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Assessing the Role of Refractory Lining to Overcome the Solar Intermittency Challenge in Particle Receivers

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Abstract – Solar energy is an abundant source, but it's highly intermittent and non-uniform across the globe. Many technological developments have been carried out over the past years to transform solar energy into chemical or thermal energy, that can be stored and transported to places outside the earth's sunbelt [1, 2]. One such development is the use of a directly irradiated cavity-type receiver-reactor in which concentrated solar radiations directly heat-up solid particles for thermal power or chemical conversion into synthesis biofuels, which can be stored for later use or transported for use throughout the world. The use of solid particle, as heat transfer fluid and thermal storage medium, is one of the currently focussed areas for the practical implementation of receiver-based concentrated solar thermal technology to different industrial processes requiring temperature above 1000°C [3, 4]. Because the design temperature of these particle receivers is above the melting temperature of mild steel, they must either use more expensive high temperature metals, adding to cost, or a refractory lining, which is both brittle and has high thermal inertia. The transient response of directly irradiated particle receivers with a refractory lining is fundamentally different from that of tubular receivers, which typically employ thin conducting ductile materials. That is why the intermittent nature of solar resource can directly influence the thermal behaviour of these receivers. On the other hand, the optimize design of refractory lining can also help in damping the solar intermittency issue which is one of the major criticisms of this vast renewable energy source. This requires further investigations to understand the role of refractory lining on the thermal behaviour of particle receivers considering real-time solar resource variability. The assessment of refectory lining's role to overcome the issue of solar intermittence in directly irradiated cavity receivers is the aim of this research.

A transient mathematical model was developed and validated considering variable input solar energy to the receiver aperture. The developed transient model is employed to study the influence of refractory lining thickness on the transient distributions of cavity wall and particle phase temperature using minutely variability of the solar resource on a day with fluctuating direct normal irradiance (DNI). The central receiver considered in this study is a cylindrical cavity with a diameter of 12m, aperture to cavity diameter ratio of 0.55 and length to cavity diameter ratio of 1.6. The receiver cavity has an inner lining of fireclay bricks of thickness 50mm and the outer surface is covered by fiberglass insulation having a thickness of 250mm. The outside of the insulating layer is protected with a carbon steel ring.

Figure 1 presents the thermal behaviour of the receiver for a cloudy day with fluctuating DNI to evaluate the effect of transient conditions concerning the refractory lining thickness (20 to 80mm). It can be seen that the rate of increase in temperatures of the cavity wall and particles increases with a reduction in the lining thickness. It can also be observed that, even for the case of the thin refractory lining (20mm), the refractory greatly damps the fluctuations in particle temperature. For example, the particle temperature following the total slump in solar power to zero at t=280 and 390 minutes, only drops by 30 and 120°C, respectively. Furthermore, a further increase in the thickness of the refractory lining can greatly damp these fluctuations to result in a relatively stable and robust receiver operation despite the large fluctuations in the solar input. The receiver with a refractory lining thickness of 80mm is observed to

maintain a stable operation without any significant drop in temperature of the particles (less than 10ºC), following the periods of the total slump in solar power to zero. These results highlight the value of refractory in damping the fluctuations and show that careful choice of this parameter can be strongly beneficial to receiver operation. The receiver must be designed to be suitable for intermittent characteristics of the solar resource. Although, the duration of the heating up of the receiver must be shortened, which implies that the reactor is made of low thermal inertia – thinner refractory lining. However, in case of a solar flux decrease during reactor operation; due to crossing clouds, a too low thermal inertia would have a detrimental effect on temperature stability. The above results indicate that the optimization of the cavity lining thickness plays an important role for the better thermal performance of a refractory-lined receiver, which is why it should be optimized accurately. In this way, the receiver will have enough thermal mass (internal energy) to coop up with the intermittency of the solar resource. The increase in heating period at the start of the receiver operation will pay off towards the end of the day – the stored energy will keep receiver operational even after sunset as it can be observed from the presented results.

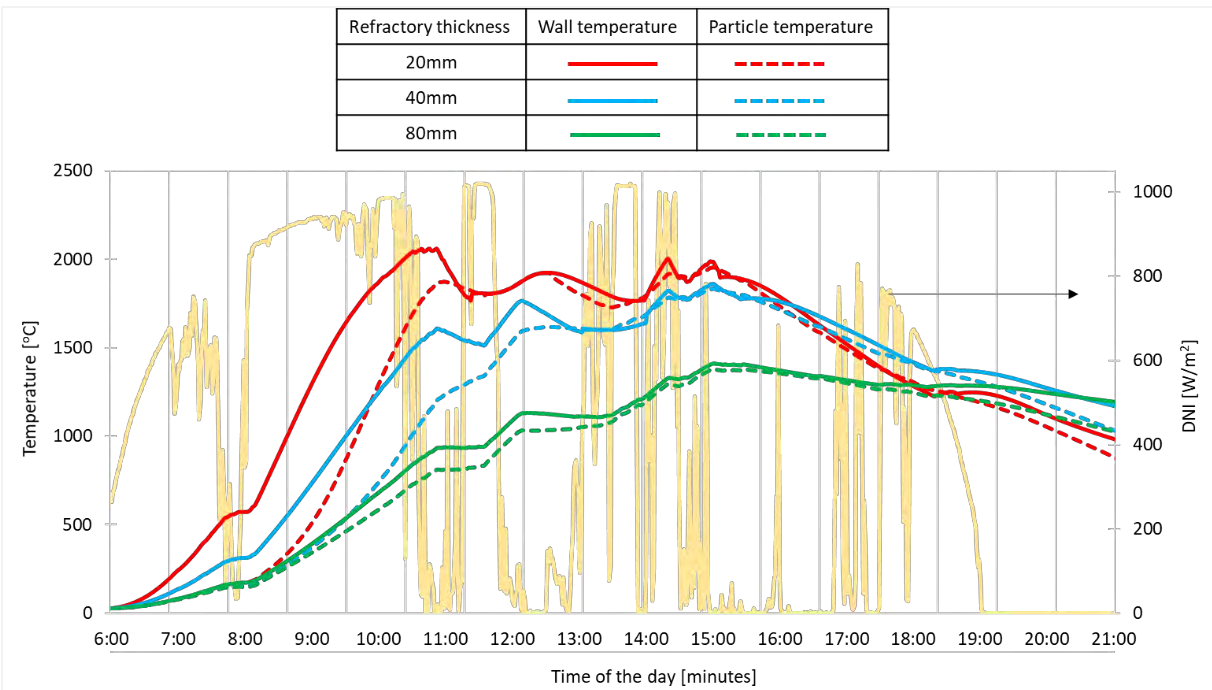

Figure 1. Influence of refractory lining thickness on the transient temperature distributions of the receiver wall and the particles for a fluctuating solar input.

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