On-Sun Experiments on a Particle Heating Receiver with Red Sand as the Working Medium

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Outline

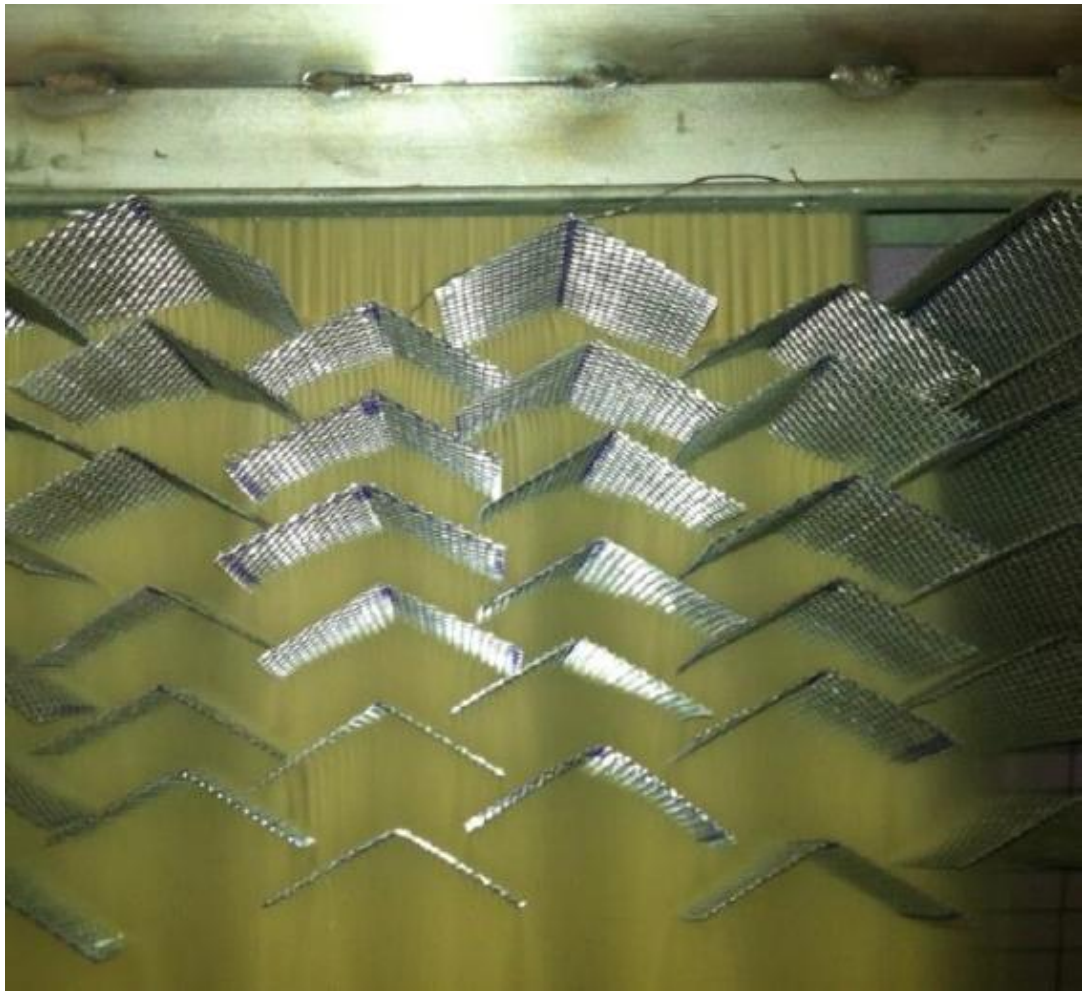
- What is a particle heating receiver (PHR)?
- Motivation and Objective
- Description of KSU PHR facility
- Experimental Methodology
- Sample Results
- Conclusion

What is a Particle Heating Receiver (PHR)?

- A receiver in which particles (rather than molten salt or steam) are heated directly or indirectly
- Types of PHR
  - **Free-falling curtain**
  - **Free-falling curtain with novel release patterns**
  - **Obstructed flow**
  - **Rotary kiln**
  - **Centrifugal particle flow**
  - **Tubular receiver with shell-side particle flow**
  - **Particle-laden gas flow**
  - **…**

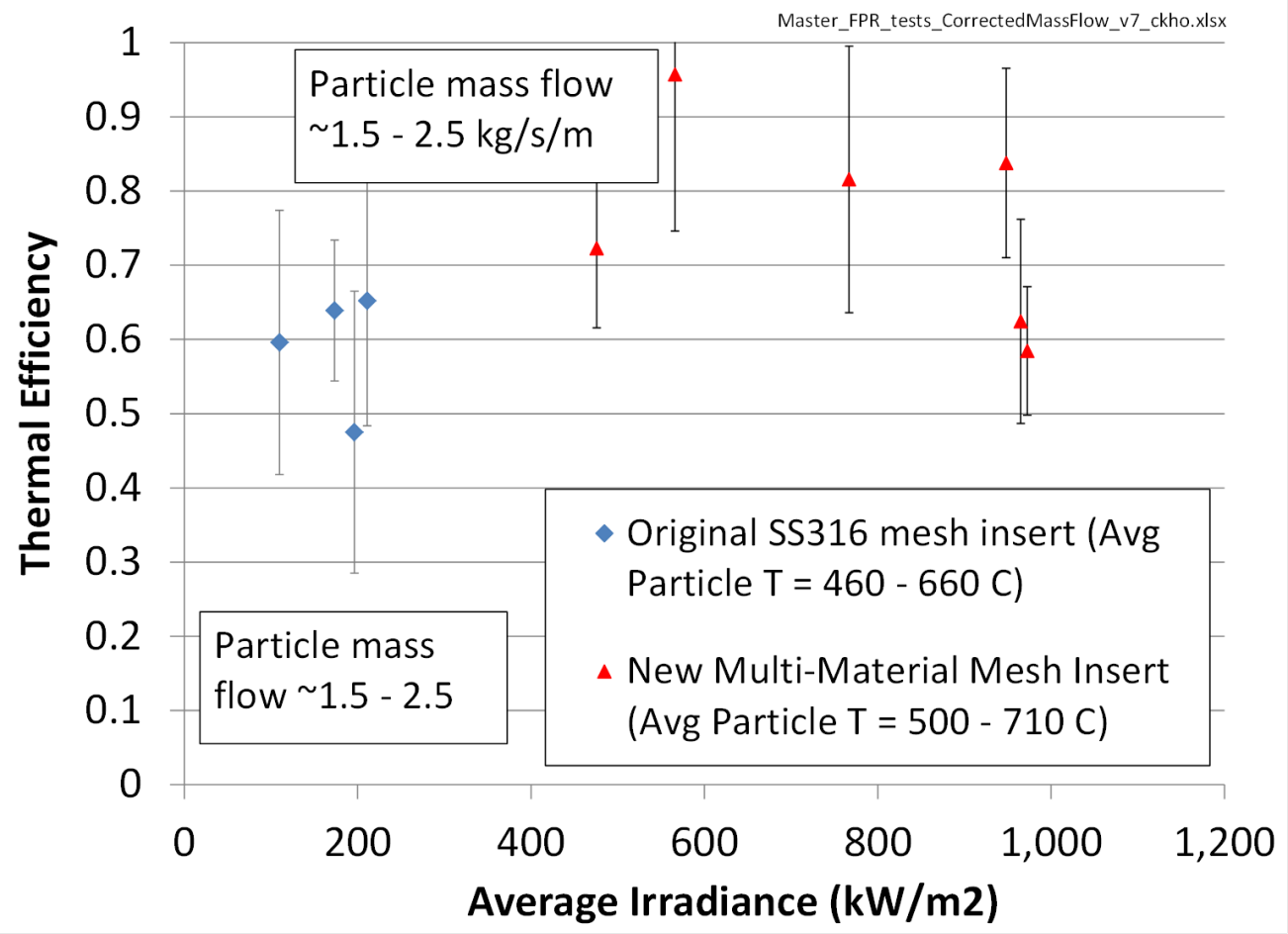
Obstructed Flow PHR

- Design developed by KSU and GIT
- Particle flow is impeded by chevron obstructions
  - **Increases particle residence time and efficiency**



Previous Tests of Obstructed Flow PHR

- Tests conducted at Sandia National Labs
- Particulate material was Accucast ID50K (alumina-based)
- Results are encouraging (efficiency approaching 90%)



Challenges With Obstructed Flow PHR

- Durability
- Suitability for high mass flow rate
- Cost of particulate material
  - **General concern with all PHR designs**
  - **Current cost of engineered particles is $1-$2/kg**

Motivation

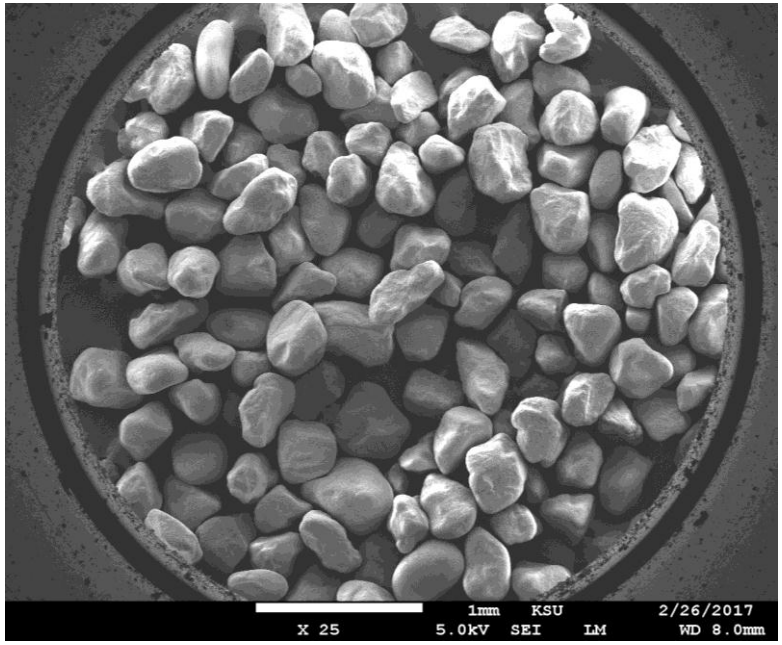
- Engineered particles are relatively expensive despite their superior optical properties
- When the material is also used for storage, the initial cost becomes considerable
- A “true” cavity receiver is less sensitive to the optical properties of the particulate material

Motivation

- It is desirable to work with less expensive particulate materials that can achieve reasonable thermal efficiency
- Small efficiency penalty may be mitigated by the significantly lower cost
- Candidate materials:
  - **Red sand**
  - **Spent catalysts**
  - **Fly ash**

Candidate Particulate Materials

- Red sand is particularly promising
  - **Abundant and very inexpensive ($0.01-$0.02/kg)**
  - **No sintering at temperatures as high as 1000°C**
- Depending on source, it can be relatively dark and round

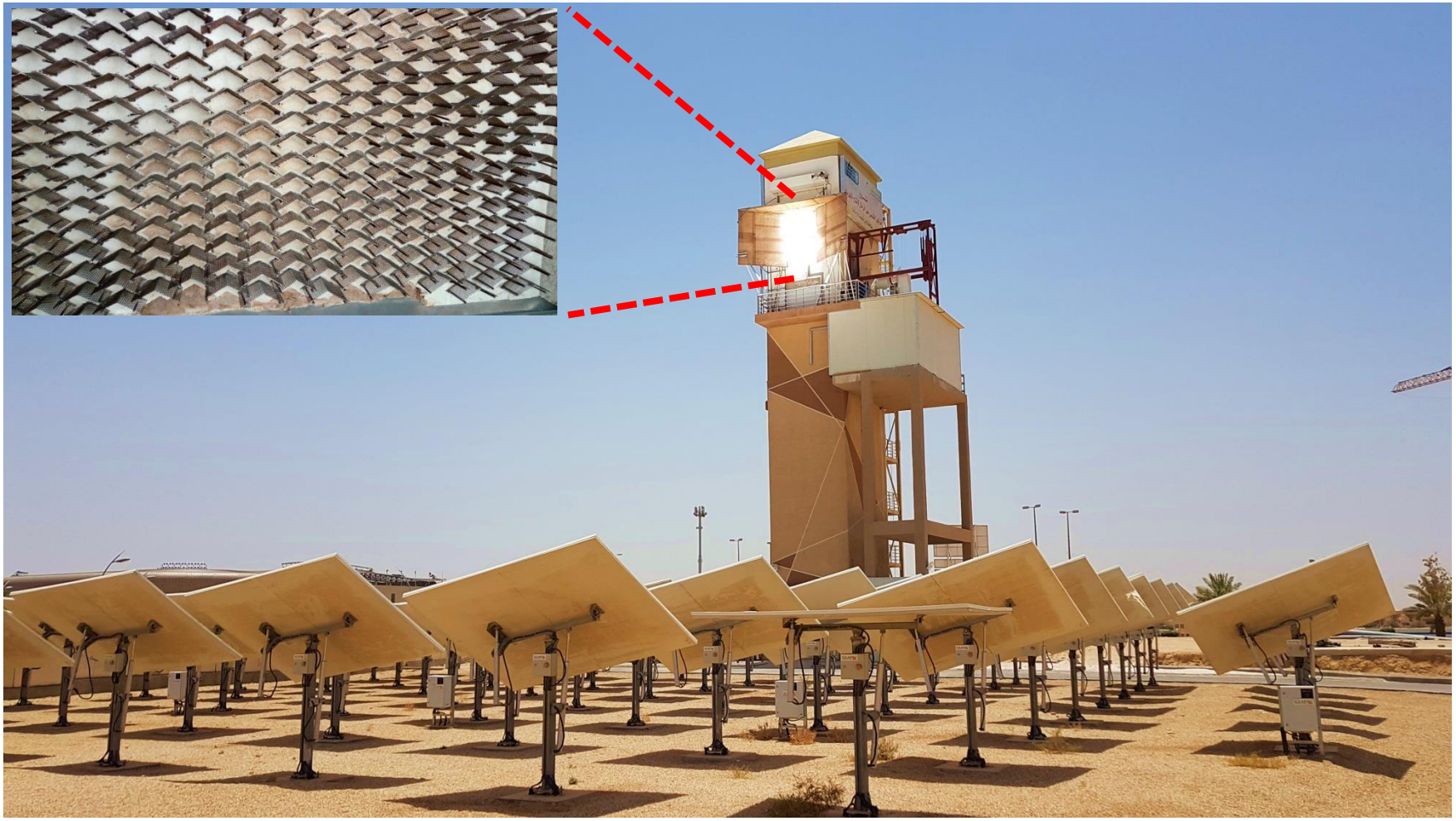


Objective

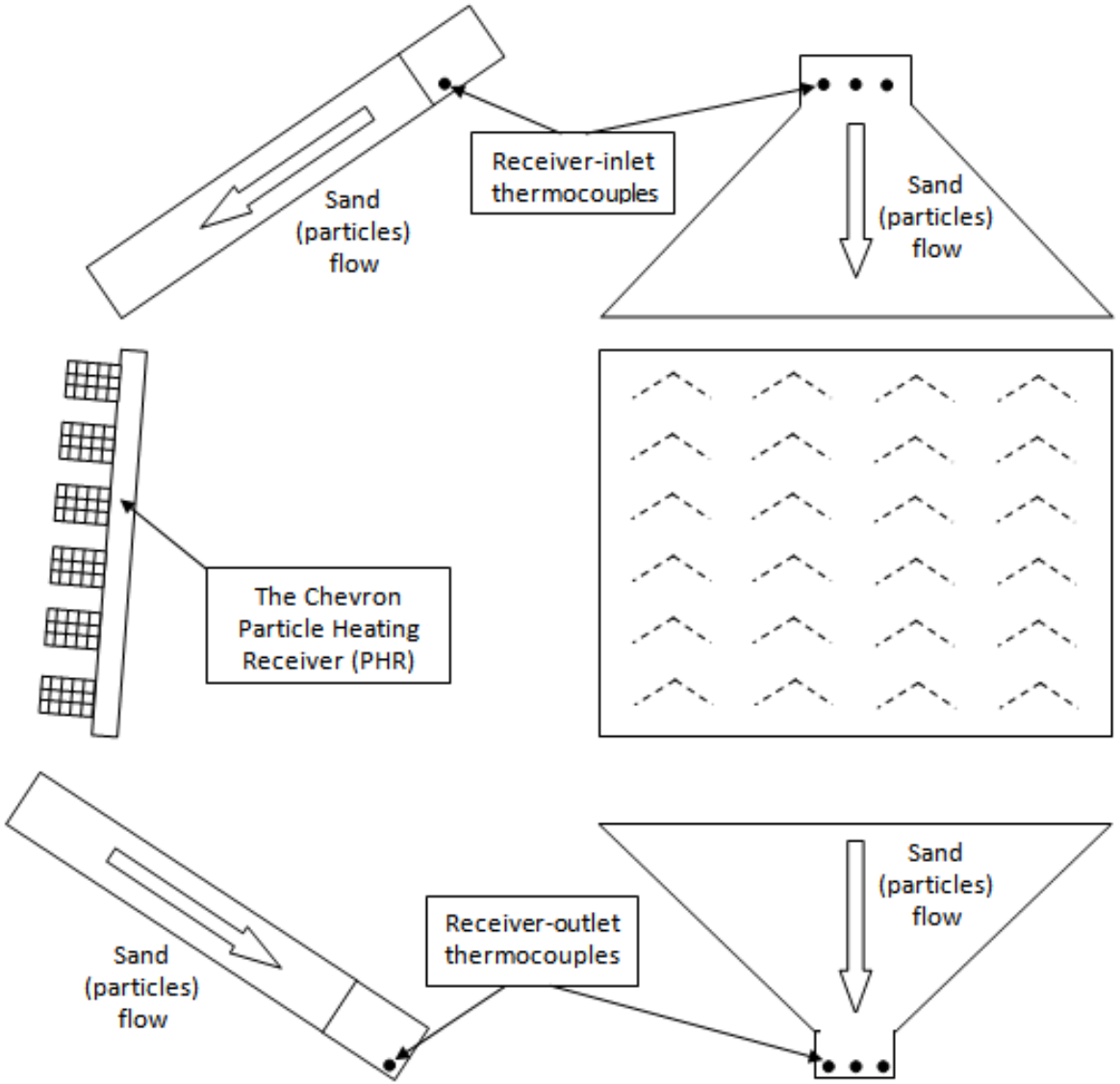
To assess the thermal efficiency of an obstructed flow PHR using red sand as the particulate material

KSU's 300 kWth Test Facility

- To meet the study's objective, the 300 kWth PHR test facility at KSU was utilized.



Experimental Setup



Experimental Methodology

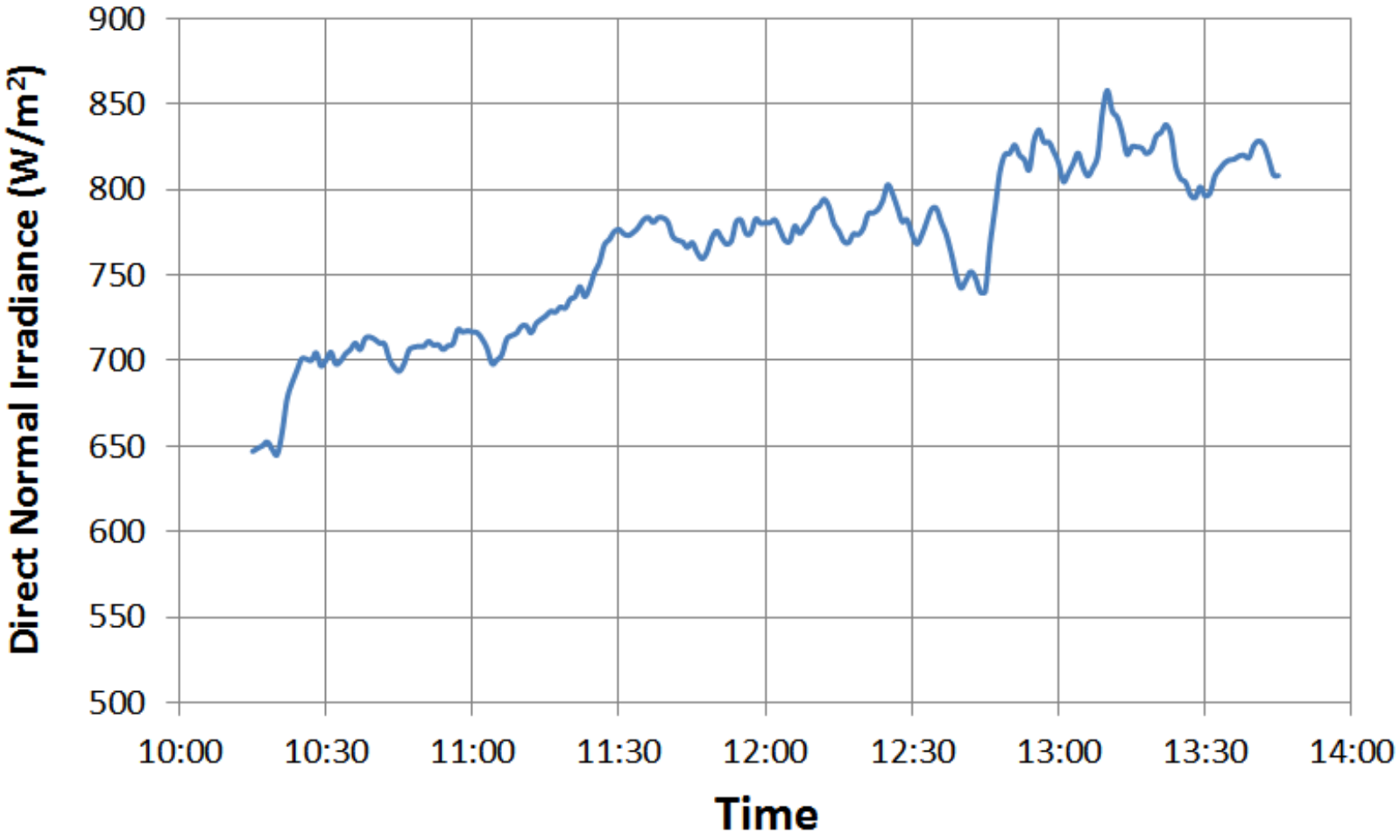
- Rate of thermal energy absorption is calculated from the energy equation:

$$\dot{Q} = \dot{m} \times C_p \times (T_{\text{out}} - T_{\text{in}})$$

- Flow rate is controlled by varying the speed of the particle conveyor
- Temperature is measured by 3 thermocouples at the inlet and outlet
- Specific heat of sand at different temperatures is found from the literature

Sample Results

Direct Normal Irradiance on August 2, 2017



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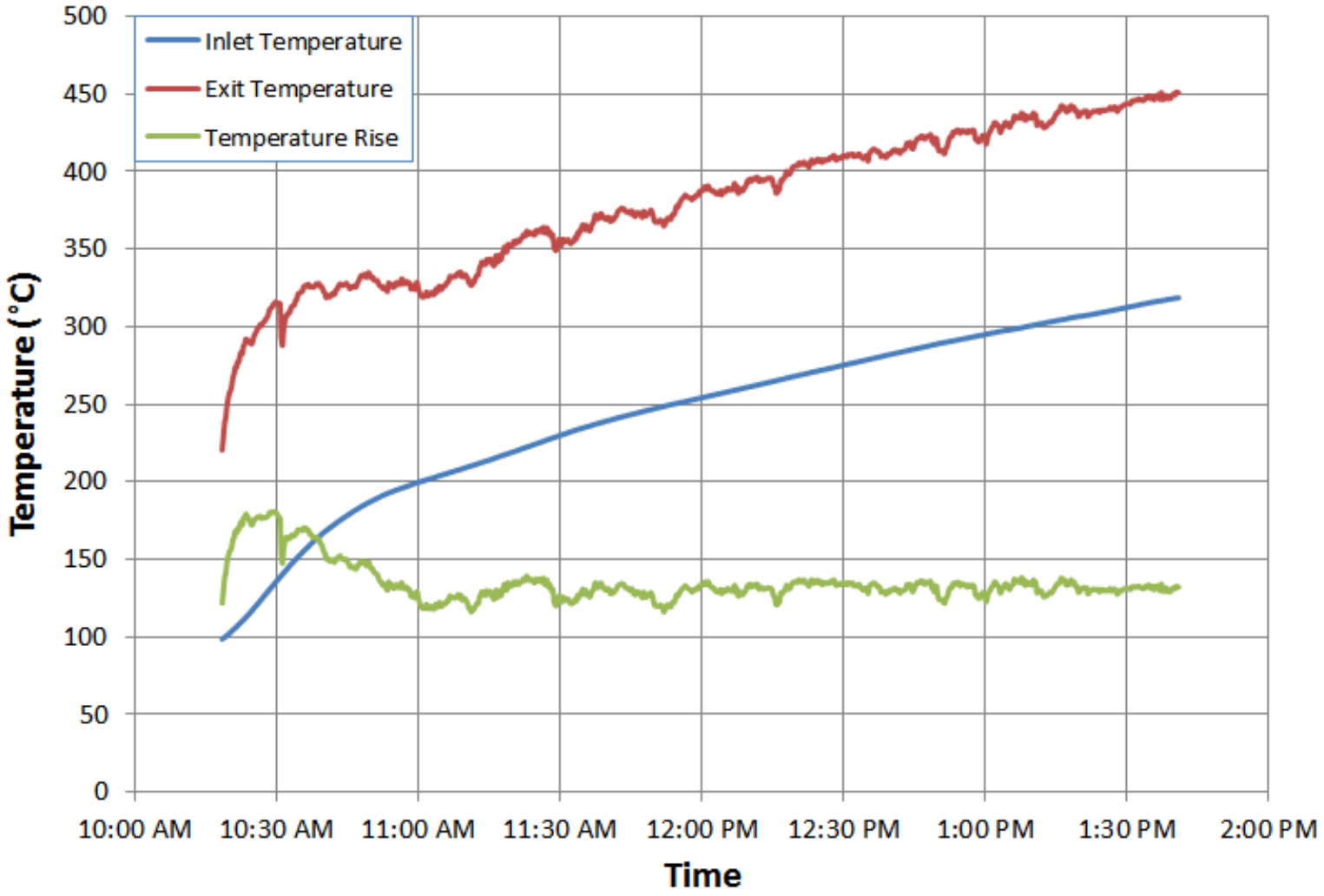

- August 2, 2017
- Flow rate: ≈ 1.2 kg/s

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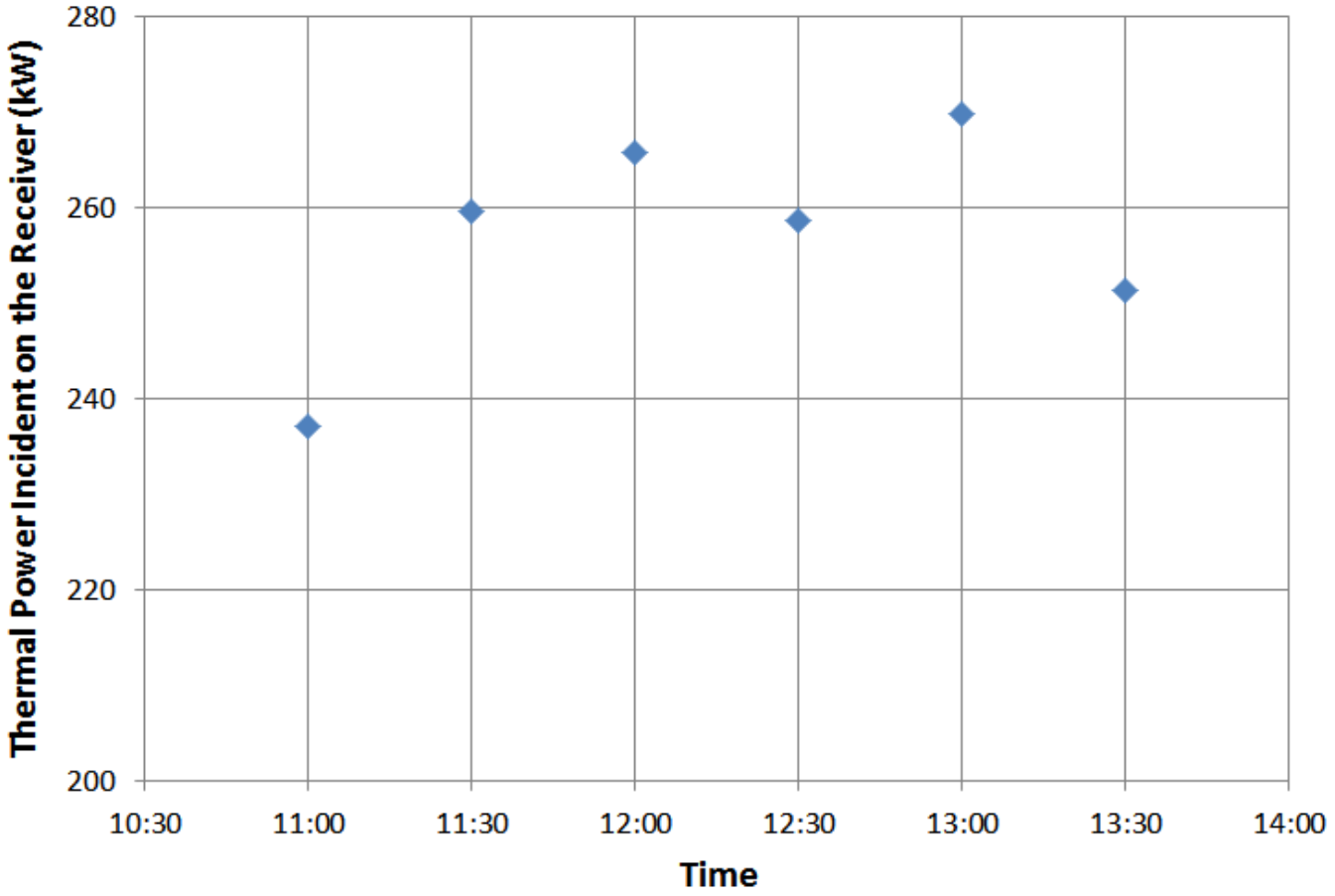
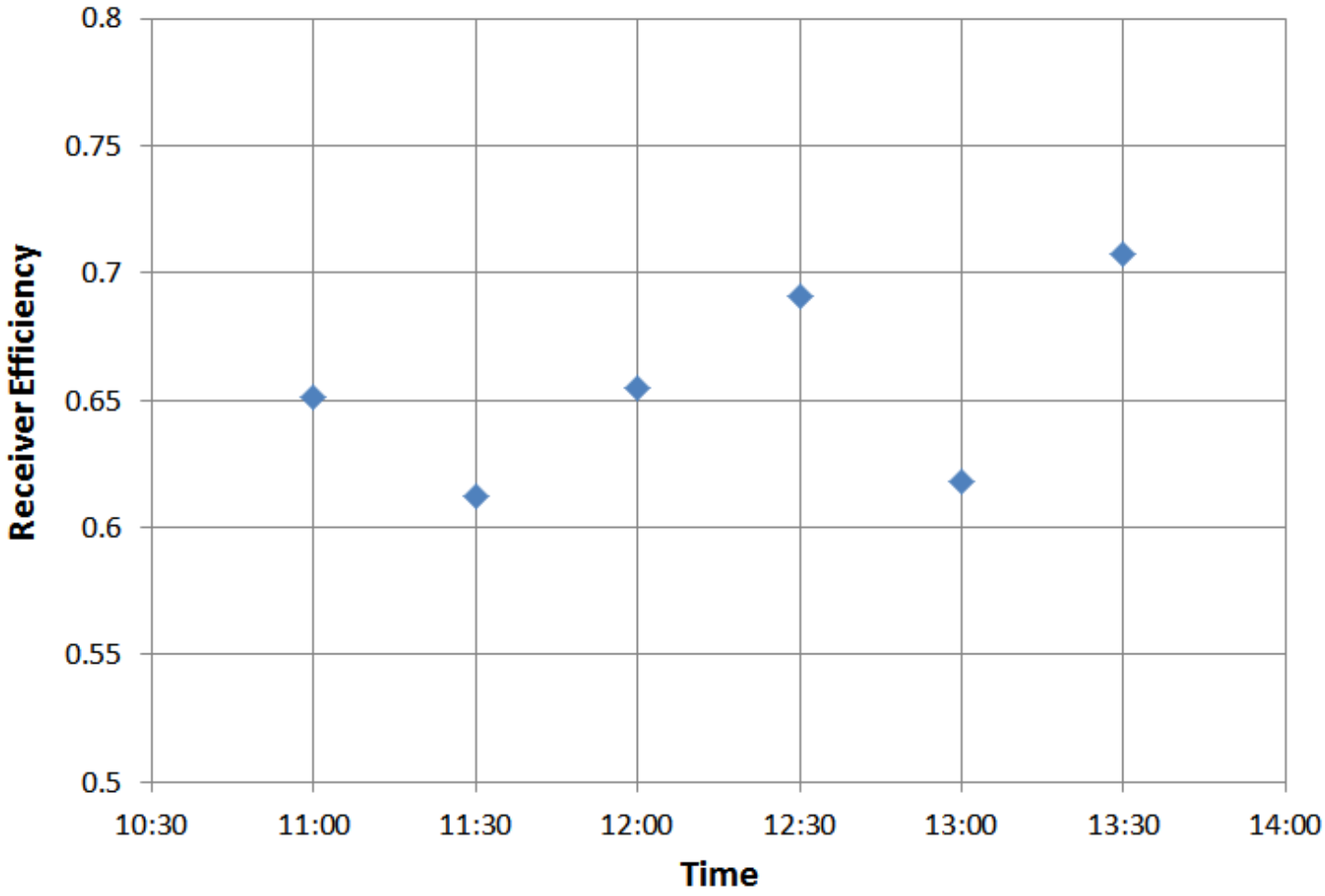


- No flux measurement tools were available to directly measure incident thermal power on the receiver
- SolTRACE was run with actual DNI data and ***some*** realistic field parameters
  - **Constitutes and upper limit on incident thermal power**

Sample Results



- These are lower limits due to some idealized SolTRACE parameters and exclusion of the thermal capacity term of the energy equation

Effective vs. Fixed Bed Absorptance

- With receiver efficiency being in the range of 60% to 70% (considering radiative and convective losses), the effective red sand absorptance is at least 70%
- Lab measurements of a fixed bed of red sand shows an absorptance of about 55%
- The difference is due to particle-to-particle interaction across the depth of the actual curtain flow
  - **Fixed bed optical properties can be negatively misleading**

Conclusions

- Preliminary results show that an obstructed flow PHR with red sand has an efficiency of at least 60%-70% at temperatures up to 450°C
- Effective absorptance of red sand is significantly higher than fixed bed asborptance
- A prolonged test campaign is needed to strengthen these conclusions
- With a cavity receiver, red sand would become an even more attractive option
- LCOE analysis is needed to assess whether the relatively small drop in efficiency by using red sand is mitigated or surpassed by the reduction in initial cost

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جامعة الملك سعود
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Thank You

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