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Research on Design of Hot / Cold Molten Salt Storage Tanks

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Design Considerations

■ Tank Wall Calculation

Design Standards	Calculation Methods	Similarities in standards	Disparities between standards
API650	One-Foot Method; Variable-Design-Point Method Stress Analysis Method	The applicable scopes of one-foot method	Tanks with diameter D<61m: Variable-design-point method For Large-diameter storage tanks: (500Dt)/H>1000/6: Stress Analysis Method t=(Nominal thickness - Corrosion allowance) H=highest liquid level
GB 50341	One-Foot Method; Variable-Design-Point Method;		Tanks with diameter D<60m:One-Foot Method Tanks with diameter D>60m:Variable-Design-Point Method

API 650's variable-point method dynamically locates maximum stress points, enabling thinner walls with greater economy but requiring complex iteration. GB 50341's single-point method uses the tank bottom as a fixed calculation point, offering simplicity but resulting in more conservative and costly designs.

■ Tank Wall Construction

Design Standards	Plate Alignment Method	Longitudinal Weld Joint Staggering Requirement	Welded Joint Efficiency Factor	Stress Distribution on the Tank Wall
API650	Centerline Alignment	Min. 5*T offset (T=tank wall thickness)	$\varphi = 1$ (For small capacity tank, $\varphi = 0.85, 0.7$)	Relatively uniform
GB 50341	Inner Surface Alignment	≥300mm	shell-to-bottom junction : $\varphi = 0.85$ others $\varphi = 0.9$	No abrupt change on the inner wall； relatively significant on the outer wall

API 650's centerline alignment prioritizes structural performance and fatigue resistance but creates an internal ledge that can interfere with floating roof movement. In contrast, GB 50341's inner wall alignment provides a smooth interior surface for unimpeded roof operation but compromises structural integrity by concentrating stress on the exterior, resulting in reduced fatigue resistance.

Design Considerations

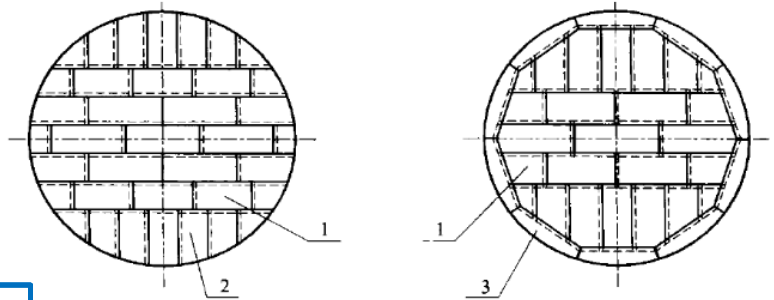
■ Tank Bottom Design

Design Standards	Thickness of the Bottom Plate
API650	(Nominal thickness of the bottom plate-Corrosion allowance) ≥ 6 mm; Min. width: 1800 mm
GB 50341	For storage tanks D ≤ 10m, (Nominal thickness of the bottom plate-Corrosion allowance) ≥ 5 mm； For storage tanks D > 10m，(Nominal thickness of the bottom plate-Corrosion allowance)≥ 6 mm The width of bottom plates is not restricted

■ Edge Plates

In accordance with GB 50341, for tanks with diameter ≥12.5m, adopt annular edge plates;

Tanks Diameter(m)	Center Plate(mm)	Edge Plate(mm)	
		Inner Ring	Outer Ring
20	10	22	
30	10	15	22
40	8	17	35



Bottom without edge plate

Bottom with edge plate

API 650 determines the necessity of annular edge plates based on the material properties and allowable stress of the bottom-course shell plates.

Design Considerations

- **Tank Roof Design**

Design Standards	Structural Configuration	Allowable Maximum Thickness
API650	Self-supporting dome	≤13 mm
GB 50341	Self-supporting dome	≤12 mm

Design Considerations: Molten salt tank design must rigorously address API 650 vs GB 50341 standard divergences, optimize stress distribution via FEA, ensuring tank safety and reliability.

Design Parameters-----Yumen molten salt tank

Design Parameters	Cold Molten Salt Tank	Hot Molten Salt Tank
Design Standards	API650	API650
Storage Medium	Solar salt	Solar salt
Design Pressure	2kPa	2kPa
Design Negative Pressure	-0.25kPa	-0.25kPa
Design Temperature	370℃	565℃
Operating Pressure	Atmospheric	Atmospheric
Operating Temperature	300℃	550℃

Design Parameters	Cold Molten Salt Tank	Hot Molten Salt Tank
Tank Material	A516 Gr70N	A240 347H
Tank Configuration	Vertical Cylindrical Dome Roof	Vertical Cylindrical Dome Roof
Tank Wall Height	15m	15m
Inner Diameter	30.4m	31.7m
Max. Operating Level	13.5m	13.5m
Min. Operating Level	0.8m	0.8m

Both the inner diameter and wall height of the tank are dimensions at operating temperature.

Preheating Scheme

■ Hot molten salt tank

1.Types of Hot Air	Natural gas-heated air and electrically heated air
2. Preheated Air Application Scope	**Electric preheating** is generally used for small storage tanks with diameters of around 15 meters. **The natural gas-heated** air method is used for preheating for tanks >30m diameter.
3. Preheating Gas Requirements	Temperature range: Inlet air: -28℃(min) Outlet air: 750-800℃ (final stage) Flow rate: Min 2,000 m^3/h-Max 14,000 m^3/h Time constraints:Total duration: 120-320 hours
4. Preheating Operation Instructions	Stop the air heater and end preheating once the salt level exceeds the Lowest Working Level (LL).

■ Preheating Scheme Process

Fan Outlet Temperature	Minimum Tank Temperature
150°C	35°C
200°C	70°C
250°C	125°C
300°C	170°C
350°C	220°C
400°C	270°C
450°C	300°C
500°C	350°C
550°C	400°C
650°C	450°C
700°C	500°C
780°C	550°C
Data sourced from preheating scheme of tank in Datang Shichengzi CSP	

Hot Tank Preheating Process:
During the initial filling stage of the hot salt tank, the hot air furnace must remain activated. Once the liquid level rises to one-third, switch the hot air furnace to the cold tank to initiate its preheating process of cold tank.

Cold Tank Preheating Process:
Repeat the initial stages of the hot tank preheating process until the tank temperature reaches 300°C, and molten salt can be charged.

Continuous Ramp-Up Condition

- Operating Condition Analysis Criteria(**Illustrative case**)

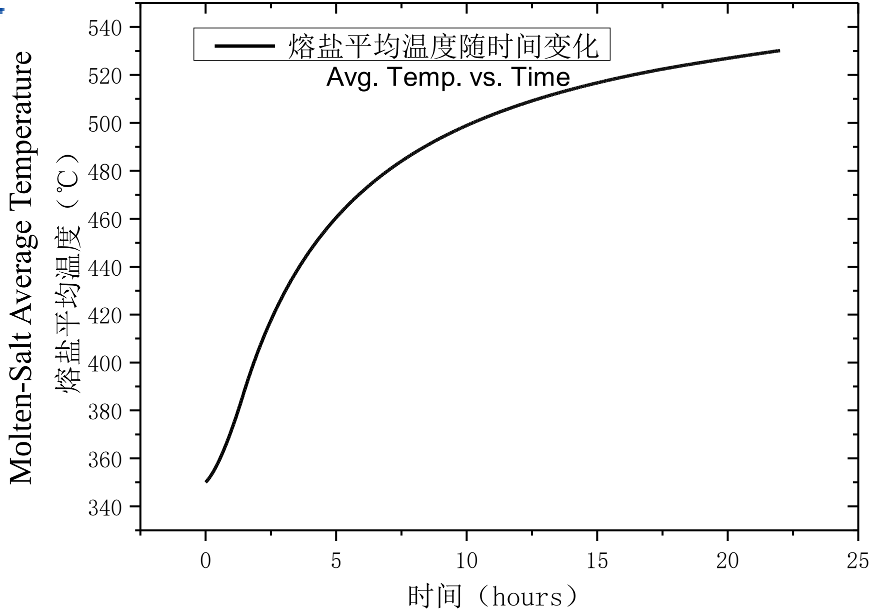
Continuous Ramp-Up Condition	Under near-empty tank conditions, raise the bulk temperature by fully filling the tank via molten salt charging.
1）Initial Tank Conditions	Hot molten salt initial level: 2 m Hot molten salt initial temperature: 350℃
2）Salt Charging Parameters	Hot molten salt injection flow rate: Constant 200 kg/s Outlet condition: No salt discharge
3）Temperature Control	Hot molten salt initial injection molten salt temperature: 390℃ Ramp rate: 2℃/min (linear increase) Upper limit: Stabilizes at 565℃ (no further increase)
4）Termination Condition	Continuous ramp-up operation until average internal temperature reaches 530℃

- Transient Flow Field

After 18 hours of operation, the molten salt level reaches full tank capacity. The tank outlet valve is opened, and the average salt temperature changes linearly over time until the predetermined temperature is achieved after 22 hours.

Continuous Ramp-Up Condition

- Transient Temperature Profile



After 18 hours of operation, the molten salt level increased to fill the tank. The molten salt tank outlet was opened, and the average temperature of the molten salt changed linearly with time. After 22 hours, it ultimately reached the predetermined temperature.

Heater Startup Operating Condition

- Operating Condition Analysis Criteria(**Illustrative case**)

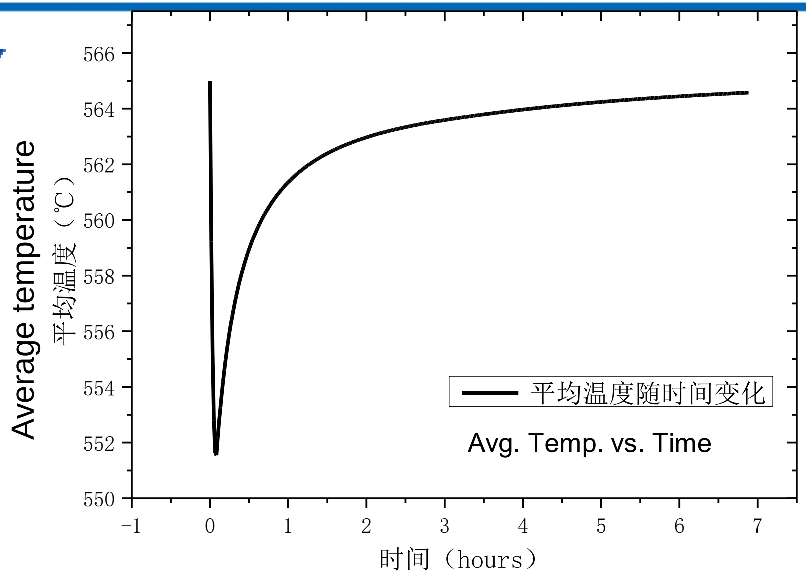
Heater startup condition definition	Heater startup is a special operational scenario in tank operation, designed to test the dynamic response of heat absorbers when activated under near-empty tank conditions.
1）Initial Tank Conditions	Hot molten salt initial level: 1 m Hot molten salt initial temperature: 565℃
2）Salt Charging Parameters	Molten salt injection flow rate: Constant 1400 kg/s Outlet condition: No salt discharge
3）Molten Salt Temperature Control	Initial injection molten salt temperature: 370℃ Upper limit: Stabilizes at 565℃ (no further increase)
4）Termination Condition	Heater startup operation continues until bulk average temperature stabilizes at 565℃

- Transient Flow Field

Molten salt is continuously injected (outlet closed), with the liquid level rising from 1m to full tank capacity over 2.8 hours.

Heater Startup Operating Condition

- Transient Temperature Profile



Initial Cooldown Phase (0-20 min)	Average tank temperature gradually decreases Minimum recorded temperature: 532℃
Rapid Recovery Phase (20 min - 1 hr)	Fast temperature rise from 532℃ → 552℃ Heating rate: 0.67℃/min
Asymptotic Stabilization Phase (1-8 hr)	Continued temperature increase at reduced rate Final average temperature: 564.59℃ Effective heating rate: 0.18℃/min (1-8 hr period)

Freeze Clogging of Molten Salt Tanks

High-risk Locations	pipe low points, elbows, valves, molten salt pumps
Triggering Conditions	1. Salt residue accumulation 2. Cooling-enduced solidification
Anti-freezing Design	1. Piping structural design: pipe slope; minimize u-bends; prioritize large-diameter straight pipes 2. Insulation system: Select insulation materials 3. Heat traceing & preheating systems: electric heat tracing(Electric heat tracing;Skin-effect heat tracing;Short-circuit heating tracing)
Freeze-Clogging Emergency Response	1. Detection methods: sensor temperature anomalies 2. Resolution procedure:Utilize high-temperature electric heat tracing to liquefy molten salt

Salt Tank Leakage

■ Causes of Leakage

Failure Causes	Description of Causes	Preventive Measures
Molten Salt Corrosion Failure	When the thermal storage medium is ternary nitrate, the corrosion rate of stainless steel increases with rising temperature.	Reasonable corrosion allowance
Localized Failure	Structurally discontinuous areasare more prone to localized failure under prolonged high-temperature operation.	Joint reinforcement
Welding Fabrication Quality	Improper welding process temperature selection, non-standard groove dimensions, lack of penetration during welding, and omission of post-weld heat treatment	Advanced welding equipment；High-quality Welding consumables； Increased Non-Destructive Testing (NDT) ratio
Foundation Settlement	Non-uniform crushing of the foundation during construction/operation, and uneven temperature differentials in the sand layer between zones.	Site selection; Insulation material optimization
Thermal Expansion Restriction	Oxidation alters the contact surface state and increases frictional resistance, restricting the tank's free thermal expansion during startup/shutdown and operation.	Optimize the structure of the storage tank bottom plate(the thickness of the edge plate and the center plate, and the layout method)
Thermal Shock	Significant temperature fluctuations in incoming molten salt cause localized thermal stress concentration and fatigue failure.	The temperature fluctuation range must be controlled within -20℃ to +25℃

Hot Tank Foundation

- GB50264-2013 Mandatory Requirements

When molten salt temperature reaches 565℃ ,
(1) Maximum allowable heat loss rate at insulation outer surface: 254 W/m²
(2) Practical design recommendations:
Heat loss rate < 200 W/m²
Temperature loss < 0.56℃/day

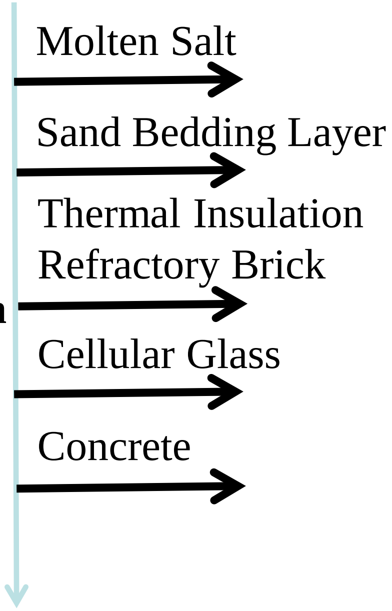
- Insulation Material Selection

(1) Requirements:
Thermal insulation performance and Foundation load-bearing requirements
(2) In compliance with leverages experience from LNG storage tank foundations

Thermal insulation material	Hot Tank Foundation	Cold Tank Foundation
Cellular glass insulation(Temperature resistance ≤450°C)	A layer of insulating firebrick is placed between the tank bottom and the cellular glass insulation layer.	defined thickness cellular glass insulation

Schematic Diagram of Tank Foundation Structural

Foundation Structural Configuration



Recommendations for Ensuring Salt Tank Safety

■ Installation (Welding) Requirements

(1) Optimize Welding Process:

Adopt intermittent welding, multi-pass welding, and low-current parameters to strictly control heat input (≤12 kJ/cm), minimizing thermal distortion and residual stress.

(2) Enhance Quality Inspection:

Full-coverage NDT (RT/UT) for large fillet welds per approved ITP, with tightly fitted triangular stiffeners (tack-welded) to control distortion.

(3) Preemptive Deformation Control:

Fabricate pre-cambering tools in advance (pre-set arching of 0.1%L) to ensure baseplate assembly flatness (laser-measured deviation ≤3mm).

Recommendations for Ensuring Salt Tank Safety

■ Non-Destructive Testing (NDT) Requirements----Cold molten salt tank

Inspection Point	Inspection Subject	NDT Method
Tank Bottom Welds	Edge Plate Butt Joint	100% Radiographic testing (RT) or 100% Phased array ultrasonic testing (PAUT)
	Other Butt Joints	100% Phased array ultrasonic testing (PAUT)
	Surface of bottom plate welds	100% Magnetic Particle Testing (MT) and Liquid penetrant Testing (PT)
Wall Plate Welds	Thickness >12mm Longitudinal/circumferential butt joints	100% Phased array ultrasonic testing (PAUT) 100% Time-of-flight diffraction testing (TOFD)
	Thickness ≤12mm Longitudinal/butt joints	100% Radiographic Testing (RT)
	Thickness ≤12mm Circumferential butt joints	100% Phased array ultrasonic testing (PAUT) 100% Time-of-flight diffraction testing (TOFD)
	Weld surfaces (internal and external)	100% Magnetic Particle Testing (MT) and Liquid penetrant Testing (PT)

■ Non-Destructive Testing (NDT) Requirements----Cold molten salt tank

Inspection Point	Inspection Subject	NDT Method
Roof Plate Welds	Pressure ring butt joints	100% Radiographic Testing (RT) 100% Time-of-flight diffraction testing (TOFD)
	Weld surfaces (internal and external)	100% Magnetic particle testing (MT) / Liquid penetrant testing (PT)
	Surface of roof plate lap joints	100% Magnetic Particle Testing (MT) and Liquid penetrant Testing (PT)
Wall-to-roof/Wall-to-base Joints	Welded joints	100% Phased array ultrasonic testing (PAUT)
Tank Roof Steel Structure	Butt joint between channels	100% Radiographic testing (RT) or 100% Phased array ultrasonic testing (PAUT)
	Center ring butt joint	100% Time-of-flight diffraction testing (TOFD)
Tank Internals	Liner-to-bottom plate/Wall plate/Nozzle	100% Magnetic particle testing (MT) / Liquid penetrant testing (PT)

Cold molten salt tank: The presence of ferromagnetic materials and complex structural configurations necessitates flexible combinations of multiple NDT methods.

■ Non-Destructive Testing (NDT) Requirements----Hot molten salt tank

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Tank Bottom Welds	Edge Plate Butt Joint	100% Radiographic testing (RT) or 100% Phased array ultrasonic testing (PAUT)
	Other Butt Joints	100% Phased array ultrasonic testing (PAUT)
	Surface of bottom plate welds	100% Liquid penetrant Testing (PT)
Wall Plate Welds	Longitudinal/circumferential butt joints	100% Radiographic testing (RT) or 100% Phased array ultrasonic testing (PAUT)
	Weld surfaces (internal and external)	100% Liquid penetrant Testing (PT)
	Surface of roof plate lap joints	100% Liquid penetrant Testing (PT)
Roof Plate Welds	Pressure ring butt joints	100% Radiographic testing (RT) or 100% Phased array ultrasonic testing (PAUT)
	Outer surface of lap joints	100% Liquid penetrant testing (PT)
	Surface of roof plate lap joints	100% Liquid penetrant Testing (PT)

■ Non-Destructive Testing (NDT) Requirements----Hot molten salt tank

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	Center ring butt joint	100% Time-of-flight diffraction testing (TOFD)
Tank Internals	Liner-to-bottom plate/Wall plate/Nozzle	100% Liquid penetrant testing (PT)

Hot molten salt tank: Due to material properties (e.g., high-temperature corrosion-resistant alloys) and operational requirements, the inspection methodology is streamlined (excluding MT and TOFD), with full PT coverage mandated.

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谢谢 Thanks!

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