Drum Warm-Up: Through-Wall ΔT and Thermal Stress for a Heating Rate

Quasi-steady through-wall temperature difference and surface thermal stress of a thick drum or header wall heated at a constant rate, and the rate for an allowed ΔT.

Method: EN 12952-3 (start-up limits, for context; not applied); Quasi-steady heating of a plane wall at a constant rate; ...

Input parameters

Unit system: SI

Parameter	Value	Unit
Wall thickness	90.000	mm
Heating rate of the inner surface	100.00	°C/h
Steel thermal conductivity	45.000	W/(m·K)
Steel density	7,850.0	kg/m³
Steel specific heat	0.50000	kJ/(kg·K)
Young's modulus	200.00	GPa
Linear expansion coefficient	13.000	µm/(m·K)
Poisson's ratio	0.30000	
Allowed through-wall ΔT	40.000	K

Calculated results

Parameter	Value	Unit
Thermal diffusivity	11.465	mm²/s
Through-wall temperature difference	9.8125	K
Surface thermal stress (magnitude; compressive at the inner surface while heating)	24.298	MPa
Heating rate for the allowed ΔT	407.64	°C/h

Notes for this case

- Plane wall, outer face insulated, quasi-steady heating; drum curvature, the initial transient and stress concentration at nozzles (which usually govern start-up limits) are not included. Code start-up curves (EN 12952-3 and similar) govern design limits; this is an engineering estimate.

Formula and method

$$\alpha = \frac{k}{\rho c_p}, \quad \Delta T = \frac{\dot{T} s^2}{2\alpha}, \quad \sigma = \frac{E\beta}{1-\nu} \cdot \frac{2}{3} \Delta T, \quad \dot{T}_{allow} = \frac{2\alpha\, \Delta T_{allow}}{s^2}$$

Variables

s	Wall thickness	m
$\dot{T}$	Heating rate of the inner surface	K/s
k	Steel thermal conductivity	W/(m·K)
ρ	Steel density	kg/m³
c_p	Steel specific heat	J/(kg·K)
E	Young's modulus	Pa
β	Linear expansion coefficient	1/K
ν	Poisson's ratio	-

ΔT_{allow}	Allowed through-wall ΔT	K
α	Thermal diffusivity	m²/s
ΔT	Through-wall temperature difference	K
σ	Surface thermal stress	Pa
$\dot{T}_{allow}$	Heating rate for the allowed ΔT	K/s

Method and standards

One-dimensional heat conduction in a plane wall heated at a constant rate on the inside with the outside insulated: after the initial transient the temperature profile is a parabola that moves with the ramp (Carslaw and Jaeger). The surface stress follows from the difference between the mean and surface temperatures for a wall restrained against bending (Timoshenko). EN 12952-3 and similar codes set the actual start-up limits from pressure and thermal stress together with fatigue; they are not applied here.

Assumptions and limits

- Plane wall; constant properties. Drum curvature (thick cylinder) and the initial transient are neglected.
- Stress concentrations at nozzles and tube holes, which usually govern drum start-up limits, are not included.
- The stress is shown as a magnitude: during heating the inner surface is in compression, during cooling in tension.

References

• EN 12952-3 (start-up limits, for context; not applied)
• Quasi-steady heating of a plane wall at a constant rate
• ΔT = Ṫ s²/(2α) (Carslaw and Jaeger); surface stress E β (T_mean − T_s)/(1 − ν) with T_mean − T_s = 2ΔT/3 (Timoshenko)

Report details

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Results are for engineering estimation. Verify critical designs against the referenced standards and your own data.

This calculator online

https://calc.firecad.com/boilers-power-plant/boiler-pressure-parts/drum-warm-up-thermal-stress

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Reopens the calculator with the inputs of this report.