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Calcium looping with inherent energy storage for decarbonisation of coal-fired power plant

Evaluation of heat losses in the storage tanks

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Evaluation of the heat loss from the storage tank in Case 3

The rate and the amount of heat loss over time from the solid storage tank (Figure 1) can be defined as[1]:

$$\dot{Q}_{loss} = \dot{Q}_{foundation} + \dot{Q}_{wall} + \dot{Q}_{top} \quad (1)$$

$$\Delta Q_{loss} = \int_{t_0}^{t_f} \dot{Q}_{loss} dt \quad (2)$$

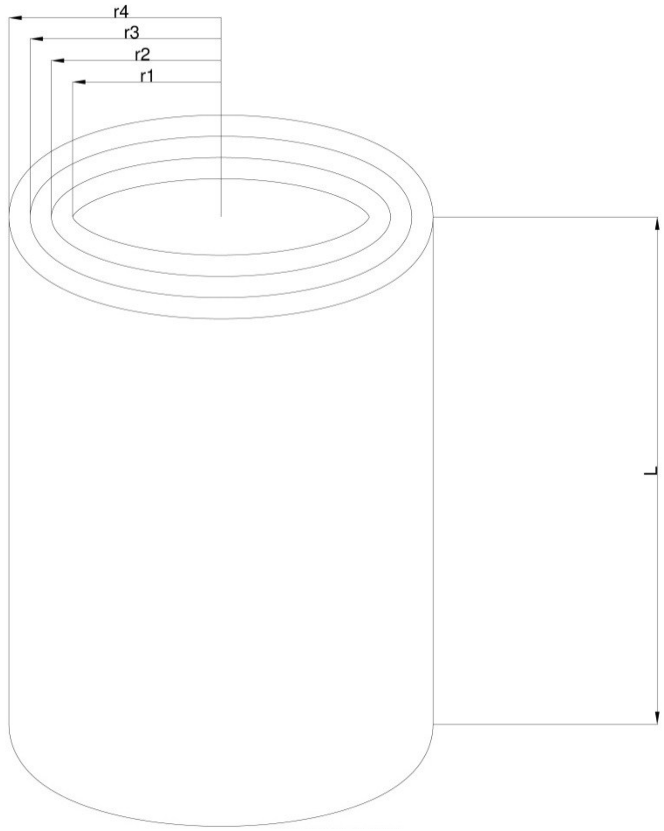

Figure 1: Drawing of insulated solid storage tank for heat loss calculation

It is expected that a particle self-insulation layer will develop near the walls of the storage tank and provide additional resistance to conductive heat loss. Hence, for the cylindrical tank lined with refractory insulation and surrounded with a concrete wall, the rate of heat transfer through the wall, top and foundation under steady state can be expressed using Eq. (3)-(5), respectively. The heat loss through the top of the tank will be due to conduction through the insulation consisting of refractory lining and cement, and due to convection to the environment. Alternatively, heat loss through the foundation will be a result of conduction only.

$$\dot{Q}_{wall} = \frac{T_{storage} - T_{ambient}}{\frac{ln\left(\frac{r_2}{r_1}\right)}{2\pi k_{p,eff}L} + \frac{ln\left(\frac{r_3}{r_2}\right)}{2\pi k_r L} + \frac{ln\left(\frac{r_4}{r_3}\right)}{2\pi k_c L} + \frac{1}{2\pi r_4 L h_{ambient}}} \tag{3}$$

$$\dot{Q}_{top} = \frac{T_{storage} - T_{ambient}}{\frac{t_c}{\pi r_2 k_r} + \frac{t_r}{\pi r_2 k_c} + \frac{1}{\pi r_2 h_{ambient}}} \tag{4}$$

$$\dot{Q}_{foundation} = \frac{T_{storage} - T_{ambient}}{\frac{t_c}{\pi r_2 k_r} + \frac{t_r}{\pi r_2 k_c}} \tag{5}$$

The effective thermal conductivity for the particles in the solid storage tank ($k_{p,eff}$) was obtained from the Okazaki et al.[2] model, which was found to reasonably represent the experimental data by Abou-Sena et al.[3].

Table 1: Parameters for heat loss calculation

Parameter	Unit	Value
Thermal conductivity of refractory-insulating lining, k_r[4]	W/mK	0.5
Thermal conductivity of cement wall, k_c[4]	W/mK	1.0
Thermal conductivity of sorbent, k_p[5]	W/mK	1.5
Convective heat transfer coefficient, h_{amb}[6]	W/K	2.0
Porosity, ε	-	0.5
Storage tank height, L	m	30
Radius of tank without insulation, r_1 ($CaO/CaCO_3$ tank)	m	13.1/14.2
Self-insulation layer thickness, t_p[4]	m	0.5
Refractory lining thickness, t_r	m	0.25
Cement wall thickness, t_c	m	1.0
Sensible heat stored, Q_{sens}($CaO/CaCO_3$ tank)	MW_{th}	190.4/165.6

Using the parameters from Table 1, it was estimated that the heat loss in the CaO and $CaCO_3$ tanks will be 0.7 and 1.3 MW_{th}, respectively. This accounts for 0.4% and 0.8% of the total sensible heat stored in these tanks, which is in line with the results obtained for thermal storage by Ma et al.[1]. In addition, sensitivity analyses on the thermal conductivities, convective heat transfer coefficient and insulation thicknesses have been performed and are presented in the following figures. These revealed that the heat loss is not higher than 1.5%, indicating that heat storage efficiency is more than 98.5%. As the analysis revealed that the heat loss will be very low and thus will not affect the performance of the system significantly, it can be assumed that there is no heat loss in the tanks at the concept development stage.

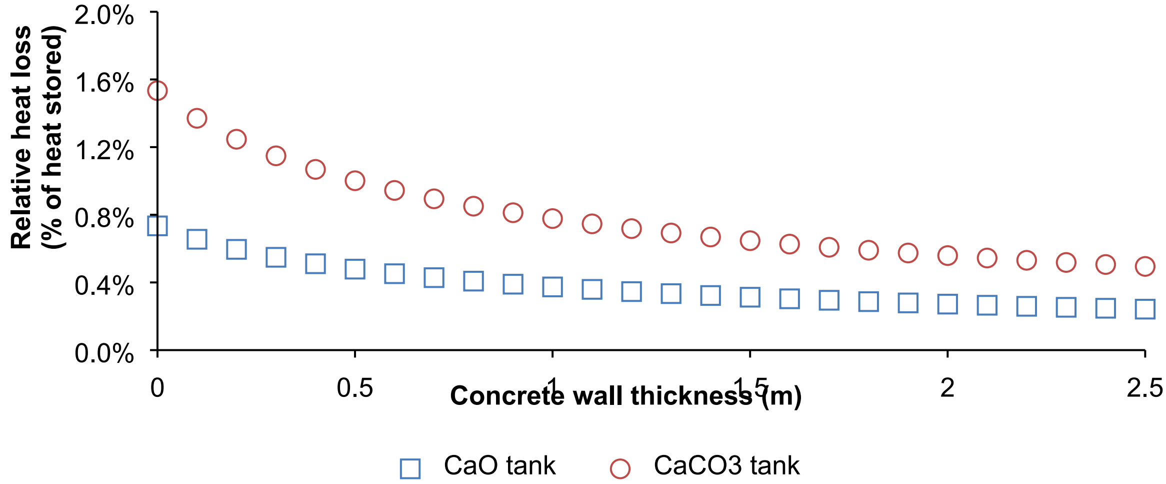

Figure 2: Effect of the concrete wall thickness on the relative heat loss in the solid storage tank

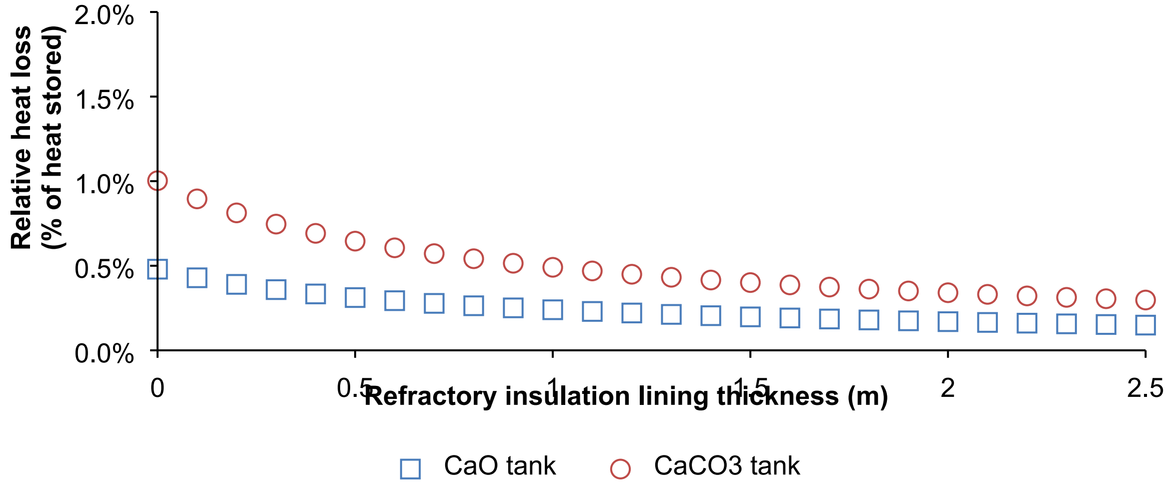

Figure 3: Effect of the refractory insulation lining thickness on the relative heat loss in the solid storage tank

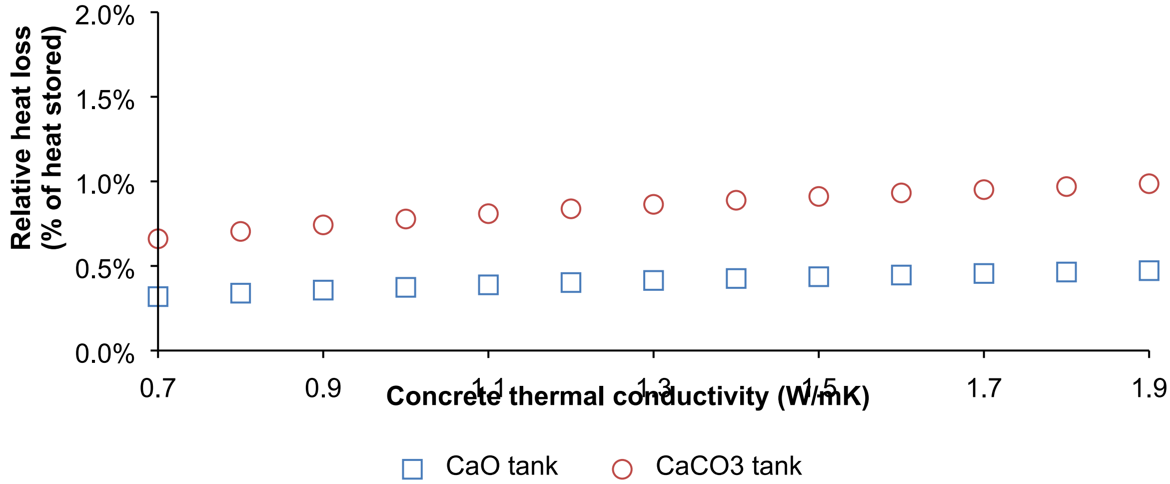

Figure 4: Effect of concrete thermal conductivity on the relative heat loss in the solid storage tank

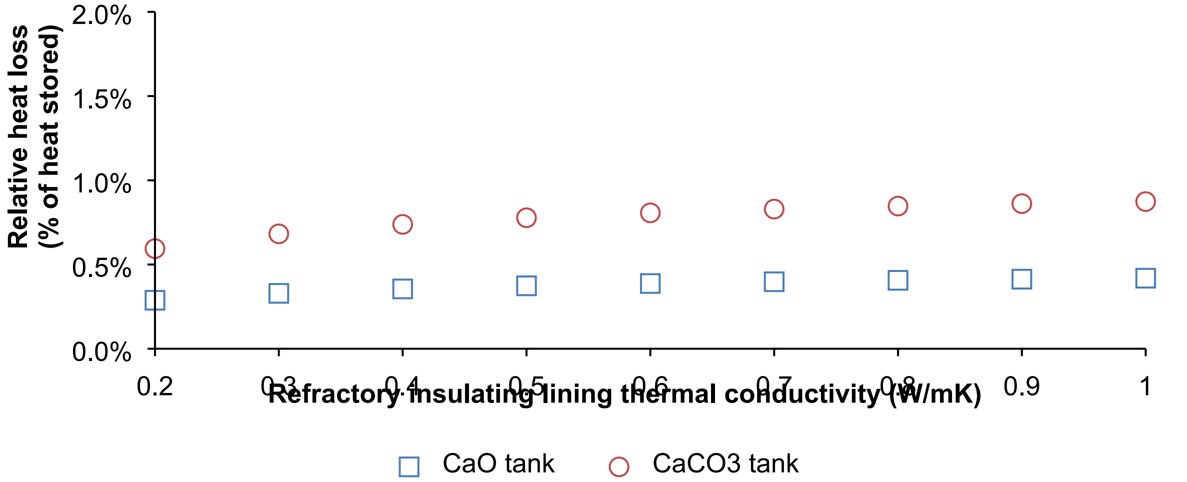

Figure 5: Effect of refractory insulating lining thermal conductivity on the relative heat loss in the solid storage tank

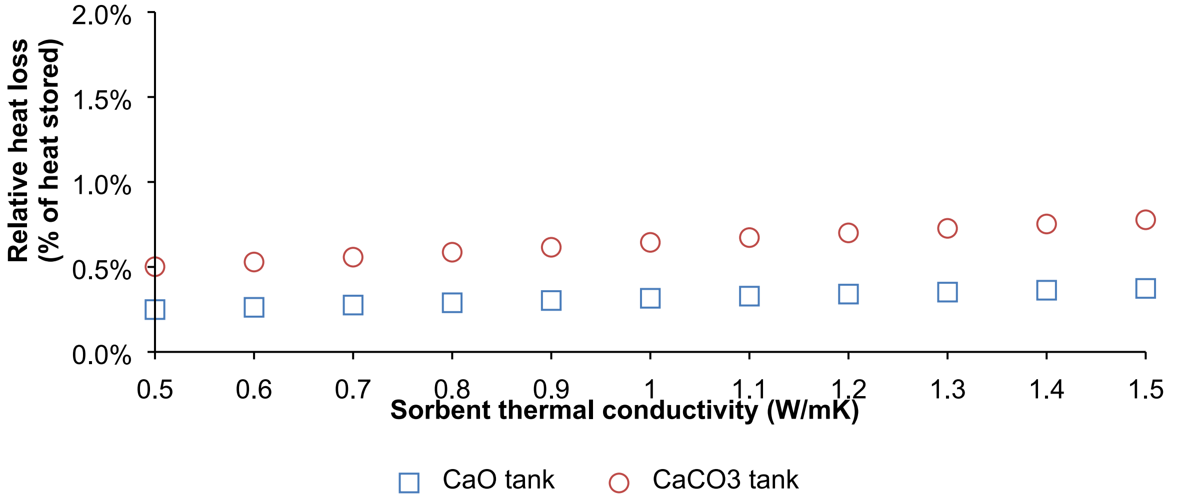

Figure 6: Effect of sorbent thermal conductivity on the relative heat loss in the solid storage tank

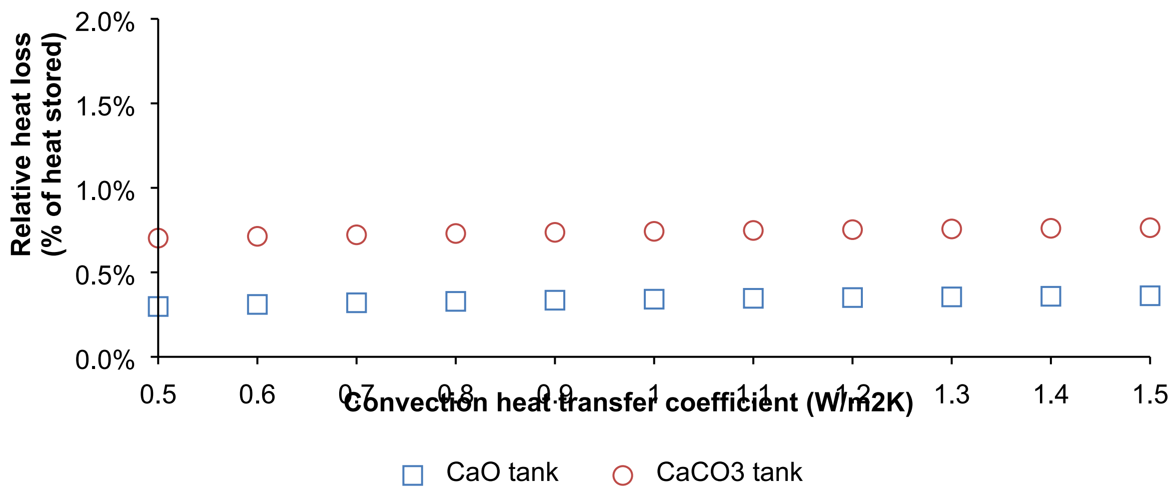

Figure 7: Effect of convection heat transfer coefficient on the relative heat loss in the solid storage tank

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