Overview on use of a Molten Salt HTF in a Trough Solar Field

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Concept & Objectives

Utilize a molten salt as the heat transfer fluid in a parabolic trough solar field to improve system performance and to reduce the Levelized Electricity Cost (LEC)

Potential Advantages

- Can raise solar field output temperature to 450-500°C
  - **Rankine cycle efficiency increases to ≥40% range**
  - **ΔT for storage up to 2.5x greater**
- Salt is less expensive and more environmentally benign than present HTF
- Thermal storage cost drops 65% to <$20/kWht compared to VP-1 HTF plant (no oil-to-salt HX)
- Solar Two experience with salts pertinent and valuable (piping, valves, pumps)

Potential Disadvantages

- High freezing point of candidate salts
  - **Leads to significant O&M challenges**
  - **Innovative freeze protection concepts required**
- More expensive materials required in HTF system due to higher possible HTF temperatures
- Selective surface durability and salt selection will determine temperature limits
- Solar field heat losses will rise, though emissivity of 0.075 (from 0.1) would regain performance

Some Key Questions

- What is the practical upper temperature limit?
- Is the O&M with salt feasible in a trough field, particularly freeze protection?
- Do materials, O&M, performance, etc. push the solar system capital cost too high, or in fact will the cost be reduced?
- Can we lower electricity cost with this approach? And add important flexibility with thermal storage?

General System Conditions

Power block type:	Steam Rankine cycle	
Power block capacity:	50 MW gross	
Steam turbine inlet conditions:		
Pressure Temperature	66 bar, 100 bar nominally 400-500C	
Steam turbine cycle efficiency: determined by GateCycle calculation, nominally 38.5-41.1% for these conditions.		
Solar field outlet salt temperature:	Nominal Maximum	450°C ~500°C
Optical:	Overall optical efficiency	0.75
Power Block	Capacity, MW	55 gross
Performance runs:	Thermal storage capacity	6h
	Annual Insolation	Barstow
Collector type	Generic SEGS type with advanced features	
Receiver	Current Solel Receiver	ε=0.1@ 400C
Operating scenario	Solar only	

Characteristics of the Nitrate Salts and Therminol VP-1

Property	Solar Salt	Hitec	Hitec XL (Calcium Nitrate Salt)	$LiNO_3$ mixture	Therminol VP-1 Diphenyl biphenyl oxide
Composition, %					
$NaNO_3$	60	7	7		
KNO_3	40	53	45		
$NaNO_2$		40			
$Ca(NO_3)_2$			48		
Freezing Point, C	220	142	120	120	13
Upper Temperature, C	600	535	500	550	400
Density @ 300C, kg/m^3	1899	1640	1992		815
Viscosity @ 300C, cp	3.26	3.16	6.37		0.2
Heat capacity @ 300C, J/kg-K	1495	1560	1447		2319

Effective Storage Fluid Cost

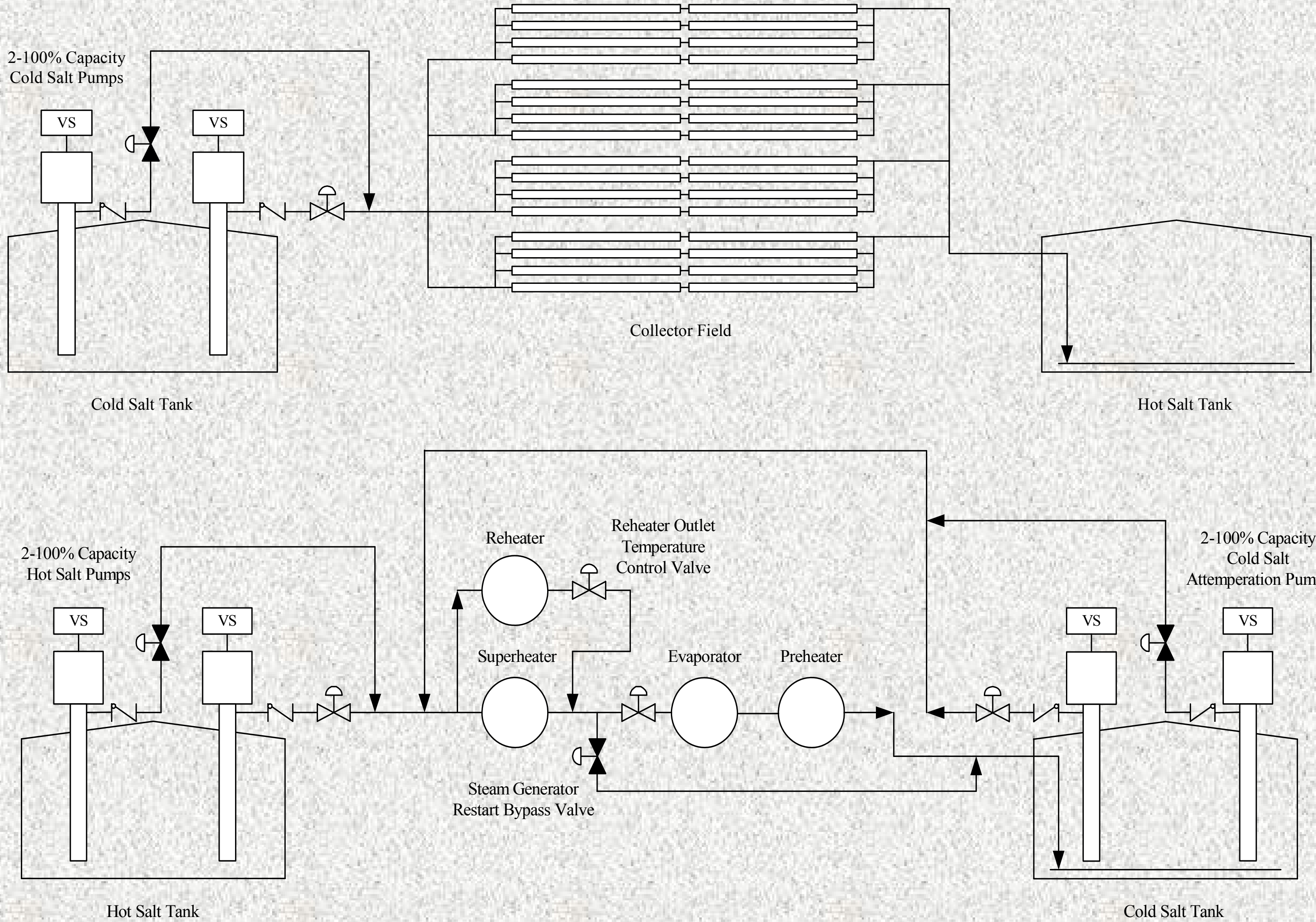
Salt	Temperature Rise	Cost per Kg	Storage Cost
	°C	$/kg	$/kWh
Hitec (a) [142°C]	200	0.93	10.7
Solar Salt (b) [220°C]	200	0.49	5.8
Calcium Nitrate [HitecXL] (c) [120°C]	200 150 100	1.19 1.19 1.19	15.2 20.1 30.0
Therminol VP-1 (d)	100	3.96	57.5

a) 7:53 Na:K Nitrate, 40 Na Nitrite
b) 60:40 Na:K Nitrate
c) 42:15:43 Ca:Na:K Nitrate
d) Diphenyl/biphenyl oxide

Candidate Thermal Storage Systems

- 2-Tank Configuration
  - Hot and Cold Tanks
  - Used at Solar Two … good engineering experience
  - Judged to ready for commercial use
- Single Tank Thermocline
  - Good option -> costs estimated to be 65% less
  - Requires further development
  - 20 MWth prototype operated at SNLA
- Freeze protection in storage systems less complex than in field piping
- With VP-1, an expensive oil-to-salt HX is required. A molten salt HTF eliminates that need.

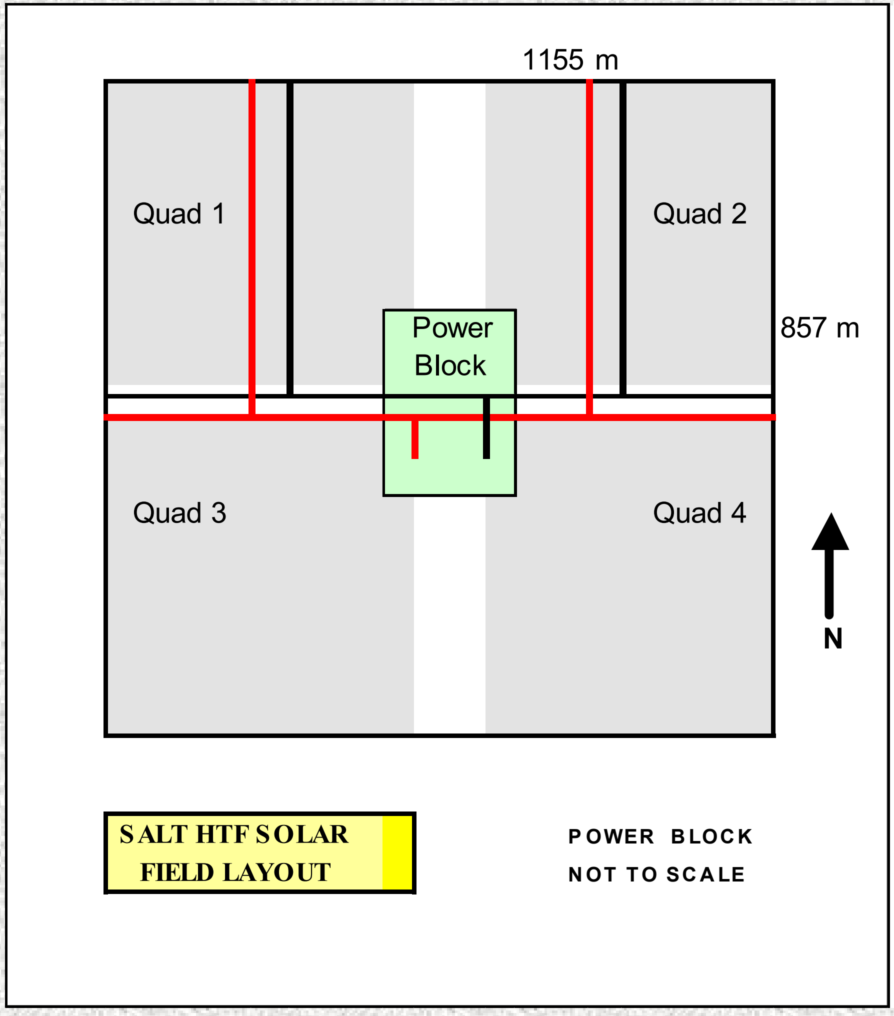
HTF System Layout



Comparative Levelized Electricity Cost

Engineering on solar field piping layout and design of major equipment was carried out for use in the performance and cost models

Solar Field Layout



Solar Field Parameters for 55 MWe Plant

125.0	Solar field peak thermal outpu	MWt
879.0	Total salt HTF mass flowrate	kg/s
28.4	Header corridor	m
100.5	Total length per SCA	m
12.2	Outer road corridors	m
69.6	Allowance E-W for power blocl	m
402	Length of 1 row with 4 SCAs	m
1155	E-W total width	m
857	N-S total width	m

hot HTF in header and illustrative loops

cold HTF in header and illustrative loops

270,320	SF aperture area	m2
496	Total SCAs	
62	Total rows	
62	Total loops	
17.4	Solar row spacing	
5.76	Mirror aperture	
4	SCAs/row	
8	SCAs/loop	
989,949	Total land area	m2
99	Total land area	hectares
245	Total land area	acres

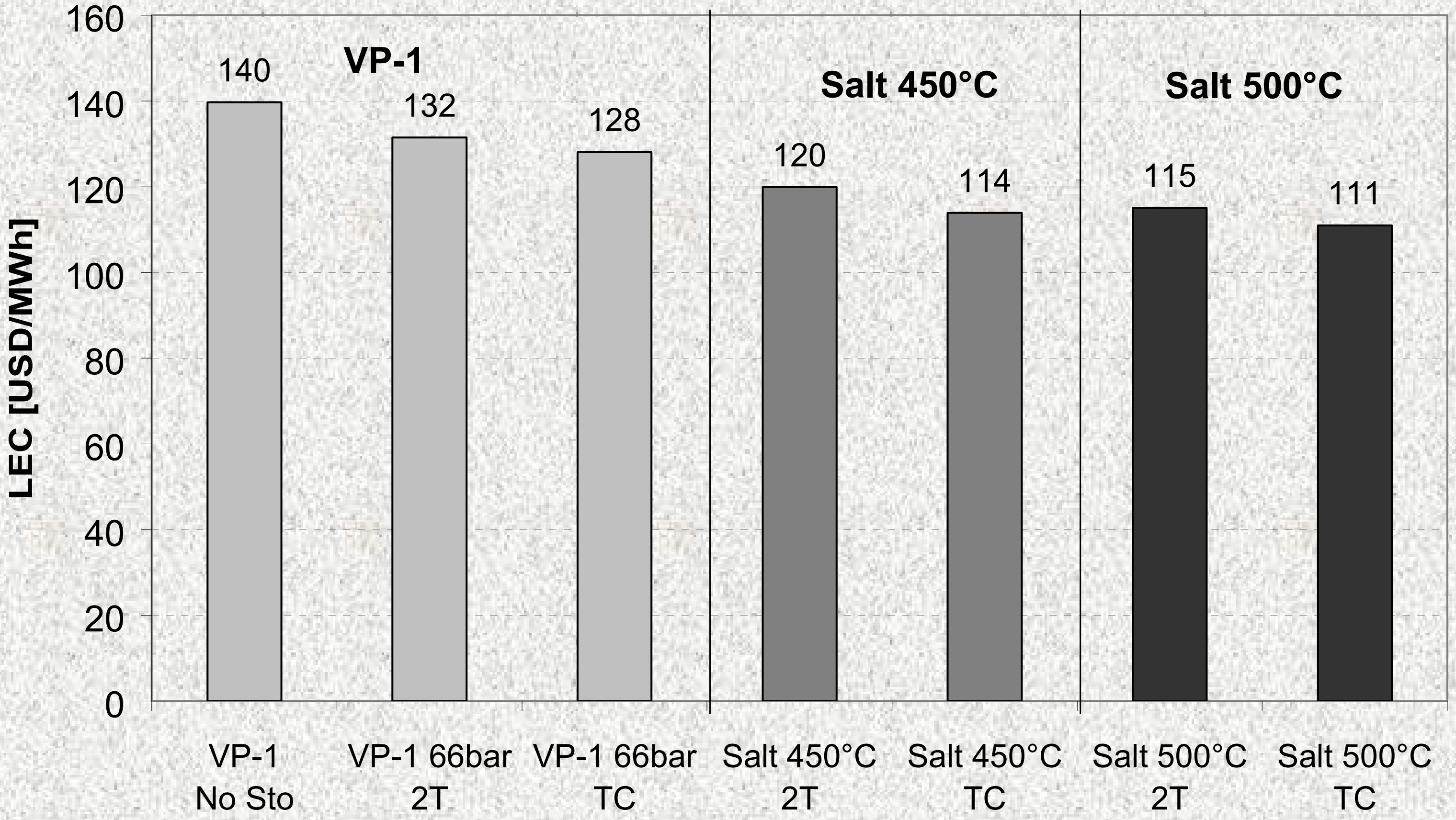
Optical Efficiency Backup

Optical Efficiency Comparison	Sandia LS-2 Test	SEGS VI LS-2 1999	New LS-2 Collector	Advanced Trough
Bellows Shadowing	0.974	0.971	0.974	0.974
Tracking Error & Twist	0.994	0.994	0.994	0.994
Geometric Accuracy	0.98	0.98	0.98	0.98
Mirror Reflectivity	0.935	0.935	0.935	0.95
Dust on Mirrors	0.974	0.931	0.95	0.97
Dust on HCE	0.99	0.977	0.983	0.99
Envelope Transmissivity	0.965	0.965	0.97	0.97
Absorption	0.925	0.937	0.96	0.97
Unaccounted	0.96	0.96	0.97	0.98
Optical Efficiency	**0.73**	**0.70**	**0.75**	**0.80**

Final Comparison

Case ID	VP-1 No Sto	VP-1 66bar 2T	VP-1 66bar TC	Salt 450°C 2T	Salt 450°C TC	Salt 500°C 2T	Salt 500°C TC
Solar Field Size [m²]	270,320	427,280	427,280	425,100	425,100	425,100	425,100
Investment Cost [M$]	110,291	175,251	169,546	171,405	159,556	164,583	156,158
Thermal Storage Cost [M$]	0	21,330	15,897	19,674	8,390	14,141	6,117
Annual O&M cost [k$/yr]	3,583	4,088	4,088	4,282	4,282	4,282	4,282
Net Electric [GWh]	107.5	169.2	169.1	183.9	182.9	185.7	184.4
Mean Solar to electric efficieny	14.64%	14.58%	14.57%	15.92%	15.84%	16.08%	15.97%
LEC [USD/MWh]	**139.7**	**131.5**	**128.1**	**119.9**	**113.9**	**115.1**	**111.0**
LEC Reduction	-	5.9%	8.3%	14.2%	18.5%	17.6%	20.6%
Thermal Storage Cost $/kWh el	0.0	64.6	48.2	59.6	25.4	42.9	18.5
Thermal Storage Cost $/kWh th	0.0	23.7	17.7	23.6	10.1	17.4	7.5

LEC Gains from Use of Calcium Nitrate Salt as HTF



Concept Overview

- Study concluded that no overriding barriers prevent its adoption at 450°C. R&D is needed, particularly to reach 500°C operation.
- Feasible solutions have been put forward for system charging, freeze protection, recovery from freezing, and routine maintenance tasks. Selective surface and ball joints present greater challenges.
- There is no compelling economic advantage to using molten salt in a trough solar field for a system without thermal storage
- There appears to be significant economic advantages for a molten salt HTF with storage. Preliminary estimates on reductions in LEC from the reference VP-1 case (w/o storage) are significant.

Engineering Issues

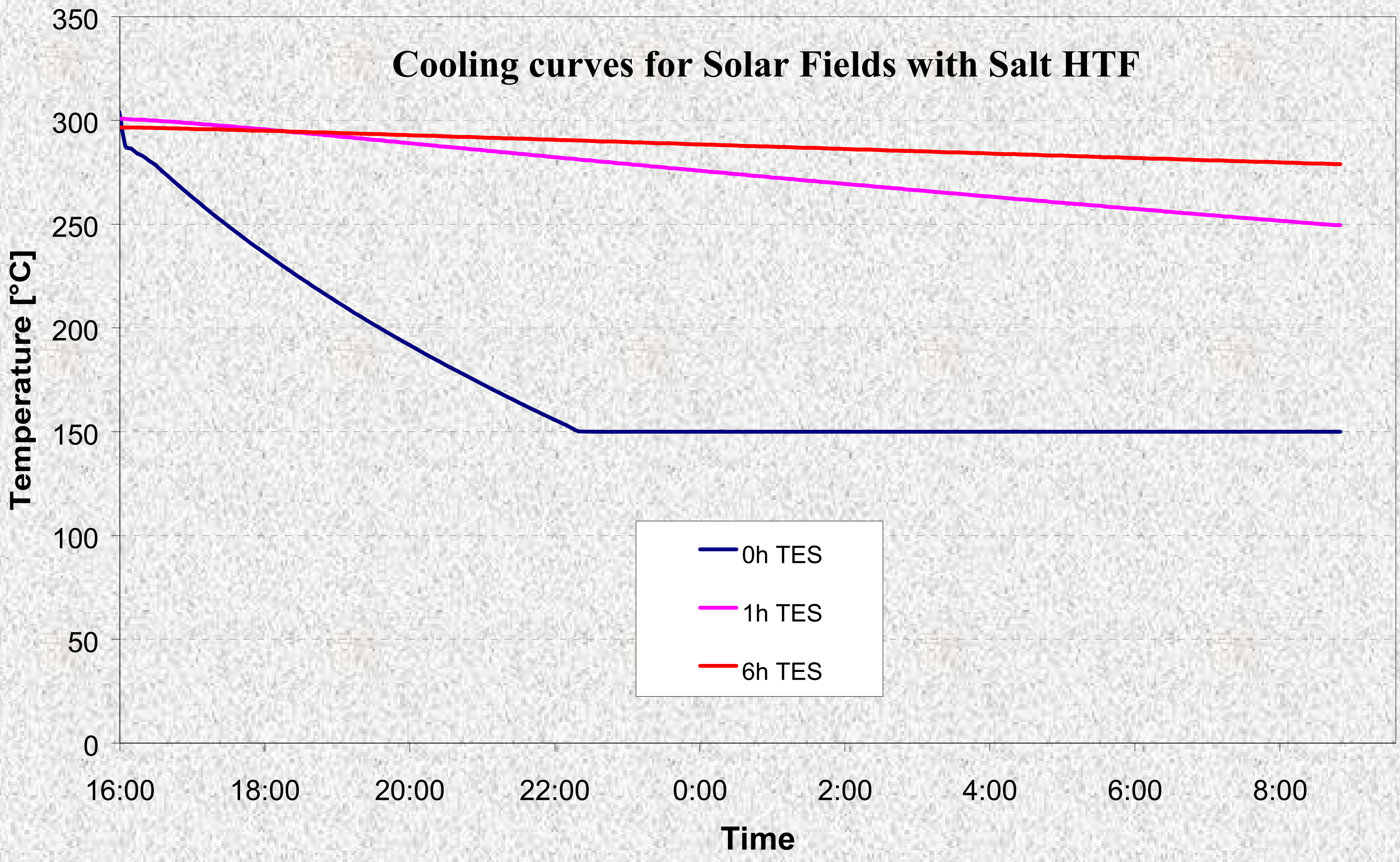
Issues addressed

- Routine Freeze Protection
- Solar Field Preheat Methods
- Collector Loop Impedance Heating
- Materials Considerations

Freeze Protection Methods

- Heat Collection Element
  - **Cold salt circulation in routine overnight operation**
  - **Impedance heating for maintenance outage**
  - **Resistance heating cable internal to the HCE**
  - **Drain loop to service truck for loop piping maintenance**
- HTF Header Piping
  - **Cold salt circulation in routine overnight operation**
  - **Electric heat tracing for maintenance outage**

Overnight Cooling



HCE Heating

- Internal resistance heating
  - Considered possible but cumbersome
- Impedance heating
  - Circumferentially uniform
  - Higher power densities possible
  - Electric system requirements high

Collector Loop Maintenance

- Drain hot HTF into maintenance truck under slight vacuum
- Perform maintenance, e.g., HCE replacement
- Heat loop with impedance heating, and pump salt mixture into loop

Normal Maintenance & Operation

- Within the solar field, O&M practices will change for HTF system and flow loop only, requiring different procedures for:
  - **HCE replacement, requiring taking loops out of service**
  - **Maintenance of valves, interconnections, and other fittings**
  - **Heat trace systems**
  - **Major equipment: Pumps; steam generator; TES**
  - **Instrumentation to monitor salt temperatures and heat trace system operation**
- Conservative but preliminary cost adders included in O&M budget

Materials Considerations

		ASTM [a] Designation				
Peak fluid temperature,	Basic material	Pipe	Fittings	Valves	Tubes [b]	Plate [c]
325°C	Carbon steel	A 106, Grade B	A 234, Grade WPA	A 216, Grade WCB	A 192	A 516, Grade 70
450°C	Ferritic steel	A 335, Grade P22	A 234, Grade WP22	A 217, Grade WP22	A 213, Grade T22	A 387, Grade 22
500°C	Ferritic steel	A 335, Grade P91	A 234, Grade WP91	A 217, Grade WP91	A 213, Grade T91	A 387, Grade 91

Notes: a) American Society for Testing and Materials; b)For steam generator heat exchangers; c) For thermal storage tanks and heat exchanger shells

Lower solar field HTF Velocities with Molten Salt

due to higher temperature rise and salt properties