CHE312- Assignment

Group-18

Group Members
Aditya Singh Kaurav : 200055
Harjap Singh : 200405
Pradhyumna Lavania : 200692
Harshit Sinha : 200436
Pratibha Anand : 200713
Raghav Prakash Agarwal : 190659

Question

A copper cube of 1 m side is to be cooled from 120 °C to 50 °C using stagnant air at 25°C. Estimate the time required for this process, with and without approximating the cube as a sphere.

Solution

ASSUMPTIONS:

- Heat transfer due to radiations is negligible (as Copper has low emissivity).
- Density of Copper is taken to be constant as 8.96g/cm^3 during whole process.
- Temperature gradient inside the body are consider negligible (later, has been proved in IPYNB file)
- Heat capacity of Copper is considered at average temperature as 385J/kgC.
- While approximating as a sphere, we consider the same mass i.e. cube of copper and sphere of copper have same mass. So using **Mass-Volume-Densiy** relation, we get radius =0.62m. (same mass imply same volume, so **a^3 = (4/3)*pi*r^3** => r =0.62m)
- Integration is simplified by taking the areas of discrete intervals of 2.5 degrees.

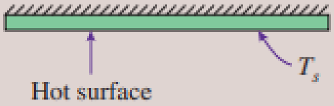
APPROACH:

Cube

- Cube is taken as made up of 4 vertical and 2 horizontal plates.
- Average Nusselt number's formula are used to calculate heat transfer coefficient at particular surface temperature.

$$\mathrm{Nu} = \left\{ 0.825 + \frac{0.387\,\mathrm{Ra}_L^{1/6}}{[1 + (0.492/\mathrm{Pr})^{9/16}]^{8/27}} \right\}^2$$

(complex but more accurate)

		10^4–10^7	(a) $Nu = 0.54 Ra_L^{1/4}$
(b) Lower surface of a hot plate (or upper surface of a cold plate) 		10^5–10^{11}	(b) $Nu = 0.27 Ra_L^{1/4}$

- We calculate Rayleigh number using characteristic length scale, which comes out to be less than 1e+7, so suitable formulas are used.
- Then, we use the discrete approach: at very temperature change of 2.5 degree C, we evaluate ‘h’. In this way, we obtain nearly 30 values .
- During the estimation of each ‘h’, we find the values of v,Pr,aplha and K at average of surface and surrounding temperature(**EXCEL FILE** is attached)
- We get a list of **‘h’** values.
- then we use numerical method approach to solve the following equation : **$-mC_pdT = hA_s(T-T_{infinity})dt$**

$$\left(\begin{array}{c}\text{Heat transfer into the body}\\ \text{during } dt\end{array}\right) = \left(\begin{array}{c}\text{The increase in}\\ \text{the of the body}\\ \text{energy during } dt\end{array}\right)$$

or

$$hA_s(T_\infty - T)\,dt = mc_p\,dT$$

NUMERICAL METHOD APPROACH:

$$mC_p\frac{dT}{dt} = -h_{conv}A_s(T - T_\infty)$$
$$\frac{dT}{dt} = -\frac{h_{conv}A_s}{mC_p}(T - T_\infty)$$
$$dt = -\frac{mC_p}{h_{conv}A_s(T - T_\infty)}dT$$
$$\Delta t = -\frac{mC_p}{h_{conv}A_s(T - T_\infty)}\Delta T$$
$$\Sigma\Delta t = \sum_{T=120^oC}^{T=50^oC} -\frac{mC_p}{h_{conv}A_s(T - T_\infty)}\Delta T$$

$h_{conv}\ is\ discretely\ calculated\ for\ different\ intervals\ of\ 2.5^oC.$

- After solving this we get t= **1074224** sec ~ 298 Hrs

INTEGRATION APPROACH:

More better results are obtained by applying polynomial fit to the h_{conv} data and then using Scipy library to evaluate integral.

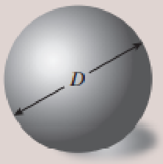
Fitted Curve Equation:-

$$h_{conv} = (1.437065 + 0.05147343T - 0.0001968346T^2)$$

Then integrating the equation we get the total time for cube as:
1115605 s ~ 308 Hrs

Sphere

- Again we follow the same approach, but now we calculate the ‘h’ at each of discrete temperature using the given formula:

Sphere 	D	$Ra_D \leq 10^{11}$ $(Pr \geq 0.7)$	$Nu = 2 + \dfrac{0.589\, Ra_D^{1/4}}{[1 + (0.469/Pr)^{9/16}]^{4/9}}$

- Again we apply numrical method approach to calculate the time:
  Which we get as **t= 1769687 sec ~ 491 Hrs.**

IPYNB file is attached containing all calculations, values and plots.

Values Obtained

Time to go from 120°C to 50°C in cube:
t_{cube}= **298 Hrs**
Time to go from 120°C to 50°C in sphere:
t_{sphere}= **491 Hrs**
Average convective Heat Transfer Coefficient (Cube):
H_{conv} = 4.33 (W/m^2K)
Average convective Heat Transfer Coefficient (Sphere):
H_{conv} = 0.54 (W/m^2K)

Biot Number comes out to be less than 0.1 in both cases (explicity, shown in IPYNB file)

Conclusions:

-We found that for the same mass of copper, but the different shape we get different time for the transient process to take place. In the case of the sphere (radius =0.62m), we get time = 1074224 sec(~298 hours) while in the case of cube we get time = 1769687 sec.(~ 491 hours) .One of the possible reason for it can be that there is less surface area ($4*pi*r^2$ ~ **$4.82m^2$**) in case of sphere while there is ($6a^2$~ **$6m^2$**) in case of cube. So large surface area will help in fastening the heat transfer process.