CREATING TOMORROW`S SOLUTIONS

HELISOL®
- ein Siliconöl basierter Wärmeträger für CSP Kraftwerke

19. Kölner Sonnenkolloquium, 2016 07 06

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- **General introduction Wacker Chemie AG**
- **HELISOL® 5A**

Requirements, testing methods, properties

Safety aspects

Economic assessment & Proof of Concept

Over 100 Years of Success

Wacker Chemie AG

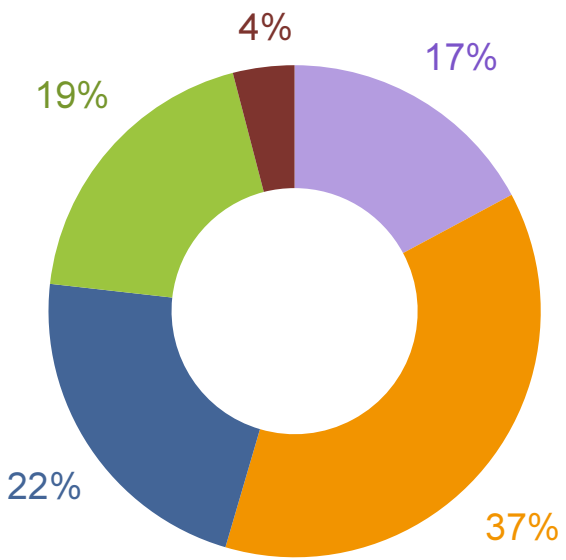
- Founded in 1914 by Dr. Alexander Wacker
- Headquartered in Munich

WACKER Group (2015)

Sales:	€5.30 billion
EBITDA:	€1.05 billion
R&D:	€175 million
Investments:	€834 million
Employees:	16,972

A Well-Balanced Portfolio

Sales
2015



€931 million*	Siltronic
€1,943 million*	WACKER SILICONES
€1,186 million*	WACKER POLYMERS
€1,064 million*	WACKER POLYSILICON
€197 million*	WACKER BIOSOLUTIONS

Group Sales	**€5,296 million**
Total Divisional Sales (incl. internal sales)	**€5,321 million****

WACKER

* Including internal sales

** Balance of other / consolidation € -25 million

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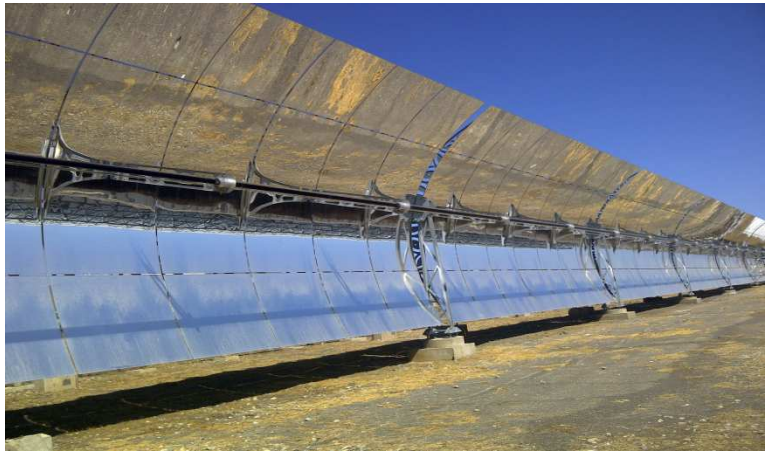
HELISOL® 5A: a new silicone based HTF developed for Concentrated Solar Power (CSP)

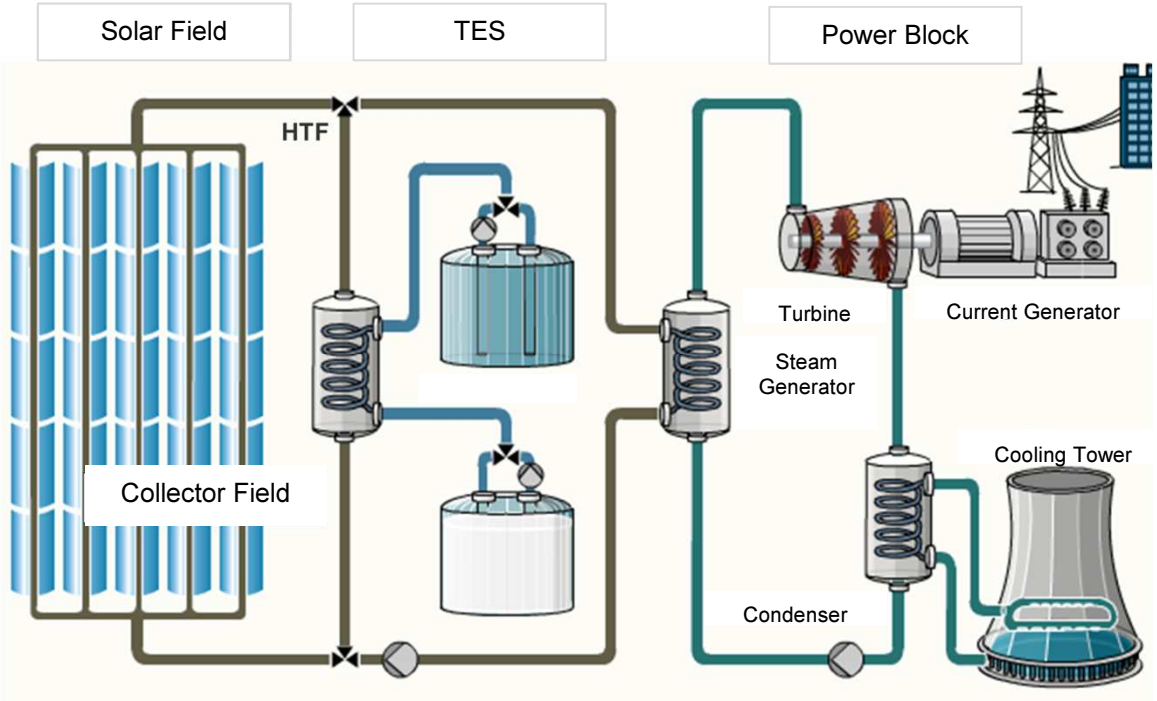


Benchmark HTF: Biphenyl / Diphenyl oxide (BP/DPO)
Maximum process temperature: 400°C

Higher process temperature
→ higher efficiency
→ lower LCOE (Levelized Cost of Electricity)

HTF requirements for CSP:

- High thermal stability
- Low temperature pumpability
- Good heat transfer
- Low volume expansion
- Low vapor pressure
- Low viscosity
- No critical degradation products
- Low toxicity
- Low fire risk
- Low cost



Si-HTF: A public funded project in order to develop and characterize a silicone based HTF

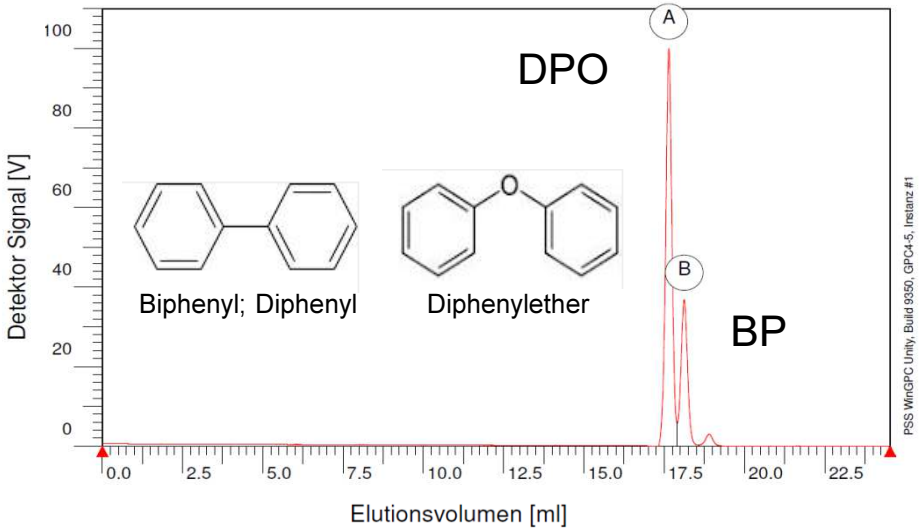
	TUM	WACKER	DLR Deutsches Zentrum für Luft- und Raumfahrt e.V. in der Helmholtz-Gemeinschaft	FLAGSOL
TOPIC	▪ Silicone based salts	▪ HTF development	▪ Evaluation of physical & chemical properties ▪ Performance simulation	▪ Profile of requirements ▪ Assessment of the results
TASKS	▪ Development, synthesis & characterization of Si-Salts	▪ Project management ▪ Si-HTF development & production ▪ Basic evaluation of heat stability ▪ EHS analysis (critical reactions, safety evaluation (TÜV-Nord))	▪ Evaluation of physical data @400°C (vapor pressure, density, viscosity, Cp….) ▪ Thermal stability & durability ▪ Evaluation of critical reactions ▪ Characterization of gas formation (H_2, CH_4) ▪ Process simulation → economic evaluation	▪ Assessment • technical • economic

Supported by:
Federal Ministry for Economic Affairs and Energy
on the basis of a decision by the German Bundestag

Differences between HELISOL® 5A and BP/DPO

BP/DPO eutectic mixture

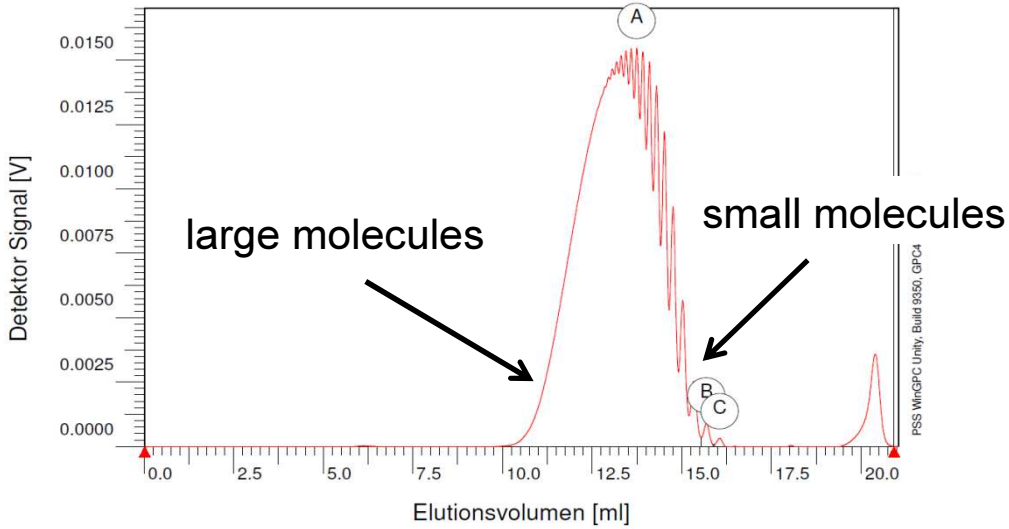
- 25-28% BP, 72-75% DPO
  (Diphyl, Dowtherm A, Therminol VP1)



- Working temp.: 60 to 400 °C
  Freeze Point: 12 ºC → freeze protection

HELISOL® 5A

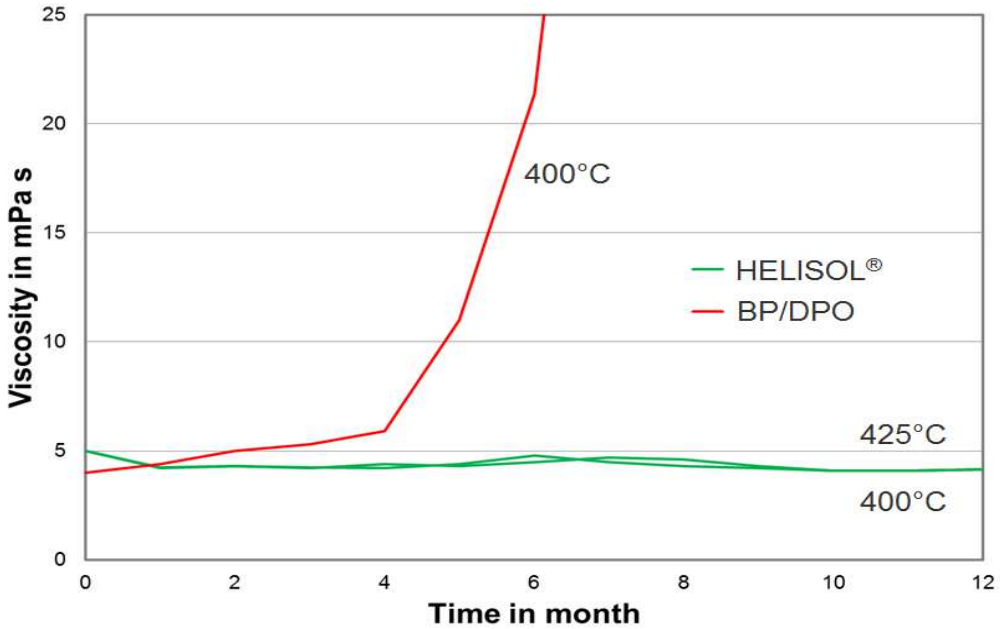
- HELISOL® 5A is a low viscosity polydimethylsiloxane, a multi-component mixture of molecules with various molecular weights

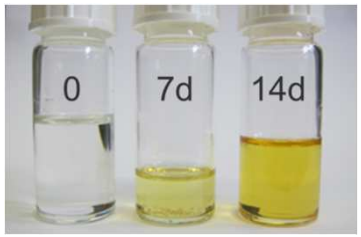


- Working temp.: -40 to 425 °C
  Freeze Point: -65°C

HELISOL® 5A offers an outstanding working temperature

Longterm stability

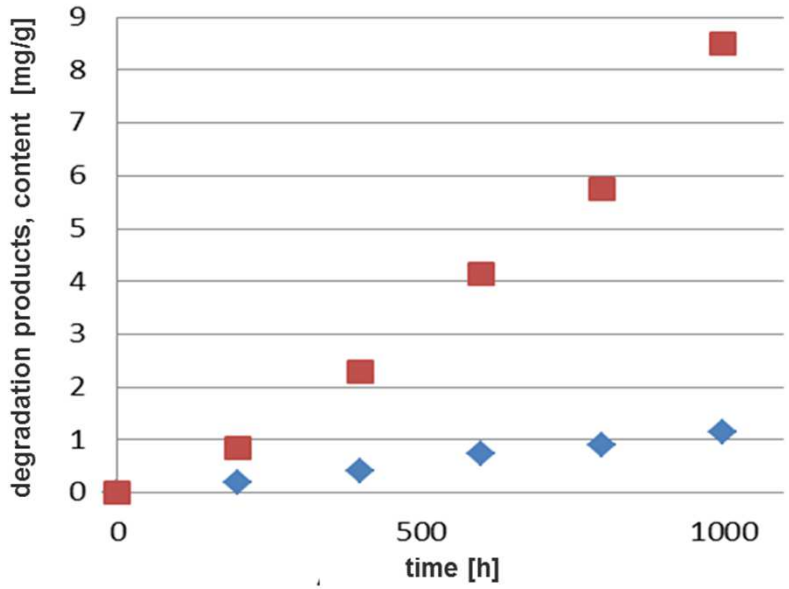




BP/DPO at 400°C

HELISOL® 5A @ 425°C

Degradation after 1000 h

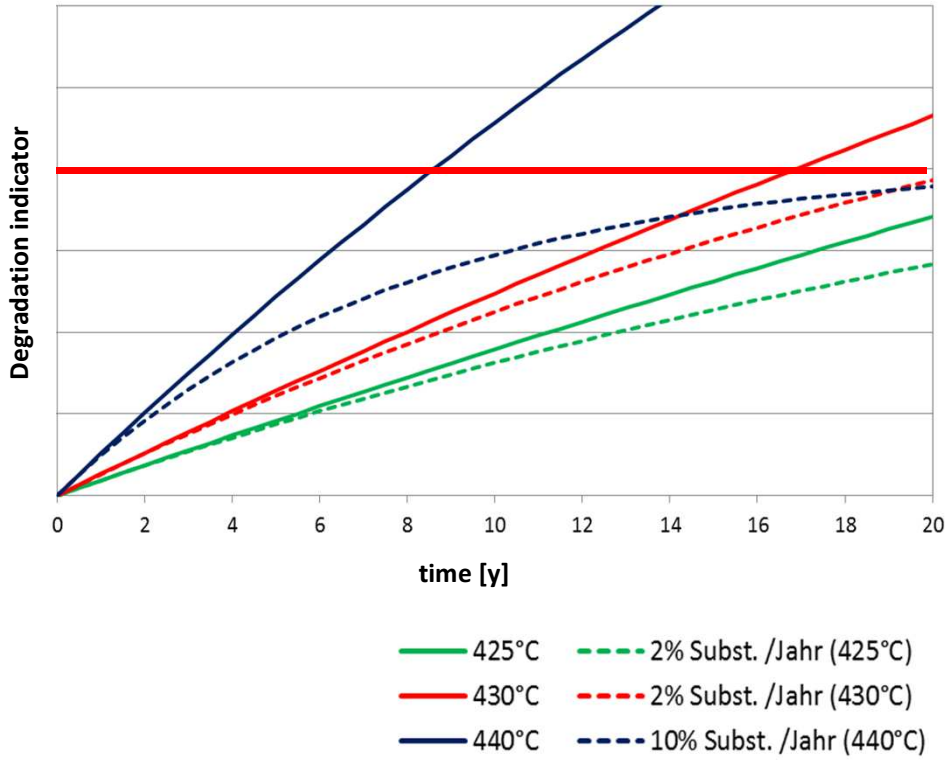


BP/DPO (400°C, 1000 h) ➔ 0.85 wt.%

HELISOL® 5A (425°C, 1000 h) ➔ 0.12 wt.%

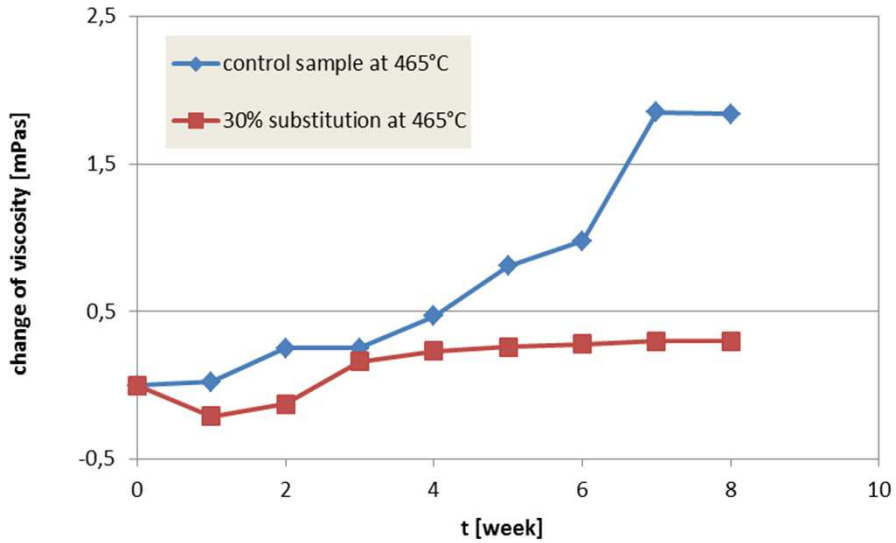
Estimation of the degradation rate of HELISOL® 5A and reworking concept

Degradation rate



- Substitution rate to be evaluated: 1-2% HTF/a @ 430°C
- Exchange rate depends on the maximal tolerable viscosity

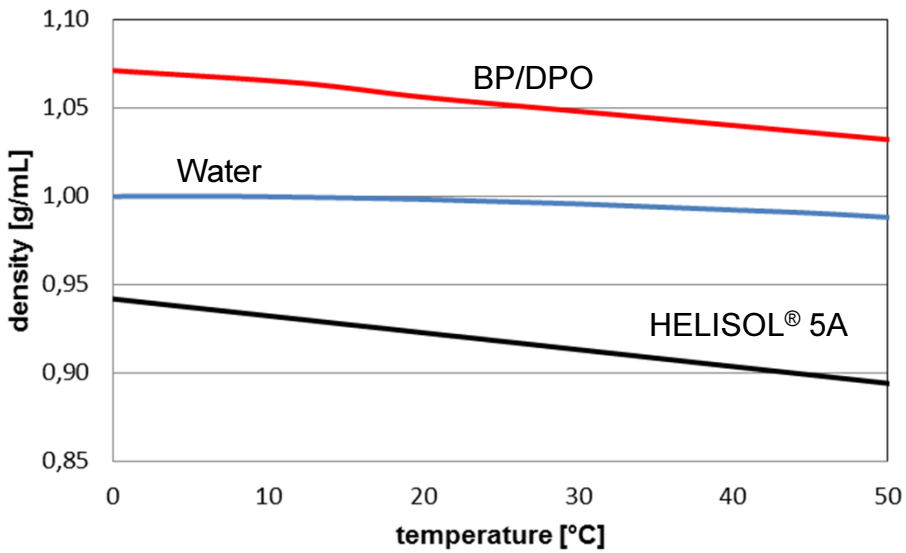
Reworking Concept



- Effect based on equilibration and dilution
- Viscosity is kept constant
- No Ullage system needed for viscosity control
- Patent: DE 10 2014 209 670 A1

Comparison of density and vapor pressure

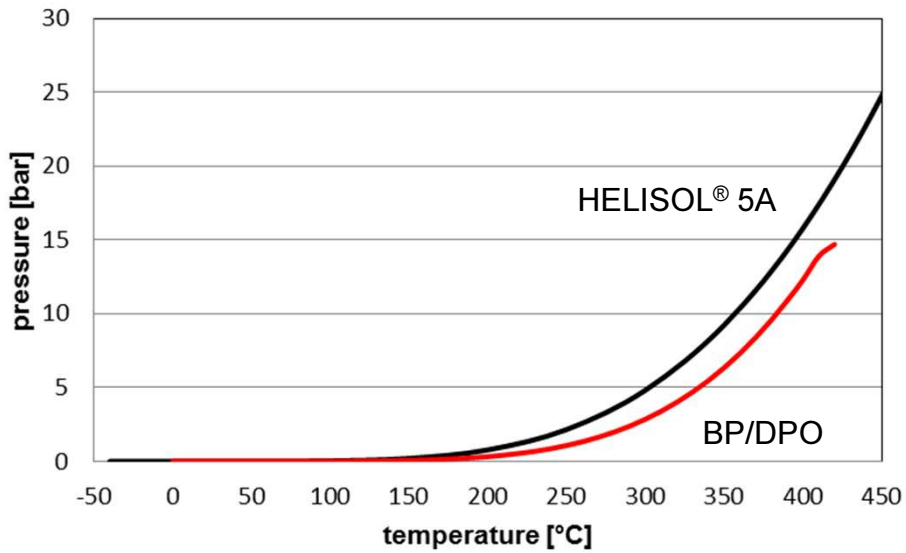
Density @ 25°C



- HELISOL® 5A : 0.92 g/mL @ 25°C
- BP/DPO : 1.06 g/mL @ 25°C
- Water : 1.00 g/mL @ 25°C

- Oil separator can be used for HELISOL® 5A only

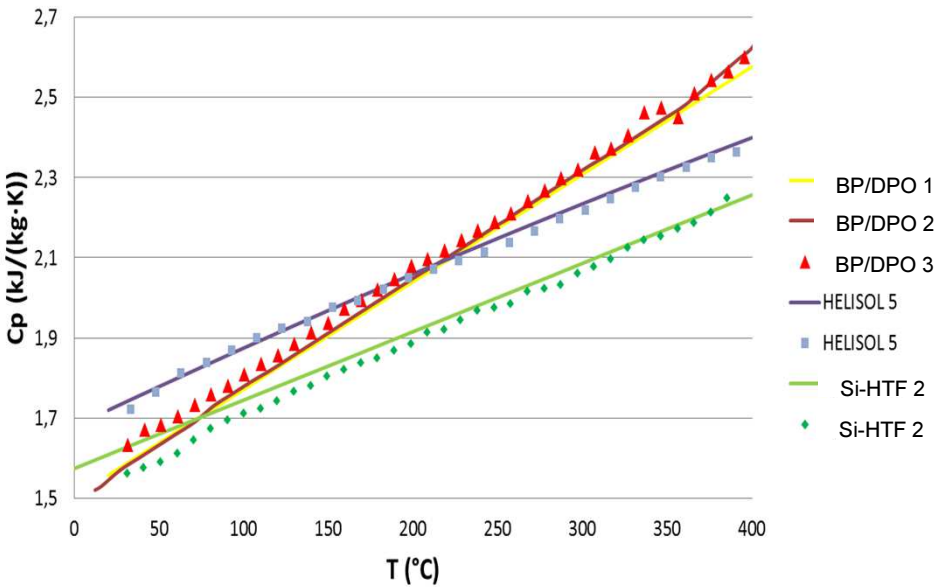
Vapor Pressure



- HELISOL® 5A shows a higher pressure level which has to be considered

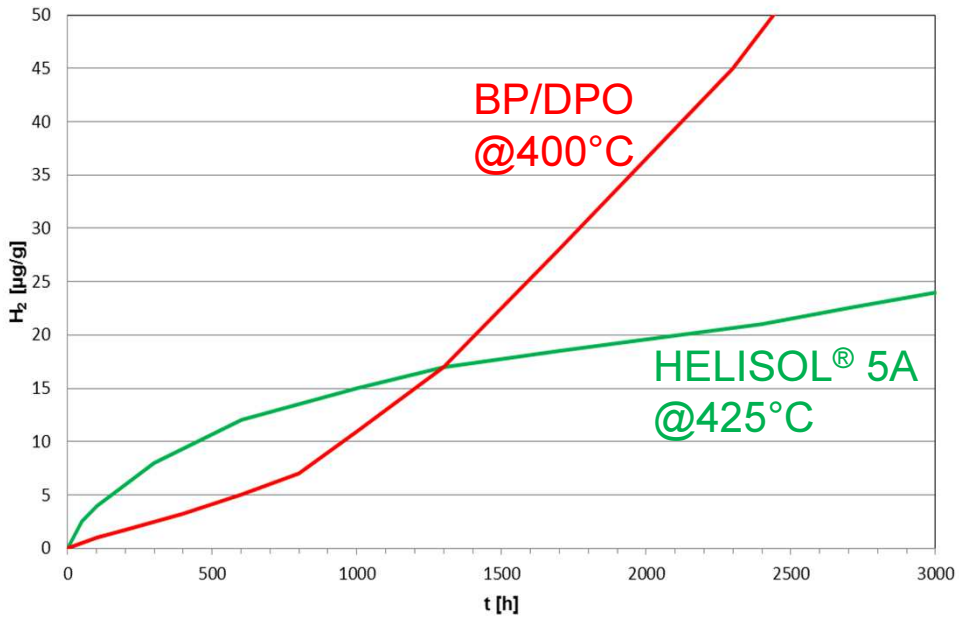
Comparison of heat capacity and hydrogen formation

Heat capacity



- The heat capacity of HELISOL® 5A is around 10% lower compared to BP/DPO
- Advantages in the heat transfer at lower temperatures

Hydrogen formation



- Equal amounts of H_2 at 1300 h
- Lower hydrogen formation expected with HELISOL® 5A for long term

Corrosion test DIN EN ISO 2160 showed no significant impact HELISOL® 5A does not show any fouling effects

Corrosion test DIN EN ISO 2160

- Corrosion of the copper stripe (3 h/100 °C): grade 1a
- Corrosion of the copper stripe (6 h/100 °C): grade 1a
- Corrosion of the copper stripe (24 h/100 °C): grade 1b

- Test specimen showed almost no change of the surface after testing

fouling / carbonization on a heating cartridge after using an organic HTF

- No fouling / carbonization effects have been seen with HELISOL® 5A

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Safety assessment – fire tests at DMT and TÜV-Nord

Flammability in contact with hot surfaces
ISO 20823

HELISOL® 5A:
self ignition at 475°C
(T_z ~ 367°C…. DIN EN 14522)

CSP-Loop << 475°C

Fire test in a heating furnace

HELISOL® 5A:
no self ignition @ 250-430°C

rock wool + HELISOL® 5A:
no self ignition

rock wool + BP/DPO:
no self ignition

Wickflame persistence
ISO 14935

HELISOL® 5A:
combustion products (SiO_2) form protective barrier
➔ fire stops burning automatically

BP/DPO:
a lot more reactive
➔ fire does not stop burning automatically

Safety assessment – fire tests at DMT and TÜV-Nord

Spray ignition test
ISO 15029

distance: 4m
afterflame time: 3-4 sec.

ignition in the area of the nozzle

fire area **HELISOL® 5A:** ~1m

fire area **BP/DPO:** ~2-3m,
→ more reactive

Simulating of leakages in pipes at 430°C

HELISOL® 5A:
no self ignition - neither direct in air nor in insulation

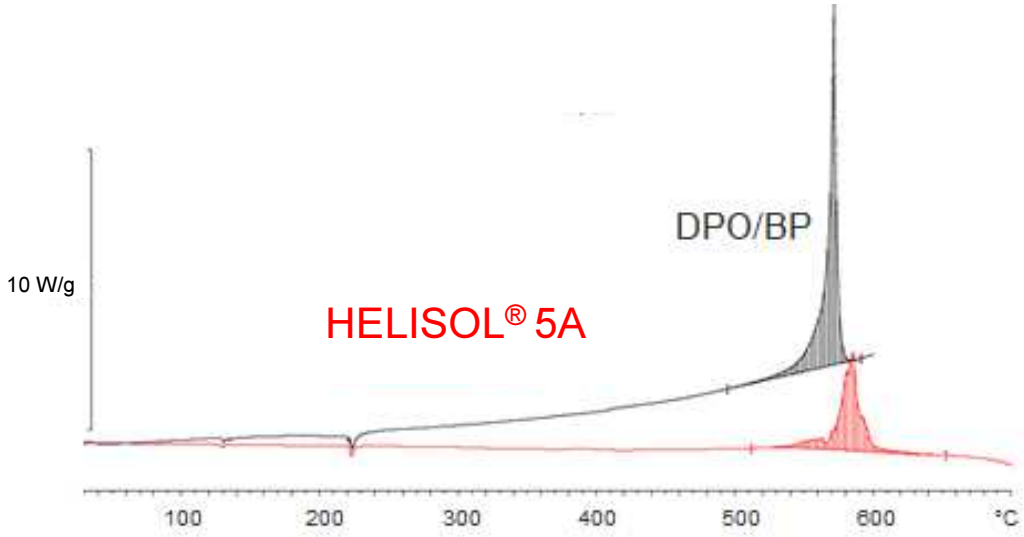
Simulating of leakages at 430°C with ignition source

HELISOL® 5A:
pyrotechnics have been burned in a distance of 5m, 2m, 1m from the exposure point

→ no self ignition

HELISOL® 5A – reaction with solar salt

Measurement: DSC (N_2) of mixtures of HTF and solar salt (60/40 wt.-% Na/K-nitrate)

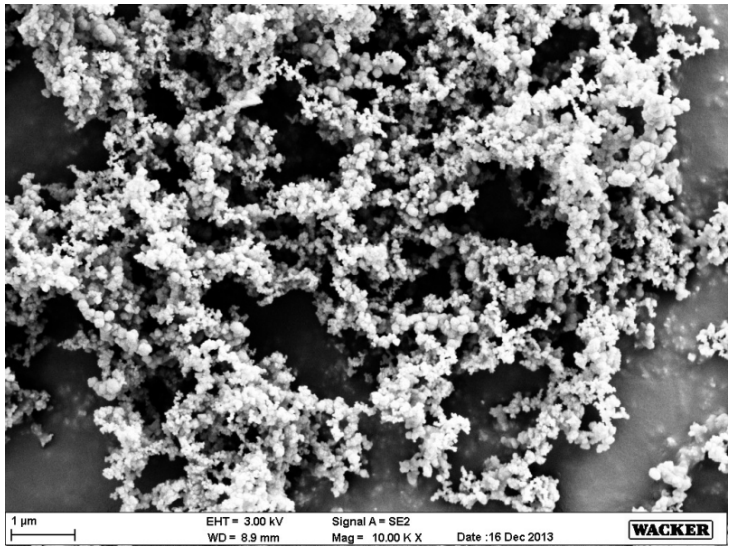


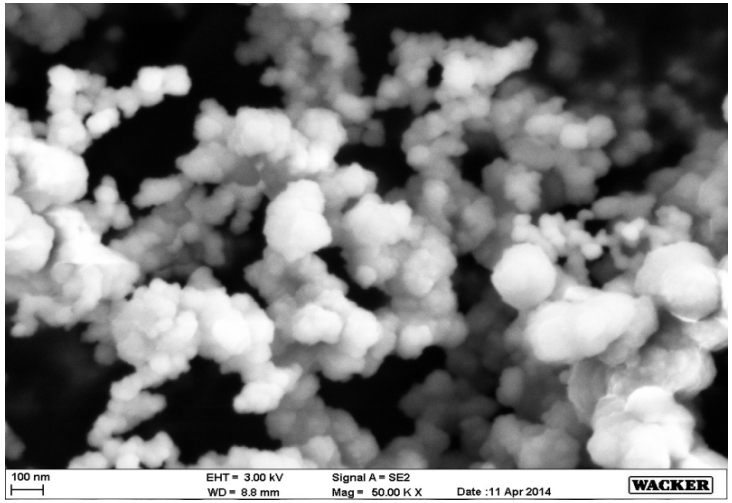
Summary:

- Onset temperature of the HELISOL® 5A is more than 100°C above the operation temperature (100 K rule)
- Heat of combustion (≙ total oxidation ≙ max. exothermicity) of Si-HTF is approx. 20% lower than that of BP/DPO

- **HELISOL® 5A is less critical than BP/DPO in combination with solar salt**

HELISOL® 5A – combustion products are not classified as hazardous





Summary:

- Primary particles (10–30 nm) form aggregates (>100 nm), which combine to form agglomerates (some µm in diameter).
- X-Ray (XRD) does not show crystalline structures
- The combustion products have a high similarity to synthetic amorphous silica (SAS)
- SAS are not classified as hazardous

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HELISOL® 5A enables lower LCOE

- Reduced costs TES
- No Ullage system needed for viscosity control
- No freeze protection
- Higher vapor pressure

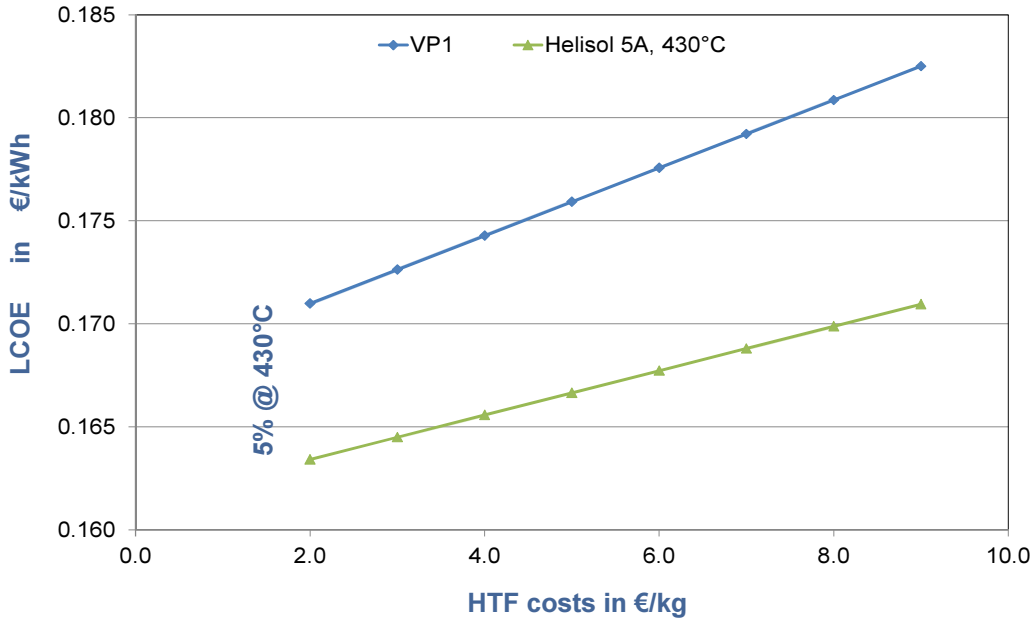
- No recirculation for freeze protection
- Easier maintenance
- Less pump energy (low viscosity)
- Shorter start up period
- Lower degradation/exchange rate @ same temp.
- Lower H2 generation
- No fouling

$$\text{LCOE} = \frac{\text{CRF}^* \sum \text{CAPEX} + \sum \text{OPEX\_annual}}{\text{Electricity\_annual}}$$

Working temp.: - 40°C to 430°C,
EHTF: 60°C to < 400°C

CRF : Capital recovery factor (Annuitätenfaktor)

HELISOL® 5A enables a reduction of the LCOE of ~ 5%



Restrictions:

- Calculation is based on LCOE calculation in Guadix (E).
- Solarfield- and storage size are based on minimal LCOE.
- Specific solarfield costs are higher…
- Specific costs of the TES are lower…

Conclusion:

- HELISOL® 5A offers advantages over commonly used HTF`s
- in terms of applicability for HELISOL® 5A in CSP plants no hindering issues were found

Si-HTF Abschlussbericht

SITEF: A public funded project (SOLAR-ERA.NET) at the PSA (2016-2017)

Proof of Concept / Qualification of HELISOL® 5A at 425°C and beyond

by courtesy of CIEMAT

EPC, CSP-Developer	Component Suppliers	Ownership, operation	Certifier
Engineering /Upgrade: ▪ TSK-Flagsol FS, ▪ CIEMAT CI, ▪ TÜV-Nord TN, ▪ DLR	▪ REPAS: Senior Flexonics SF ▪ Receiver: Rioglass ▪ HTF: Wacker WA	▪ CIEMAT CI	▪ Lab analysis: DLR ▪ techno-economic evaluation: DLR, FS ▪ Risk evaluation: TN, DLR, FS, WA ▪ external evaluation: RWE

▶ **Early Operation @ 400°C: no limiting issues identified so far**

SITEF project is funded by the governments of Spain and Germany

Protarget AG is used to work with HELISOL® 5A already

Micro CSP Plant in Bad Aibling

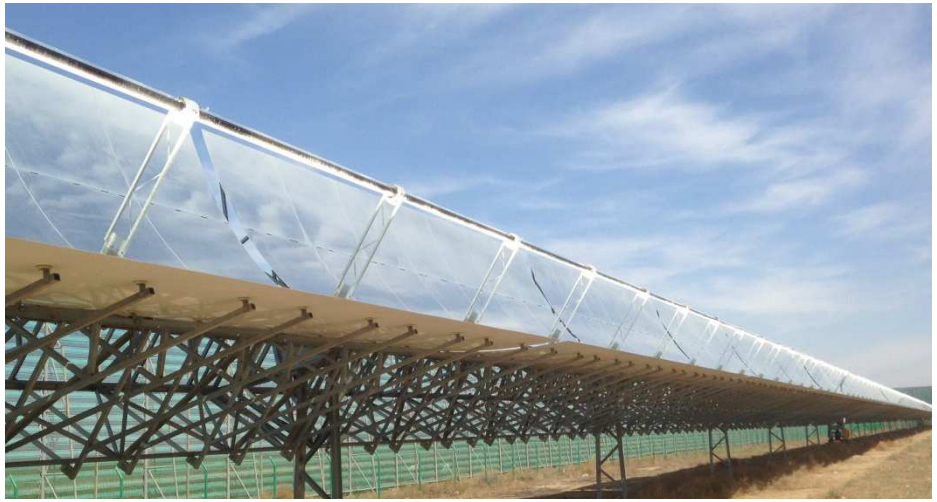
- Operating since end of 2012
- 570 m² parabolic trough
  250 kW nominal, 320 kw peak
  operating temperature: 300°C

„EDITOR“ Project in Cyprus

- Funded by: EU/BMWi
- Operating temperature: 430°C
- Time frame:
  01.2016 → plant commissioning 01.2017
- Goal: supply of process steam to an orange juice company, proof of dispatchability

by courtesy of Protarget AG

Royal Tech (CN) is currently testing HELISOL® 5A beyond 400°C



key findings / issues:

- 600m loop with 4 SCAs located in Inner Mongolia
- Typical configuration similar to Spain's PTC power plants
- Operating temperature up to 430°C
- Similar operating behavior to organic oil
- Low viscosity under high temperature need to be considered to avoid leakage

by courtesy of Royal Tech

With HELISOL® 5A it is possible to realize a parabolic trough plant with a working temperature above 400°C

The authors would like to thank the German Federal Ministry of Economic Affairs and Energy for the funding of the projects Si-HTF and SITEF and their cooperation partners

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