Gas-particle trickle flow direct contact heat exchanger for CSP application

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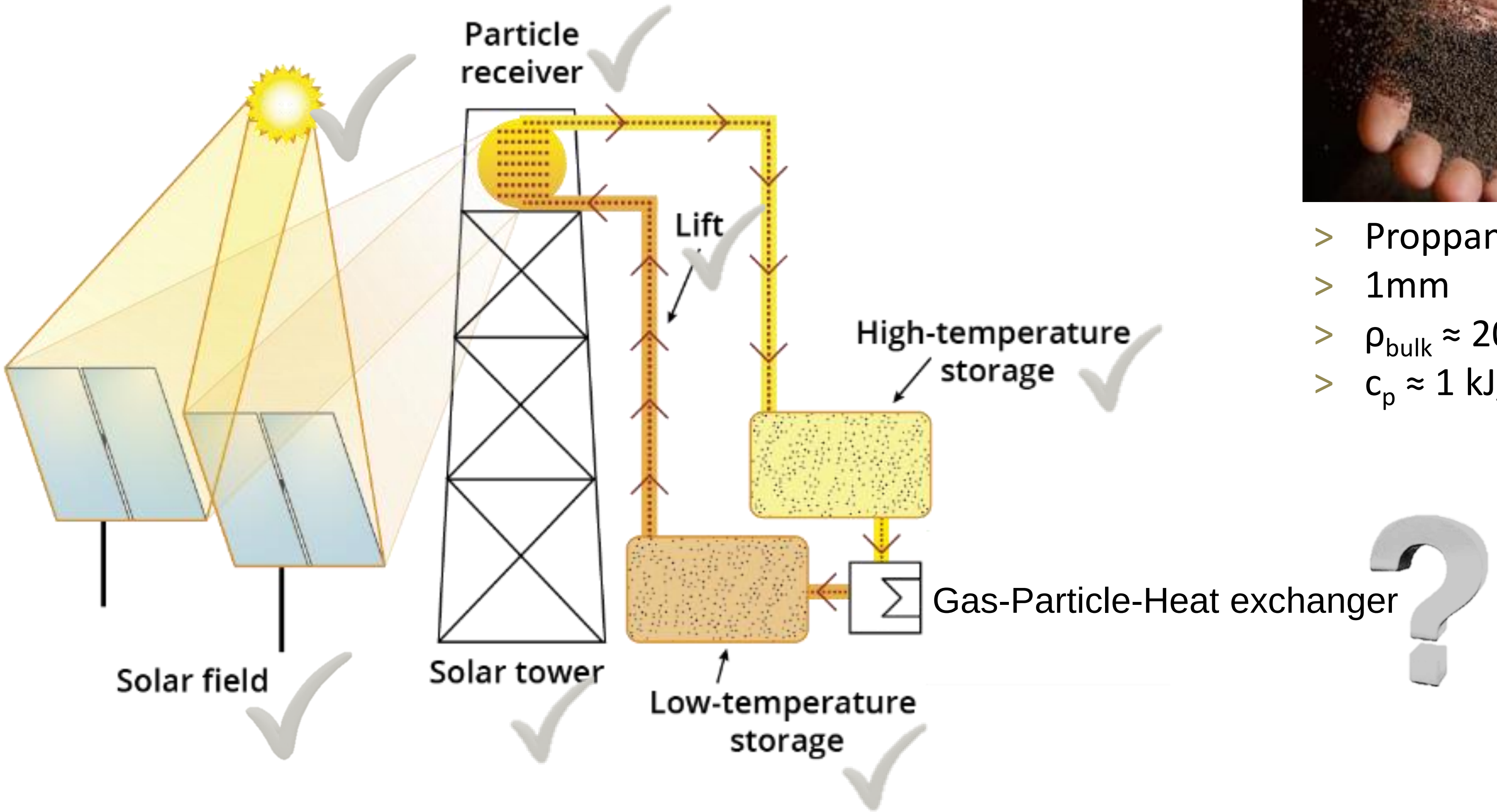
DLR

Introduction

Concentrating solar tower plants with particle



- Proppant Al2O3
- 1mm
- $\rho_{bulk} \approx 2000$ kg/m³
- $c_p \approx 1$ kJ/kg/K

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Boundary conditions

Heat transfer from hot particles to atmospheric air

MAND.	1. gas particle HX	hot particles → CentRec receiver → generate hot air at 800°C for Mn ore thermal pre-treatment		
	2. continuous operation	constant outlet temperatures of media flow		
QUANT.	3. temperatures > 900°C	high temperature heat transfer	adjustable mass flows for fluctuating process conditions	
	4. low temperature spread	direct contact heat transfer	counter current flow	
	5. power density	compact design	insulation	
	6. OPEX	pressure drop	maintenance	staff
	7. life span	erosion	thermo mechanical load	mechanical load
	8. CAPEX	used materials	manufacturing	…

PRÉMA
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focus on technical feasibility

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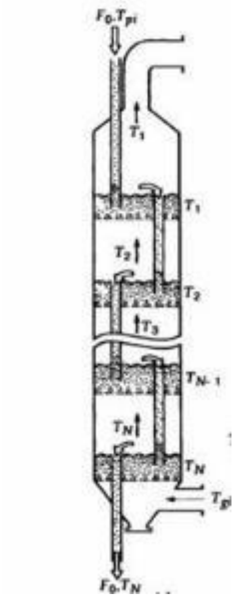
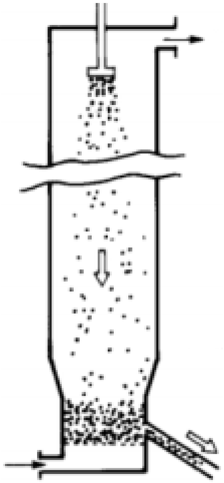
Technical proposal

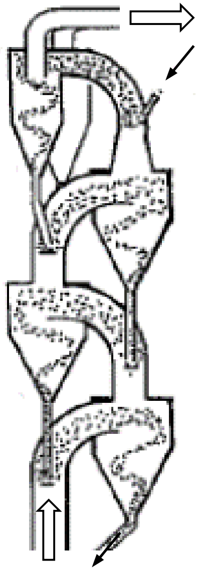
Qualitative preselection – best five



multi staged
fluidized bed

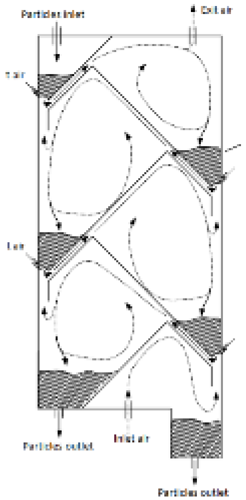
falling cloud

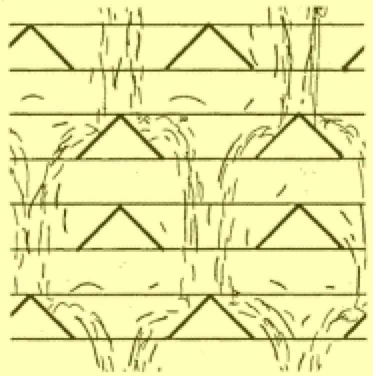




multi staged
cyclones

multi staged
shaft heater





trickling particles with
countercurrent gas flow

comparison of exemplary systems in literature results in best ratio of power density at low volume specific pressure drop

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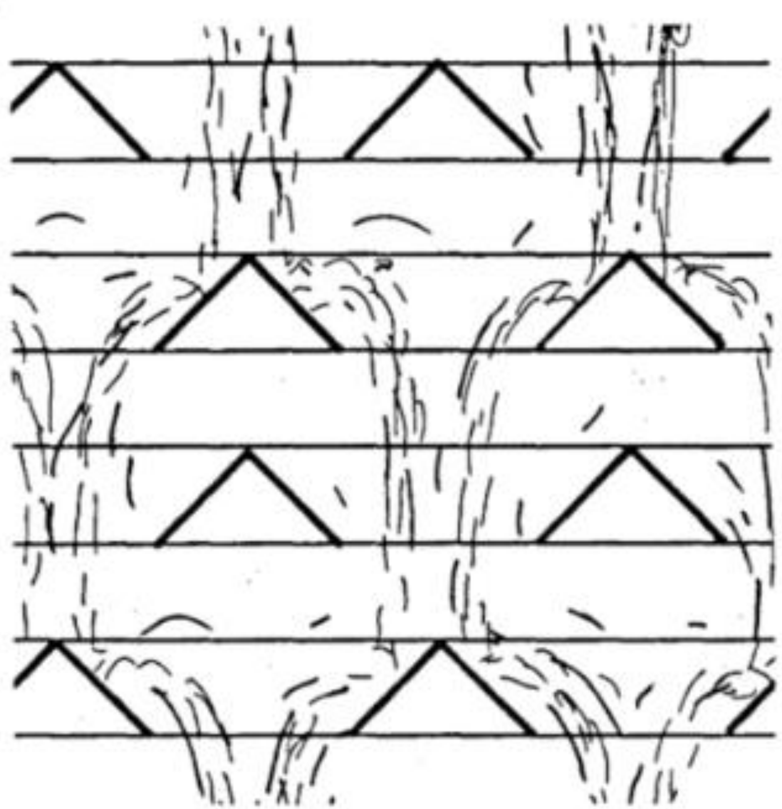
State of the art

"Trickle flow" (TFHX) or "raining particle" heat exchanger (RPHX)



Verver 1986

Nagata 1998; 0,370mm-Partikel

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State of the art

The gas-particle trickle flow reactor | gas-particle trickle flow heat exchanger

number of publications

process engineering	sulfur production
	off-gas cleaning
	methanol- / ammonia synthesis
	CO2 deposition steam reforming
particle hydrodynamic	pressure drop with varying media flow
	hold-up (volume fraction particle / void fraction) function of packing structure and media flow
	particle density distribution, axial and radial
particle – gas heat transfer	qualitative indication of expected high heat transfer capabilities as analog to mass transfer
	view studies for heat transfer available

focus on particle hydrodynamic and heat transfer

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State of the art

Which knowledge is missing today?

hydrodynamic

- simplified correlations available for constant temperatures
  - Drag force → sink velocity (Schiller-Naumann, Kaskas…)
- no reliable prediction of flow regimes
- particle distribution entering the packing
  - overall particle distribution
  - total particle surface

heat transfer

- 1D-analytical model using single sphere correlations
  - Nu correlation → heat transfer (Ranz-Marshall)
- experimental investigation of averaged convective heat transfer only valid for
  - investigated temperatures < 500 °C
  - specific packing-particle combination
- no radiative heat transfer taken into account

Available results not directly transferable to other packing-particle-temperature combinations

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State of the art

Research question and approach

Transfer to research question

How can a gas particle direct contact trickle flow heat exchanger be developed for high temperature application?

1. Geometry & Hydrodynamic
2. Heat transfer
3. Construction
4. Scale-up

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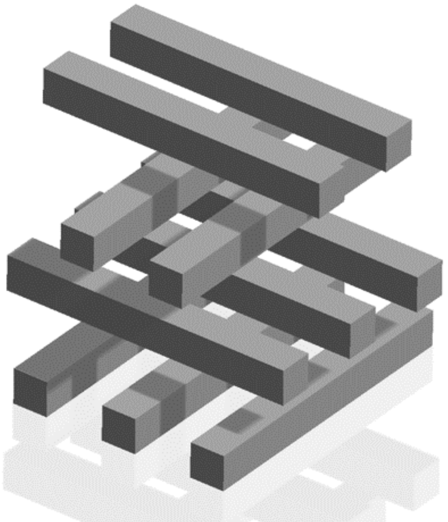
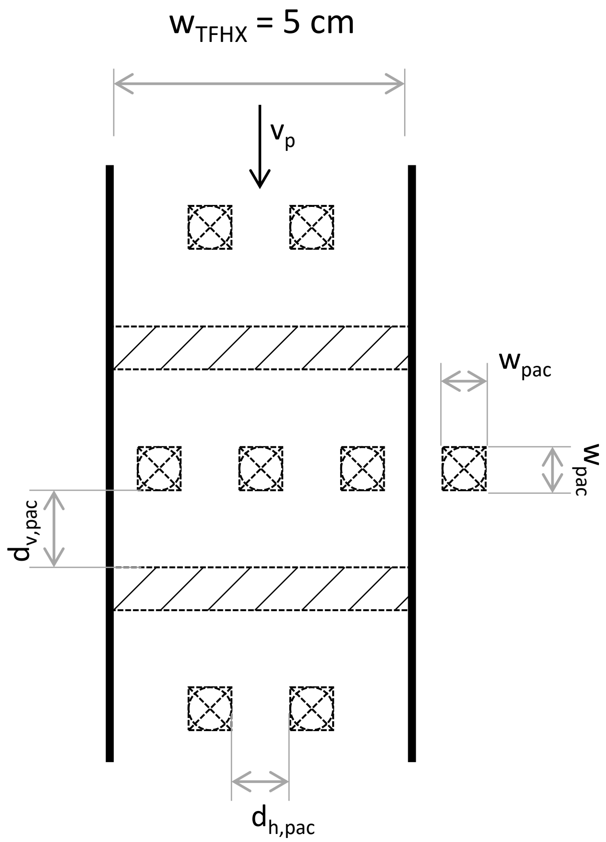
Design packing structure

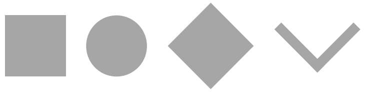
Pre-Study: Identification of packing structures -> ASME SE 2021

Regular Packings





- Literature: regularly arranged bar elements → even particle density distribution within void
- DEM simulations [1]
  - 44 packing structures varying bar: geometry, number, width, distance



  - flat surfaces → best particle retainment
- Bar elements with flat surface for further investigation

[1] M. Reichart, M. Neises-von Puttkamer, R. Buck, and R. Pitz-Paal, “Numerical Assessment of Packing Structures for Gas-Particle Trickle Flow Heat Exchanger for Application in CSP Plants”

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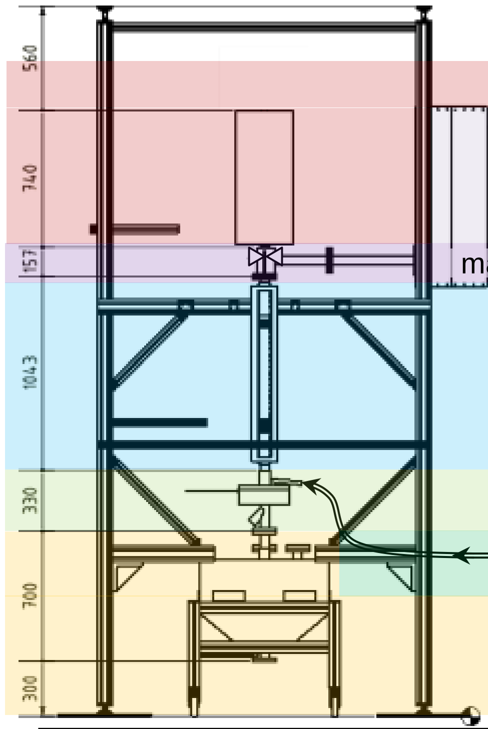
Design packing structure

Experimental setup

Test target

- Focus on flat packing element
- Investigation of particle hydrodynamic in packing with gas flow
- Heat transfer capabilities
- Benchmark for theoretical work



	concept	basic eng.	detail eng. & construction	procurement	assembled
particle heating	●	●	●	●	○
exhaust air cooler	●	●	●	●	●
mass flow manipulation	●	●	●	●	●
heat exchanger	●	●	●	●	●
particle drainage	●	●	●	●	●
air pre-conditioning	●	●	●	●	◕
particle silo	●	●	●	◕	○
Data logging: sensors	●	●	●	◔	○
Data logging: electical installations	●	●	●	○	○
Data logging: programming SPS, LabView	○	○	○	○	○

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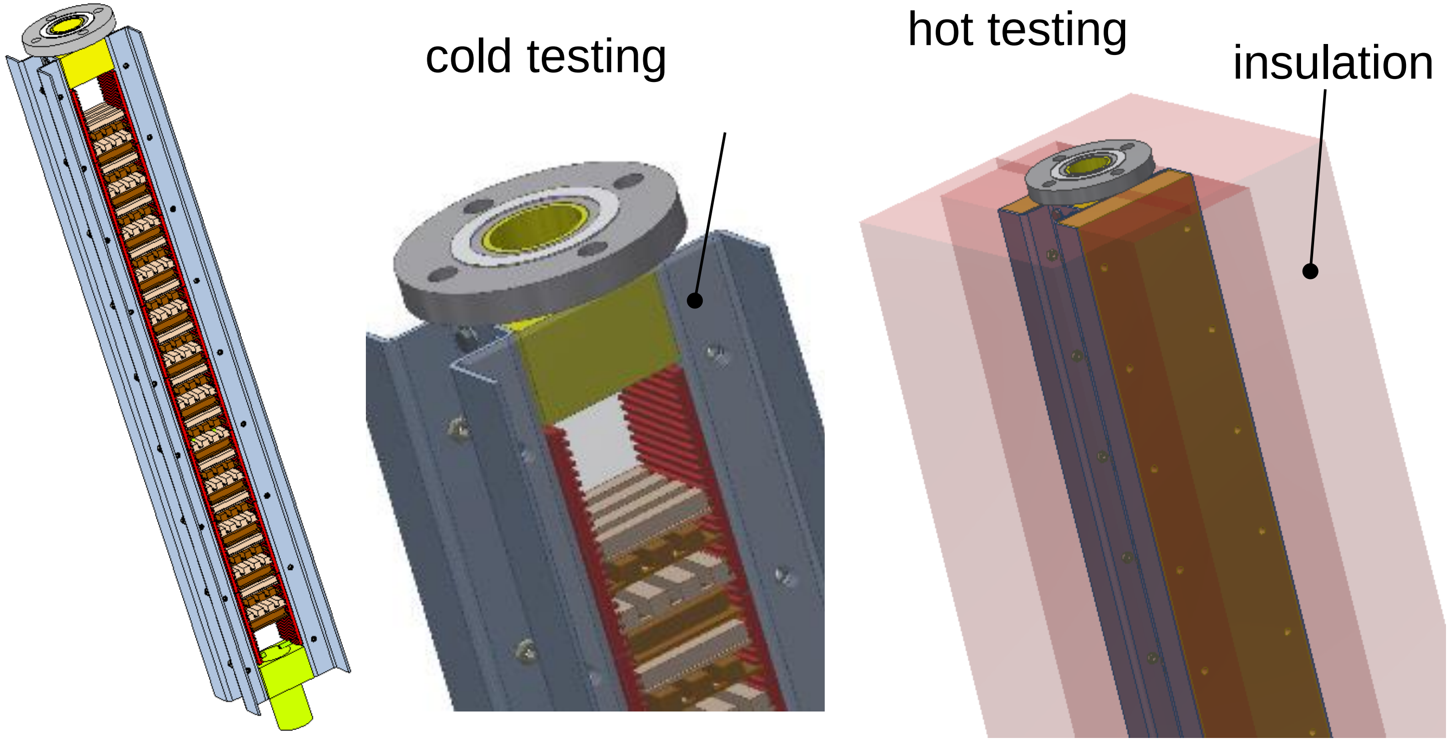
Design packing structure

Experimental setup



requirements

- variable packing elements
- no air leakage
- front and back wall removable
- front and back wall
  - transparent for cold testing
  - closed for hot testing

concept

- focus on screw connections to avoid welding distortions
- quadratic cross section 5 x 5 cm
- packing swappable
  → „backing oven principle“

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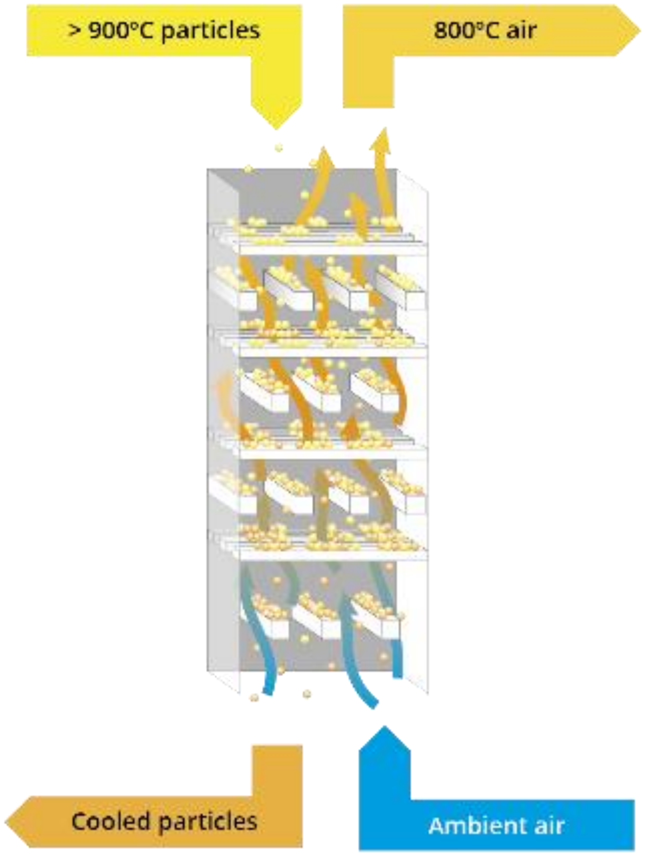
Outlook

next steps



- Cold testing autumn 2021
  - identification of packing structure, providing highest particle hold-up
  - pressure drop
  - varying media flow
- Hot testing summer 2022
  - investigation of heat transfer capabilities
  - varying media flow
- Comparison with theoretical work
  - hold-up
  - heat transfer

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Thank you!

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