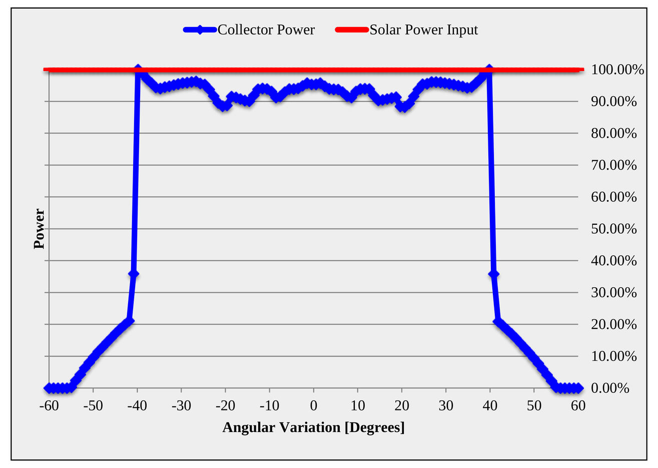


Fig. 5 - Fully Constructed East-West XCPC Prototype

Performance

To characterize the performance of the newly designed East-West collectors and the "Superman" tubes, a prototype was connected to a test loop designed to pump Druatherm 600 heat transfer oil. The test loop consisted of a pump, heating element, flow meter, and calorimeter, as well as thermocouple clusters across the inlet and outlet to the collectors and the inlet and outlet to the calorimeter. To determine the efficiency of the collector at different operating temperatures a general heat transfer equation was used to first calculate the power output of the collectors.

$$q = \dot{m}c_p(T_{out} - T_{in}) \qquad \text{(eqn. 1)}$$

For testing, the flow rate, m_{dot} was kept constant at 100 g/s. To calculate the heat capacity, c_p of the oil, calorimetric measurements were taken by measuring the power input (Voltage times Current) to the calorimeter, the flow rate, and the temperature difference across the calorimeter. From these measurements and rearranging equation 1, the heat capacity of the oil was determined.

$$c_p = \frac{IV}{\dot{m}(T_{cal,out} - T_{cal,in})} \qquad \text{(eqn. 2)}$$

Figure 6 shows the calorimetric measurements and the resulting equation for determining the heat capacity at various temperatures. From here the power output of the collectors could be calculated from various measurements of collector temperatures.

The efficiency of the XCPC collectors was calculated using equation 3

$$Efficiency = \frac{q_{col.}}{G} \qquad \text{(eqn. 3)}$$

where $G = Direct + {Diffuce}/{C_x}$, and C_x=1.5 is the concentration ratio of the collectors.

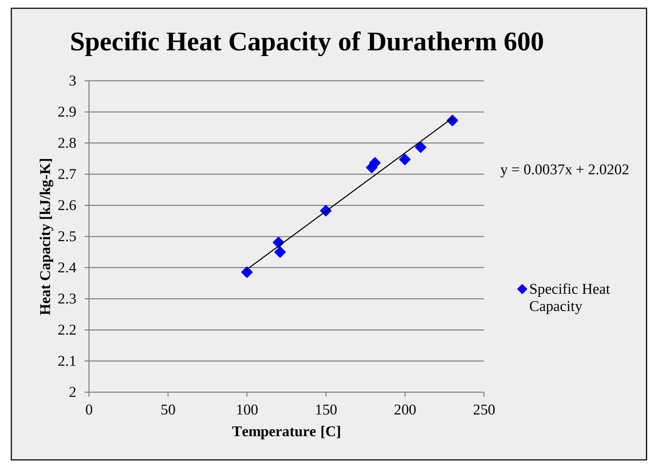


Fig. 6 - Heat Capacity characteristics of heat transfer oil measured via calorimetry.

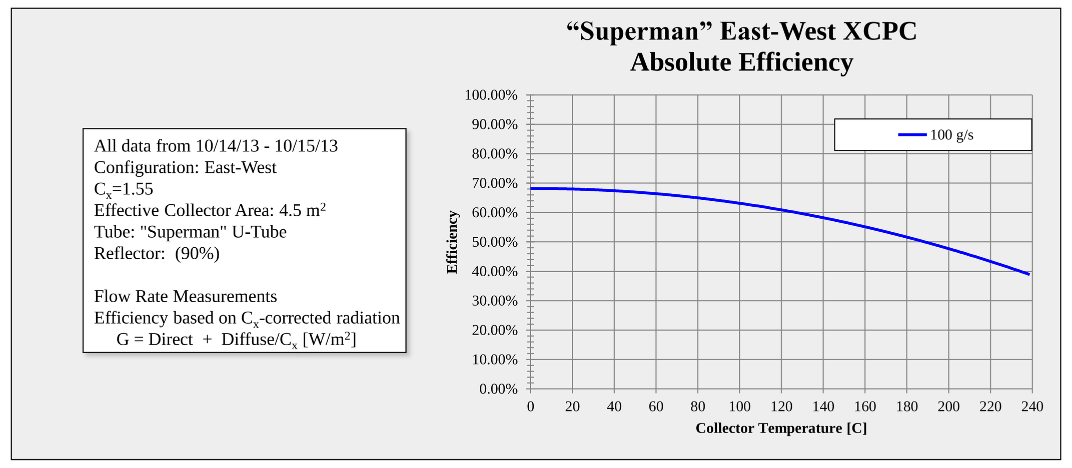


Fig. 7 - Efficiency of the East-West XCPC collectors at various operating temperatures.

Applications

There are many industries around the world that use process heat in some form. Many of these industries require temperatures between 200ºC and 400ºC for either manufacturing or processing of their products. A majority of the world currently uses natural gas or fossil fuels to produce those high temperatures. With this new XCPC design, solar thermal could potentially offset or even replace most of the worlds natural gas usage. The industrial applications where these new solar thermal collectors could be applied include but are not limited to:

•Food Processing

•Textiles

•Paper manufacturing

•Medical Sterilization

•Boiler Preheating

•Desalination

•Absorptive Chilling

Conclusion

Many current technologies used for solar thermal are either relatively low temperature or require large tracking systems which are expensive and difficult to maintain. Our new XCPC design based on the principles of Non-Imaging Optics is able to achieve a medium range temperature output without the need to track the sun. While operating at temperatures around 200ºC the East-West "Superman" XCPC is able to achieve efficiencies above 40%. The "Superman" XCPC has the potential to alleviate much of the worlds natural gas usage without requiring a large footprint or heavy machinery.

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