Lattice design for porous volumetric Central Receivers in Concentrated Solar Thermal applications

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In the post Energy Transition era, the composition of Total Primary Energy Supply is expected to be dominated by two direct solar energy capture technologies: photovoltaic and solar thermal, unless the dream of abundant and affordable fusion energy becomes a reality. Concentrated Solar Thermal (CST) technology captures solar energy in the form of high temperature heat, which can be directly used for various industrial applications, or can be converted into electricity, namely concentrated solar power (CSP). CSP is currently a more expensive method for producing electricity than photovoltaic. However, its better unit and total scalability makes CSP a serious contender if solar energy is harnessed on a greater scale. CST systems are composed of three main components: a concentrating optical arrangement, a thermal receiver and a thermal storage. CSP systems have an extra power generation component. Increasing the thermal efficiency and decreasing the cost of different components of CST systems is an ongoing field of research, globally.

This paper details research on a novel thermal receiver concept for CST systems with two-dimensional concentration optics (i.e. a dish), central tower and beam-down systems. In most existing receivers of such systems, the incident solar radiation is absorbed as high temperature heat on a continuous solid surface within the focal volume of the optical arrangement. The heat is then conducted through the solid and delivered to a thermal fluid in contact with the other side of the solid. However, confining the capture of concentrated radiation energy to a 2-D surface is limiting. Research is now concentrating on methods to capture the same radiation energy throughout a, practically, 3-D volume to improve the exergetic performance of central receivers. One of the major challenges inhibiting 3-D receiver technologies is the lack of control over the spatial rate of capture of solar energy.

In this research, the authors propose a novel 3-D receiver concept that employs lattice geometries described using implicitly defined triply periodic surfaces, whose volume fraction and other physical properties vary smoothly across the structure. The lattice provides a porous medium for the flow of thermal fluids in direct contact with the hot surfaces. The aim of this research is to design and manufacture lattices that can maintain a certain capture distribution. Furthermore, these lattices must successfully surrender the captured exergy to the thermal fluid with minimal loss and withstand thermo-mechanical, and perhaps chemical, stresses. We manipulate geometry of the lattice and use ray tracing method to map the solar energy capture within the volume of the receiver. We then use a thermodynamic model to compute the temperature field. It is shown that the absorption of energy takes place, effectively, within the whole volume of the receiver and in, a fractally-speaking, 3-D distribution. Finally, it is shown that the distribution of absorption can be manipulated through manipulation of the lattice geometry.

Initially, we assume that there is no flow through the receiver and the only means of heat transfer is through radiation. We also assume that the lattice surfaces are perfectly black, in absorption and radiation. Generalisations, including the effects of reflectiveness of the lattice surfaces, the influence of thermal fluids, the mechanical stresses in lattice as a result of its mechanical interaction with the thermal fluids and its own thermal expansion are planned as future work.

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