Available online at www.sciencedirect.com

SciVerse ScienceDirect

Energy Procedia 00 (2013) 000–000

Energy Procedia

www.elsevier.com/locate/procedia

SolarPACES 2013

Molten Salt for Parabolic Trough Applications: System Simulation and Scale Effects

Thomas Ruegamer[1], Hanno Kamp[1], Thomas Kuckelkorn[1], Wolfgang Schiel[2], Gerhard Weinrebe[2], Paul Nava[3], Klaus-Jürgen Riffelmann[3]

[1] SCHOTT Solar CSP GmbH, Address: Erich-Schott-Str. 14, 95666 Mitterteich, Germany

thomas.ruegamer@schottsolar.com, phone: +49(0)9633 80-224

[2] sbp sonne GmbH, Address: Schwabstrasse 43, 70197 Stuttgart, Germany

[3] Flabeg GmbH, Address: Im Zollhafen 18, 50678 Köln, Germany

Abstract

The trend of solar thermal power plant engineering towards lower investment and energy costs leads to a demand for higher operating temperatures in the plant cycle. The use of molten salts withstanding temperatures up to 550 °C is considered for use in CSP plants, in particular for parabolic trough systems. In thermal storage systems fluids as “Solar Salt” ($NaNO_3$/KNO_3) are already state of the art.

As the thermodynamic boundary conditions are completely different from those of plants utilizing thermal oil, the resulting changes in storage, collector and receiver design have a considerable impact on energy output and on the business case. Simulations carried out in cooperation of SCHOTT, schlaich bergermann und partner -sbp sonne gmbh and Flabeg show the effect of different plant layouts and operating conditions in terms of annual power generation, investment costs and LCoE. A comparison to power tower plants is made.

Selection and peer review by the scientific conference committee of SolarPACES 2013 under responsibility of PSE AG.

SCHOTT; PTR 70; Flabeg, Ultimate Trough, schlaich bergermann, Parabolic trough, receiver; high operation temperature; molten salt

1876-6102© 2013 The Authors. Published by Elsevier Ltd.
Selection and peer review by the scientific conference committee of SolarPACES 2013 under responsibility of PSE AG.

1. Introduction

In solar thermal business a growing pressure is exerted onto the existing technology facing and demanding for technological innovations, cost reduction as well as higher competitiveness with other renewable or conventional power generator technologies. In this context many reports and studies were published in the recent years dealing with the discussion of technical and economic challenges to confront these tasks. *Erroi et al.* have shown the potential reduction of LCoE down to 13 €ct/kWh caused by the use of molten salt in parabolic trough, tower and Fresnel power plants [1]. The motivation of the present work is to continue this discussion by taking on recent technical developments in core components for molten salt technologies designed for parabolic trough solar power plants and to show the related potentials and effects to reduce LCoE.

In various simulation steps different scenarios of a solar power plant design were discussed taking into consideration parameters like solar field size, site conditions, type of heat transfer fluid, dimensioning of parabolic trough collector, absorber tube coating and diameters as well as storage tank sizes to show the effects on LCoE. The goal of the simulation work is to show the effect of a major technology step by introducing improved solar field components resulting in higher operation temperatures at adapted thermal losses.

Nomenclature

LCoE	Levelized Cost of Electricty	ET	Euro Trough Collector
DNI	Direct Normal Irradiation	UT	Ultimate Trough Collector
MENA	Middle East and North Africa	TES	Thermal Energy Storage
HCE	Heat Collecting Element (absorber tube for parabolic trough collectors: e.g. SCHOTT PTR70)	VP-1	Synthetic Heat Transfer Fluid / Oil (T_{max} 400 °C)
		SSe	Solar Salt (T_{max} 550 °C)
SCE	Solar Collector Element	SCA	Solar Collector Assembly

2. Calculation & Simulation Work

Throughout the simulations, different parameters influencing the plant engineering were varied to evaluate their impact on LCoE. The focus of the simulations was on parabolic trough plants which were compared to a power tower reference case. The most important variation was the heat transfer fluid as it governs the temperature range in which the plant could be operated. A standard synthetic oil case was compared to different salt mixtures, namely *Solar Salt* (T_{op}: 300 °C – 550 °C) and *Hitec* (T_{op}: 250 °C – 500 °C).

A hypothetical salt *HypoHitec* (T_{op}: 250 °C –550 °C) has been introduced, with the following properties: Melting temperature T_m = 150 °C, maximum operation temperature T_{op} = 550 °C, to be able to consider the effect of melting temperature and operation temperature separately. Another crucial power plant parameter is Thermal Energy Storage (TES) size. For any heat transfer fluid the optimum TES size is calculated and assumed for calculation of investment costs and LCoE (Tab. 1). Calculation and simulation of solar power plant characteristics were performed using System Advisor Model (SAM) of NREL.

The choice of technology and plant design may depend on the DNI and climatic conditions. Therefore we compare the well-known US location Daggett as a reference case to a MENA location to account for the conditions in future CSP markets. Particularly in the operating conditions driven by molten salt, the use of bigger collectors as the Ultimate Trough may be advantageous. In these evaluations, we compare different collectors in combination with various receiver geometries and absorber coating parameters. LCoE were determined using the simplified IEA method (8 % discount rate, 1 % annual insurance cost, 25 years project lifetime).

Table 1: Simulation matrix used for comparison of different power plant design types.

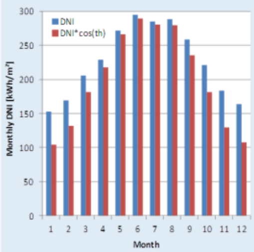
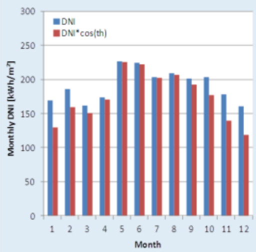
System Setup	Parabolic Trough 50 MW	Parabolic Trough 50 MW	Parabolic Trough 100 MW	Parabolic Trough 100 MW	Parabolic Trough 200 MW	Solar Tower 100 MW
HTF	Oil	Oil	Oil	Solar Salt Hitec HypoHitec	Solar Salt Hitec HypoHitec	Solar Salt Hitec HypoHitec
Operation Temperature [°C]	290 – 390	290 – 390	290 – 390	300 – 550 250 – 500 250 – 550	300 – 550 250 – 500 250 – 550	300 - 550
Power Block Efficiency [%]	38.5	38.5	38.5	43.3 (550°C) 41.7 (500°C)	43.3 (550°C) 41.7 (500°C)	43.3 (550°C)
Collector Type	ET	UT	ET/UT	UT	UT	
Receiver	PTR70 60/70/80mm	PTR90E	PTR70	PTR70 PTR70 LT/HT PTR90 LT/HT 60/70/80/90mm	PTR70 PTR70 LT/HT PTR90 LT/HT 60/70/80/90mm	
Field Design	H	H	H, I	I	H	
Storage	0h/ 7.5h	0h/ 7.5h	14h	14h	14h	14h
Output Parameters	Generation MWh/y Invest €/m² LCoE	Generation MWh/y Invest €/m² LCoE	Generation MWh/y Invest €/m² LCoE	Generation MWh/y Invest €/m² LCoE	Generation MWh/y Invest €/m² LCoE	Generation MWh/y Invest €/m² LCoE

3. Simulation & Discussion

3.1. *Solar Radiation Input Data*

Comparative simulation runs were performed for two reference locations to assess the impact of site conditions: Daggett (U.S.) with high annual DNI sum, located at ~35°N, and Abu Dhabi (MENA region) with comparatively lower annual DNI but closer to the equator (~24.4°N). Table 2 shows a summary of the respective site conditions: while annual DNI for the selected site in Abu Dhabi is 2300 kWh/m² as compared to 2723 for Daggett, i.e. only about 16 % less, the distribution over the year is more uniform. The latter is especially pronounced when looking at the product of DNI and the cosine of solar incidence angle. This fact mainly originates from the location being closer to the equator. One objective is here to show the effects of using molten salt not only for high-DNI locations in the US but also for a site representative for the emerging CSP market in the MENA region.

Table 2: DNI analysis for the considered sites Daggett, CA, and Abu Dhabi, UAE.

	Daggett	Abu Dhabi
Annual DNI [kWh/m²]	2723	2300
Latitude [deg]	34.9	24.4
Monthly DNI sums [kWh/m²]		

3.2. Main Input Parameters

Table 3 shows input parameters for three of the cases. Note that the parabolic trough collector optical performance depends on the diameter of the HCE, which was varied during optimization. The given value is only valid for the shown diameter. Specific costs scale differently for different components. To pick one example, the reduced power block/HTF system cost for the molten salt case results from both the simplified HTF system for a direct-storage plant and the increased power-block size compared to the other cases.

The solar field costs per m² when changing from UT to ET were reduced mostly due to a significant reduction of components (swivel joints, drives, etc.). When the UT is used with molten salt, solar field costs are slightly increased due to additional equipment for salt melting after freeze events and due to the higher cost of stainless steel piping. The vastly decreased storage cost for the molten salt case is due to the much higher temperature difference between the two tanks, which vastly increases the capacity of a given tank volume.

Table 3: Main characteristics for comparison of EuroTrough and Ultimate Trough [2,3].

	Case ID		ET 50MWe VP-1 at 393°C Daggett	UT 50MWe VP-1 at 393°C Daggett	UT 100MWe SSe at 550°C Daggett
Project data	Location and meteo data designation	-	Daggett_1	Daggett_1	Daggett_1
	Cost model reference date	-	Apr-2013	Apr-2013	Apr-2013
	Longitude	deg	-116,8	-116,8	-116,8
	Latitude	deg	34,9	34,9	34,9
	Annual DNI	kWh/m²a	2.723	2.723	2.723
	Expected plant availability	%	96,0	96,0	96,0
Solar Field	Number of collectors per loop	-	4	4	4
	Collector	-	ET	UT	UT
	Collector optical efficiency	%	77,7	80,1	75,5
	Row spacing	m	18,0	24,0	24,0
	Solar field layout	-	H	I	H
	Solar field inlet temperature	°C	293	293	288
	Solar field outlet temperature	°C	393	393	550
	Freeze-protection temperature	°C	62	62	272
	Freeze-protection mode	-	Thermal freeze-protection from storage	Thermal freeze-protection from storage	Thermal freeze-protection from storage
	HCE type	-	SCHOTT_LT	SCHOTT_LT	SCHOTT_HT
	HCE diameter	mm	70	94	70
	Heat transfer fluid	-	VP-1	VP-1	SSe
Power Cycle	Design gross output	MWe	50	50	100
	Conversion efficiency	%	38,5	38,5	43,3
	Condenser definition	-	Wet cooling, ref. dT=13.5K, T_approach=5K, T_amb=23°C	Wet cooling, ref. dT=13.5K, T_approach=5K, T_amb=23°C	Wet cooling, ref. dT=13.5K, T_approach=5K, T_amb=23°C
	Startup behaviour	-	Startup power fraction: 25%, startup time: 0.5hrs	Startup power fraction: 25%, startup time: 0.5hrs	Startup power fraction: 25%, startup time: 0.5hrs
Thermal Energy Storage	Thermal capacity	MWhth	1.010	1.010	3.233
	Equivalent full load hours	h	7,5	7,5	14,0
	Parallel tank pairs	-	1	1	1
	Storage fluid	-	Solar Salt	Solar Salt	Solar Salt
Costs	Civil works	€/m²	20	20	20
	Solar field specific cost	€/m²	228	198	210
	Power block / HTF system / BOP	€/kWe	1.286	1.286	973
	Thermal energy storage	€/kWhth	45	45	16

Table 4: Parameters for estimation of tower performance using SAM calculations [4].

Variable	Value	Variable	Value
Location	Daggett, CA	Receiver cost	SAM defaults
Gross electric power	100 MW	Power Block & BoP cost	$1100 / kW
Cooling	Air-Cooled	Thermal storage cost	$23 / kWh
Solar Multiple	1.9	Required IRR	8 %
EPC and Owner cost	5 % of direct cost	Analysis Period	25 years
O&M cost	SAM defaults	Annual Insurance Rate	1 %

For the tower case an overall layout process of heliostat field, tower and receiver the complete system is modeled using SAM or an in-house tool to determine investment cost, annual electricity generation and resulting levelised electricity costs [4]. Different heliostat types and field layouts can be directly illustrated using LCoE as a figure of merit permitting further a comparison to the parabolic trough simulation. Table 4 shows the parameters for tower performance calculations.

3.3. Heat Collecting Element Properties

Figure 1 shows HCE emissivity ε as a function of absorber surface temperature. For conventional operation temperatures (T < 400 °C), i.e. for standard oil loops, the properties following the product specifications of the standard SCHOTT PTR70 with optical values $\alpha = 95.5$ and $\varepsilon_{(400°C)} = 9.5$ were used (Fig. 1, curve SCHOTT_LT). Further, for calculations of molten salt operated solar fields a high temperature solar receiver with adapted optical values $\alpha = 92.0$ and $\varepsilon_{(400°C)} = 7.0$ was applied (Fig. 1, curve SCHOTT_HT). The values of the high temperature receiver were based on recent coating development approaches being part of the development of the molten salt receiver at SCHOTT Solar CSP [5]. A coating with low thermal emission is required for receivers with reduced thermal losses designed for high temperature operation consequently optimized for molten salt technology.

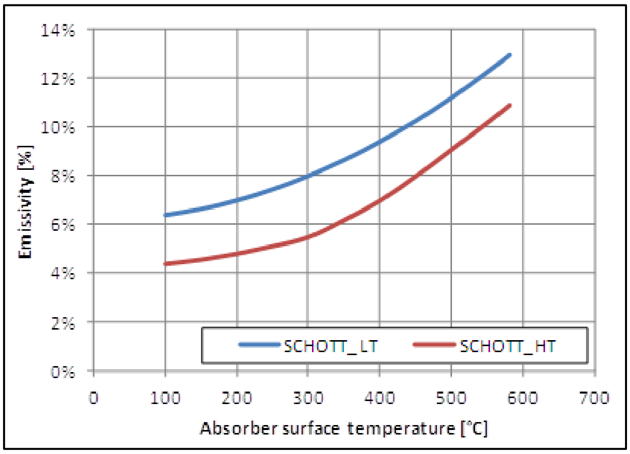


Fig. 1. Analysis of emissivity properties for two HCE absorber coating types defined for high (HT) and low temperature (LT).

3.4. *LCoE for Parabolic Trough Plants: Impact of Component Layout and Power Plant Dimensions*

Consequently, in the present study the effect of several parameters, namely (i) type of trough technology, in particular aperture size and intercept factor, (ii) solar field dimensions and (iii) nature of heat transfer fluid (HTF) has been investigated. In figure 2 the results for selected configurations are illustrated. Generally it can be seen, that for all calculation steps of LCoE both considered locations showed similar trends whereas the site Daggett exhibited, with an advantage of approx. 0.5 to 1.0 €ct/kWh, slightly better LCoE conditions as the calculations for the site Abu Dhabi. Hence in the following discussion the values for Daggett will be highlighted preferentially.

A solar power plant layout similar to Andasol 3 was used as base case, presenting a state-of-the-art plant in operation with (i) the Euro Trough Collector (ET), (ii) a solar field dimensioned for 50 MW_e, (iii) thermal oil (VP-1) as heat transfer fluid, and (iv) 7.5 h molten salt storage. Calculated LCoE were 16.9 €ct/kWh for Daggett and 17.6 €ct/kWh for Abu Dhabi, respectively. In a first optimization step the collector technology was changed from ET to the new developed Ultimate Trough (UT) with optimized aperture size and intercept factor [3]. This improvement showed a reduction effect on LCoE of 9 %, i.e. costs of 15.4 €ct/kWh for Daggett (Abu Dhabi: 16.0 €ct/kWh).

Doubling installed capacity from 50 to 100 MW_e in a successive simulation step resulted in LCoE of 13.9 €ct/kWh (Abu Dhabi: 14.4 €ct/kWh). Economies of scale thus cause an additional LCoE reduction of 10 %.

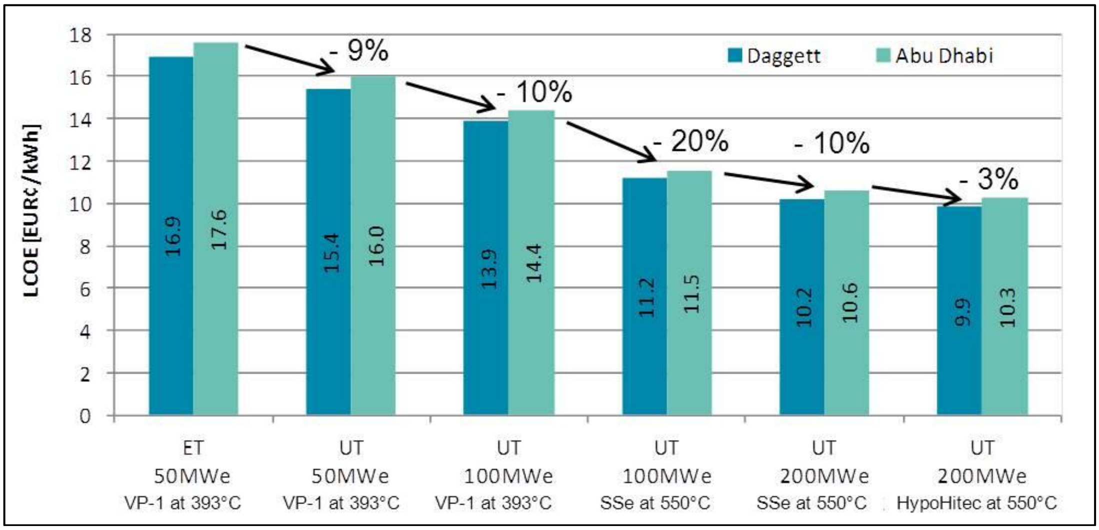


Fig.2. Path of LCoE reduction potential for parabolic trough power plants.

It can be observed that changing from a thermal oil (VP-1) to a molten salt (Solar Salt, SSe) enables a significant increase of operating temperature from initially 393 to 550 °C. A higher output temperature of the solar field means the possibility to use turbines with higher efficiencies. On the other hand, installation and energy consumption of a freeze protection system has to be considered as well. A considerable advantage of the high-temperature molten salt system is the lower relative storage cost, originating from a higher optimum storage size of 14 h. The LCoE determined for this configuration amounts to 11.2 €ct/kWh (Abu Dhabi: 11.5 €ct/kWh), which means a further significant cost reduction step of 20 % relative.

With the stepwise adaption of the above mentioned state-of-the-art configuration (LCoE: 16.9 €ct/kWh), including a doubling of solar field area, the implementation of the Ultimate Trough, the change in heat transfer medium to molten salt, and the modification of the storage size, the simulation shows the potential to reach LCoE of 11.2 €ct/kWh. This represents at that point of calculation a cumulated cost reduction potential of approx. 34 %.

Prior work has shown that the advantages of molten salt are more pronounced for larger plants. Thus, in continuance of simulation a calculation with the doubling to the size of 200 MW_e yielded LCoE of 10.2 €ct/kWh (Abu Dhabi: 10.6 €ct/kWh) correlating to a further 10% reduction of LCoE. In a last simulation step the molten salt mixture was varied to the parameters of HypoHitec which allows a lower freeze protection temperature and thus decreased energy efforts. The effect is rather low compared to the previous measures with a relative cost reduction of 3 % resulting in LCoE values of 9.9 €ct/kWh (Abu Dhabi: 10.3 €ct/kWh).

Considering the complete simulation all included technical innovation and scale-up processes possess a cumulated reduction potential for LCoE of 42 % gross compared to state-of-the-art layout.

3.5. Investigation and Influence of different Molten Salt Mixtures on LCoE

As shown in chapter 3.4, switching to molten salt as heat transfer fluid combined with technical alignments may result in 42 % lower LCoE for parabolic trough power plants. The biggest challenge in molten salt technology is the relatively high melting temperature of 150 °C (Hitec) or even 240 °C (Solar Salt). We consider two different salt mixtures with their melting point and temperature limit (500 °C for Hitec and 550 °C for Solar Salt) to evaluate the effect on LCoE. To be able to consider the effect of melting temperature and operation temperature isolated from each other, we introduce a hypothetical salt HypoHitec, possessing the properties: T_m = 150 °C, T_{op}=550 °C.

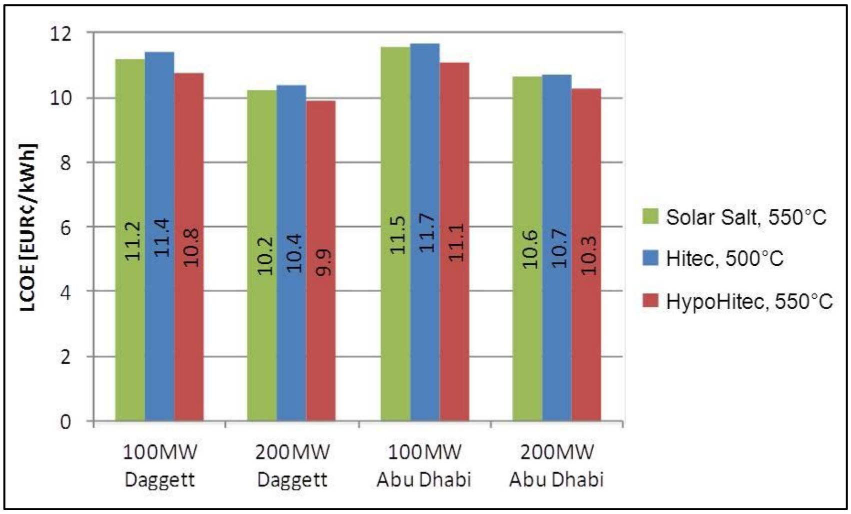


Fig. 3. Impact of different salt mixtures on LCoE for defined conditions and power plant size based on UT collector.

Figure 3 shows the simulation results of calculated LCoE for Solar Salt, Hitec and HypoHitec with respect to following boundary conditions: location, power plant size layout and operation temperature. The effect of about 10 % reduction due to the power plant size scale-up to 200 MW is visible and comparable for all salt mixture setups at both sites, Daggett and Abu Dhabi. Looking closer on the simulated use of the lower melting Hitec and HypoHitec, it can be deduced that the overall effect of operation temperature level between 500 and 550 °C can be estimated to account for a 4 - 5 % reduction in LCoE. This effect is due to the higher turbine efficiency at 550 °C as compared to 500 °C. The isolated effect of lower melting point of HypoHitec (with assumed operation temperature 550 °C) vs. Solar Salt is about 3 %. This is primarily due to the smaller amount of energy necessary to operate the heat tracing system at 150 °C.

The conclusion from these simulations considering three types of molten salts is that the overall cumulated effect of the variation of the salt mixtures with maximum 5 % lower LCoE is rather small compared to the demonstrated scale effects. Comparing the two real salts, the LCoE difference is smaller than the calculation error.

3.6. Simulated Influence of Absorber Diameter on LCoE

For the technical realization of parabolic trough solar power plants different versions of component layouts (e.g. trough aperture area or length, HCE dimensions) exist on the market. To discuss and estimate the general effects and impact of varying layouts for parabolic trough power plants a simulation with varied absorber diameters as well as trough configuration (ET, UT) and heat transfer medium (oil, molten salt) were estimated.

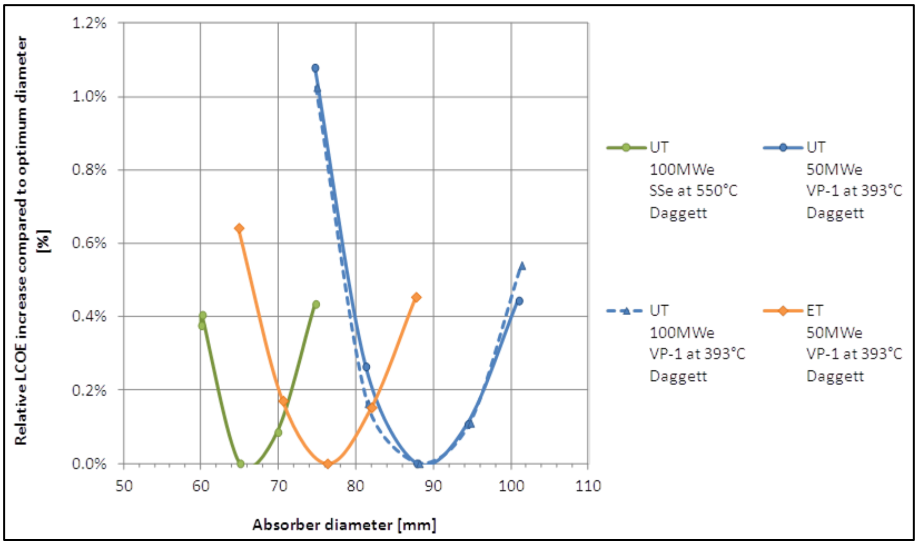


Fig.4. Influence of absorber tube diameter to relative increase of LCoE in parabolic trough plants.

Initial calculations for the site Daggett were performed with basic settings as follows: (i) EuroTrough collector (ii) 50 MW_e power plant capacity and (iii) thermal oil. The simulations for this configuration shown in figure 4 revealed an optimum absorber tube diameter of 76 mm, whereas the common standard diameter geometries 70 and 80 mm displayed a minor increase of LCoE of approx. 0.2 and 0.1 %, respectively.

Application of the characteristics of the Ultimate Trough technology to this simulation illustrated that for the combination UT & oil as heat transfer medium the necessary diameters increased towards an optimum absorber tube diameter of 88 to 90 mm to enable higher mass flow at similar piping conditions (Fig. 4, blue line). The results indicated further that a significant increase in relative LCoE became obvious for smaller diameters like 70 mm (>1.2 %) or 80 mm (0.4 %). These findings also were consistent for calculations with an increased power plant size of 100 MW_e.

The implication of molten salt mixtures to this calculation revealed a significant drop in optimum absorber tube diameters and the simulation results yielded reduced necessary steel tube cross sections in the range of 66 mm.

With this investigation of component scale effects onto power plant performance it could be clearly shown that beside increased concentration factors the Ultimate Trough technology provides and supports a diversification of absorber tube geometries with respect to the existing heat transfer medium. Hence, the respective optimum absorber diameters were determined in system simulations as (i) molten salt: 65 to 70 mm and (ii) thermal oil: 90 mm. Variations of absorber tube diameters from the calculated optimum dimensions (> 10 mm) generally showed no significant effects on relative LCoE increase with deviation in the range of 0.5 to max. 1.5 %.

3.7. Simulation and Comparison of Solar Tower LCoE

Similar calculations were performed for power towers to estimate the influence of technology steps on LCoE and further to draw conclusions about potentials and differences compared to parabolic trough technology. In a first approach the dimensioning as well as construction costs for a solar tower were calculated and the *tower cost vs. tower height* function was estimated (sbp Solar Tower Design) by designing, calculating and costing several towers, drawing on sbp's several decade long experience of designing towers and high-rise buildings [6]. The findings were compared to established *tower cost vs. tower height* functions (SAM (NREL) & Delsol3) [7], and the newly determined results used for power tower LCoE calculations (Tab. 5). Tower receiver costs were evaluated following the default SAM receiver cost curve; receiver cost data from Abengoa Inc. was available but not used due to unclear scope and content of cost composition [8].

Table 5: Calculated boundary conditions for estimation of geometry and cost functions for simulated solar tower designs.

Tower Height [m]	Tower Costs [M€]	Tower Costs (SAM & Delsol3) [M€]	Receiver Area [m²]	Receiver Costs (SAM default) [M€]	Receiver Costs (Abengoa Inc.) [M€]
150	6	8	600	50	20
250	10	25	1100	75	30
350	20	75	1600	98	40

In addition two types of heliostats have been assumed for assessment, a benchmark calculation based on a Brightsource heliostat (net mirror area: 17.86 m², σ_{total} = 2.8 mrad) and a technological improved case assuming an advanced heliostat (net mirror area: 43.35 m², σ_{total} = 2.3 mrad). For these heliostats cost per m² mirror area add up to 140 €/m² (benchmark) and 120 €/m² (advanced), respectively [4].

The calculation of LCoE for power towers at the sites Abu Dhabi and Daggett were effected choosing comparable technical layouts at tower height in the range of 245 m (Tab. 6). Obtained electric annual energies were determined as 590 GWh (Daggett) and 568 GWh (Abu Dhabi). The evaluation of LCoE considering the benchmark heliostat at the U.S. site Daggett yielded 11.7 €ct/kWh (Abu Dhabi: 12.1 €ct/kWh). The power tower design using the advanced heliostat design yielded LCoE of 10.8 €ct/kWh (Abu Dhabi: 11.0 €ct/kWh) signifying an LCoE reduction potential of approx. 8 %.

Table 6: Technical layout and simulated costs for power tower operation at locations Abu Dhabi, UAE and Daggett, CA.

	[Unit]	Abu Dhabi	Daggett
Annual Energy	GWh / y	568	590
No. of Heliostats	Pcs.	96.279	97.628
Mirror Area	1000 m²	1.720	1.744
Tower Height	m	245	246
Receiver Diameter	m	18.7	18.7
Receiver Heigth	m	22.8	23.3
LCoE (Benchmark Heliostat)	€ct/kWh	12.1	11.7
LCoE (Advanced Heliostat)	€ct/KWh	11.0	10.8

4. Conclusion

In the present publication simulations and calculations are presented evaluating the effect of improved component performance on LCoE for parabolic trough power plants regarding two different geographical sites (U.S. and MENA). Further a comparison to established tower designs is drawn demonstrating the competitiveness of both technologies.

It was demonstrated that defined modifications of power plant layout, like the installation of improved collector technology (Ultimate Trough technology) and subsequent up-scaling of power plant size show a significant impact on the reduction potential of LCoE in the range of 10 %, respectively. Still, the usage of molten salt as HTF including application of enhanced heat collector elements (solar thermal vacuum receiver) which permit higher operation temperatures and increased power block efficiencies represents the most significant measure, reducing LCoE by 20 % and thus significantly improving competitiveness of parabolic trough technology. Furthermore the simulations provided evidence that in total the combination of all three discussed modifications shows an absolute LCoE reduction potential of 42 %.

In the study another focus was set on the impact of different absorber tube diameters on LCoE. It was demonstrated in simulations that with introduction of the Ultimate Trough collector the optimum absorber tube diameter is defined in the range of 65 mm to 70 mm – which represents the current standard diameter of commercial receivers like the PTR70. In contrast, the simulations state that if standard synthetic oil is used as HTF the Ultimate Trough requires absorber tube diameters of about 90 mm to attain improved cost efficiency.

Three types of molten salts (2 commercial, 1 hypothetical) with different physicochemical properties were investigated and simulated in solar power plant operation. It was shown that the effect and performance of the three molten salt types onto reduction of LCoE accounted for 3 to 5 %. Consequently it can be deduced that differences between the examined specific salt mixtures have a minor influence on cost reduction compared to the demonstrated improvements of key components like collector and absorber.

An assessment of solar towers was made estimating realistic tower costs as well as two different heliostat options (1 established 1 improved heliostat). The simulations yielded an LCoE value of 10.8 €ct/kWh, which is comparable and competitive to the respective value found for parabolic trough power plants with LCoE of 9.9 to 10.2 €ct/kWh.

Further simulation work is planned considering different optimized absorptance and emissivity distribution as well as varying tube diameters of a same loop.

5. References

[1] P. Erroi, F. Buttinger (2012): Technology and Cost Roadmap, Proceedings of SolarPACES 2012.
[2] K. Riffelmann et. al. (2013): Ultimate Trough – A Significant Step Towards Cost Competitve CSP, Proceedings of SolarPACES 2013.
[3] K.-J. Riffelmann et al. (2012): Performance of the Ultimate Trough® Collector with Molten Salts as Heat Transfer Fluid, Proceedings of SolarPACES 2012.
[4] G. Weinrebe et. al. (2013): Towards Holistic Power Tower System Optimization, Proceedings of SolarPACES 2013.
[5] H. Kamp et al. (2012): SCHOTT Parabolic Trough Receivers for Operation with Molten Salt, Proceedings of SolarPACES 2012.
[6] "schlaich bergermann und partner." [Online]. Available: http://www.sbp.de/en. [Accessed: 28-Jun-2013].
[7] Battleson, K.W. (1981): Solar Power Tower Design Guide: Solar Thermal Central Receiver Power Systems, A Source of Electricity and/or Process Heat, Sandia National Labs Report SAND81-8005, April.
[8] B. Kelly, "Advanced Thermal Storage for Central Receivers with Supercritical Coolants," Abengoa Solar Inc., Lakewood, CO, DE-FG36-08GO18149, Jun. 2010.