Module 4: Solution Heat confinement

Exercise 1

1. To assess whether the operation is thermally safe, the critical radius for the drum using Frank-Kamenetskii must be applied. Indeed, there is no forced convection in the drums. Furthermore, natural convection might not be possible.
   The heat release rate at 75°C is calculated from the reference heat release rate:

$$q' = q'_0 \exp\left(-\frac{E}{R}\left(\frac{1}{T}-\frac{1}{T_0}\right)\right)$$

$$q' = 10\exp\left(-\frac{80'000}{8.314}\left(\frac{1}{348}-\frac{1}{453}\right)\right) = 0.016 \text{ W/kg}$$

   The critical radius is

$$r_{crit} = \sqrt{\frac{\delta_{crit}\cdot\lambda\cdot RT_0^2}{\rho\cdot q'_0\cdot E}} = \sqrt{\frac{2.37\cdot 0.1\cdot 8.314\cdot 348^2}{1100\cdot 0.016\cdot 80'000}} = 0.406m$$

The critical radius is larger than the drum radius (0.3m). Therefore, the operation is safe.

2. At 90°C, the heat release rate is 0.052 W/kg and the critical radius 0.24m. At 90°C the operation is not safe.

Exercise 2

First the TMRad is evaluated at 40°C and 50°C.

$$q' = q'_0 \exp\left(-\frac{E}{R}\left(\frac{1}{T}-\frac{1}{T_0}\right)\right)$$

At 40°C

$$q' = 12\exp\left(-\frac{70'000}{8.314}\left(\frac{1}{313}-\frac{1}{413}\right)\right) = 0.018 \text{ W/kg}$$

$$TMR_{ad} = \frac{c_{p'}\cdot R\cdot T_0^2}{q'_{(T_0)}\cdot E} = \frac{1800\cdot 8.314\cdot (313)^2}{0.018\cdot 70'000} = 1.17\cdot 10^6 s = 13.6 \text{ days}$$

At 50°C

$$q' = 10\exp\left(-\frac{70'000}{8.314}\left(\frac{1}{323}-\frac{1}{413}\right)\right) = 0.041 \text{ W/kg}$$

$$TMR_{ad} = \frac{c_{p'}\cdot R\cdot T_0^2}{q'_{(T_0)}\cdot E} = \frac{1800\cdot 8.314\cdot (323)^2}{0.041\cdot 70'000} = 5.4\cdot 10^5 s = 6.3 \text{ days}$$

Based on the TMRad, storage is possible for 1 day at 40 and 50°C. For one week the TMRad at 40°C is long enough, however one usually takes a factor 4 between TMRad and storage time.

The critical radius is then calculated using Frank-Kamenetskii

At 40°C

$$r_{crit} = \sqrt{\frac{\delta_{crit} \cdot \lambda \cdot RT_0^2}{\rho \cdot q'_0 \cdot E}} = \sqrt{\frac{2.37 \cdot 0.1 \cdot 8.314 \cdot 348^2}{1000 \cdot 0.018 \cdot 70'000}} = 0.39m$$

At 50°C

$$r_{crit} = \sqrt{\frac{\delta_{crit} \cdot \lambda \cdot RT_0^2}{\rho \cdot q'_0 \cdot E}} = \sqrt{\frac{2.37 \cdot 0.1 \cdot 8.314 \cdot 323^2}{1000 \cdot 0.041 \cdot 70'000}} = 0.27m$$

Storage is thus possible for any length of time at 40°C (r<rcrit). At 50°C, this is not the case and thus only storage for 1 day is possible.