Investigating more efficient solar power

Prof Ken Craig

Renewable energy sources, unlike biomass energy, have not yet been fully exploited in South Africa. Domestic solar panels and geysers are becoming more widespread, but these provide only local power and are therefore not suitable for large-scale power generation. As a result, there is a need for renewable power plants that are capable of large-scale power generation.

Prof Ken Craig and his research team in the Department of Mechanical and Aeronautical Engineering at the University of Pretoria focused their research on the sun and the energy it can provide. The research team decided to focus on concentrated solar power (CSP).

The concept of concentrating the sun's rays is not new. The ancient Greek mathematician and physician, Archimedes, devised a weapon that used the sun's rays. During the siege of Syracuse a few centuries BCE, he aimed a group of mirrors at enemy ships and destroyed them with fire. CSP uses this same principle to focus the sun's rays to heat a transfer fluid that stores and transports thermal energy.

Parabolic troughs are the oldest and most established CSP technologies in the world. These troughs (often more than a kilometre long) focus the sun's rays onto a line at the focal point of the parabola-shaped reflector. Although the heat transfer fluid is usually synthetic oil, new research is investigating other liquids that are more environmentally friendly. Another linear-focus CSP concept uses the idea of a Fresnel lens, which is based on the work of the French engineer Augustin-Jean Fresnel in the 1800s. This CSP technology is called linear Fresnel reflection, and Prof Craig's research team is particularly interested in these reflectors. A series of long, flat mirrors are each aimed at a downwards-facing receiver located above them, each tracking the sun throughout the day to remain focused on the receiver.

As shown in Figure 1, the mirrors are located on a horizontal plane and reflect the solar rays onto the cavity receiver. This receiver has a glass cover like a glass greenhouse to trap the heat from the sun. It lets the sun's energy through, but blocks some of the energy that is radiated from the hot pipes. The research is aimed at improving the efficiency with which heat from the sun's rays is transferred to the liquid inside the pipes.

The researchers are using computer simulations called computational fluid dynamics (CFD) to accomplish this. These computer programs solve the equations that describe how fluids flow and how heat is transferred through radiation, conduction and convection. Coupled with optimisation software, these simulations allow the researchers to seek the best geometry for the cavity and mirror array, as well as investigating different coatings on the cavity surfaces that will soak up as much of the sun's heat as possible without losing too much of it to the surrounding air.

Another CSP technology that is used for large-scale power production is that of a solar power tower. The largest solar power tower in the world is located in the Ivanpah Dry Lake, California. The plant can produce close to 400 MW of electricity a year. For this technology, a central receiver is located on a tower in the middle of a field of mirrors. These mirrors are called heliostats. Each heliostat tracks the sun, much like Archimedes' sun weapon. This means that the sun's heat is focused on one spot, rather than on a linear focal point as in the parabolic troughs and linear Fresnel reflectors. In this way, much higher temperatures (easily more than 1 000 ˚C) are reached.

Designing a receiver that can withstand high temperatures and conduct the heat to a steam plant where electricity is generated without radiating too much of it back to the surrounding air is extremely challenging. The research team is collaborating with researchers in

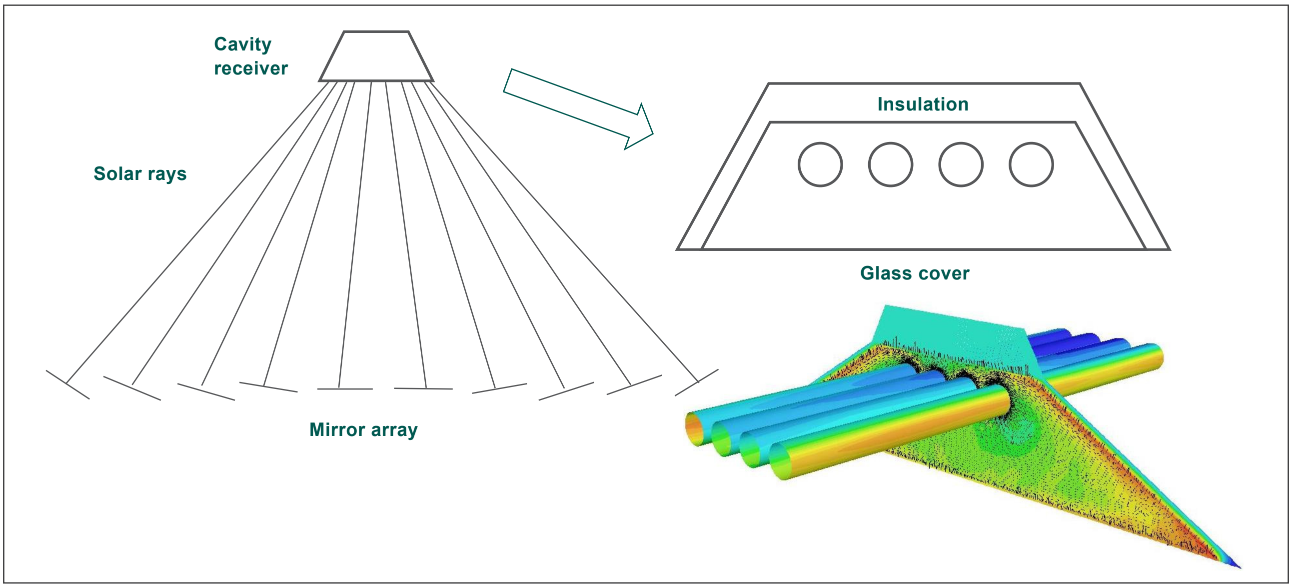

Figure 1: A linear Fresnel reflector with a cavity receiver and computational fluid dynamics solution of temperatures in the cavity and pipes that carry heat transfer fluid.

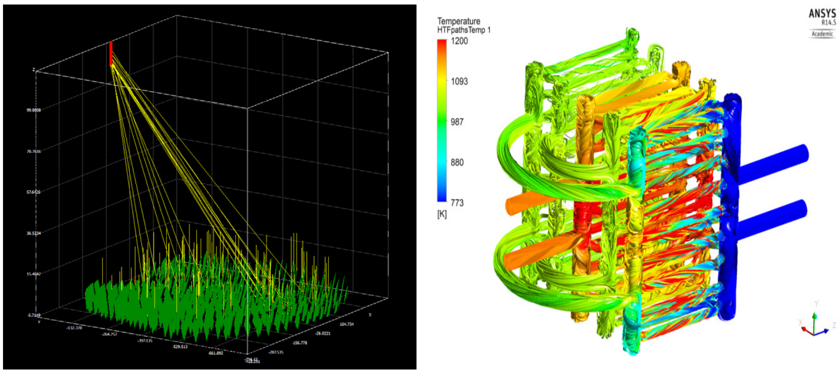

Figure 2: Simulation of the sun's rays onto a central receiver using SolTrace and a CFD simulation using ANSYS® Fluent software. Pressurised air is being heated by the sun's rays in a hybrid cavity receiver.

the Solar Thermal Energy Research Group (STERG) at Stellenbosch University. CFD is used to investigate innovative concepts of central cavity receivers and is then optimised to maximise the optical and thermal efficiency of these central receivers. It is particularly difficult to model the sun's rays and the way in which they are absorbed, reflected and transmitted. Prof Craig's team is researching new ways in which CFD software can simulate the radiative properties of the receiver surfaces for different temperatures and different wavelengths of the sun's energy. Other optical software, such as SolTrace from the National Renewable Energy Laboratory (NREL) in the USA, is also linked with CFD software to provide the thermal energy of the sun as a boundary condition.

The heliostats that make up the combined reflectors in these solar tower power plants can number in the hundreds of thousands and their cost could be half that of the initial costs of such a solar plant. Obviously, if each heliostat can be made lighter and cheaper, the overall savings could be significant. As these heliostats or mirrors are located outside and are exposed to a variety of environmental conditions such as high winds, hailstorms and dust storms, depending on their location, they need to be designed to withstand these conditions for the duration of the solar plant's life, which is often more than 20 years. Several undergraduate and postgraduate students are using both CFD and finite element analysis (FEA) software to design cheaper lightweight heliostats that are strong and capable of withstanding wind loads and other environmental conditions.

Along with the computer simulation of these interesting CSP topics, plans are underway to establish experimental research facilities where these designs can be evaluated. Several UP buildings are being evaluated as possible sites for such facilities. These would not only provide much-needed laboratory space in the form of rooftop labs, but could also assist in reducing the University's carbon footprint by providing thermal and electric energy to the buildings from a renewable source.

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