CLASS TEST

S.No. : 02SPME_ABCDEFG_1311

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HEAT TRANSFER

MECHANICAL ENGINEERING

Date of Test : 13/11/2024

ANSWER KEY

1.	(b)	7.	(a)	13.	(c)	19.	(a)	25.	(b)
2.	(c)	8.	(b)	14.	(a)	20.	(c)	26.	(b)
3.	(d)	9.	(b)	15.	(a)	21.	(d)	27.	(b)
4.	(b)	10.	(c)	16.	(a)	22.	(b)	28.	(c)
5.	(a)	11.	(d)	17.	(a)	23.	(c)	29.	(c)
6.	(a)	12.	(b)	18.	(b)	24.	(b)	30.	(a)

DETAILED EXPLANATIONS

1. (b)

$$\frac{dT}{d\tau} = u\frac{dT}{dx} + v\frac{\partial T}{dy} + w\frac{\partial T}{dz}$$
$$= 2y^2 \times 5y^2 + 3x \times 10xy + 0.0$$
$$\frac{dT}{d\tau} = 10y^4 + 30x^2y$$
$$= 10(2)^4 + 30(1)^2 \times 2 = 220 \text{ units}$$

2. (c)

$$C_h (T_{h_i} - T_{h_e}) = C_c (T_{c_e} - T_{c_i})$$
$$\Rightarrow \quad C_h (20) = C_c (80)$$
$$\frac{C_{\min}}{C_{\max}} = \frac{C_c}{C_h} = \frac{20}{80} = 0.25 = \text{Capacity ratio}$$

3. (d)

$\frac{Gr}{\text{Re}^2}$ signifies the type of convection

$$\frac{Gr}{\text{Re}^2} << 1, \text{ forced convection}$$
$$\frac{Gr}{\text{Re}^2} >> 1, \text{ free convection}$$
$$\frac{Gr}{\text{Re}^2} \simeq 1, \text{ mixed convection}$$

4. (b)

The R value is, $\frac{L}{k} = \frac{0.15}{0.04} = 3.75 \text{ (m}^2\text{ K/W)}$

5. (a)

For oils Prandtl number (Pr) >> 1 and $\delta_t << \delta$.

6. (a)

For counterflow operation, the minimum exit temperatures of oil would be when effectiveness equal to 1.

$$\varepsilon = \frac{C_h(T_{h_1} - T_{h_2})}{C_{\min}(T_{h_1} - T_{c_1})} = 1$$
$$C_h = C_{\min}$$
$$\frac{165 - T_{h_2}}{165 - 30} = 1$$
$$T_{h_2} = 30°\text{C}$$

7. (a)

The total irradiation can be obtained by

$$G = \int_0^\infty G_\lambda d\lambda$$

$$= \text{Area under the curve}$$

$$= \frac{1}{2} \times 2000 \times 10 + 2000 \times 30 + \frac{1}{2} \times 2000 \times 10$$

$$G = 80000 \text{ W/m}^2$$

8. (b)

$$q'' = h(T_w - T_\infty) = -K\left(\frac{dT}{dy}\right)_{y=0}$$

$$\frac{-dT}{dy} = (T_w - T_\infty)\left[\frac{a_1}{L} + 2a_2 \frac{y}{L^2}\right]$$

$$\left(\frac{dT}{dy}\right)_{y=0} = -(T_w - T_\infty)\frac{a_1}{L}$$

$$\Rightarrow \quad h(T_w - T_\infty) = K\frac{a_1}{L}(T_w - T_\infty)$$

$$\frac{hL}{K} = a_1$$

$$Nu = \frac{hL}{K} = a_1$$

9. (b)

We know that,

$$Q = hA_s(T_5 - T_0) \quad \text{...(1)}$$

$$A_s = 5 \times 0.4 \times 0.4 = 0.8 \text{ cm}^2$$

$$Q = \frac{4.8}{24} = 0.2 \text{ W}$$

From eqn. (1), $0.2 = 18 \times 0.8 \times 10^{-4} \times (T_s - 30)$

$$T = 168.88°\text{C} \simeq 169°\text{C}$$

10. (c)

$$\text{NTU} = \frac{UA}{C_{min}} = \frac{1800 \times 15}{3 \times 4.18 \times 10^3} = 2.153$$

For steam condenser,

$$\varepsilon = 1 - \exp(-\text{NTU})$$

$$= 1 - \exp(-2.153)$$

$$\varepsilon = 0.88$$

11. (d)

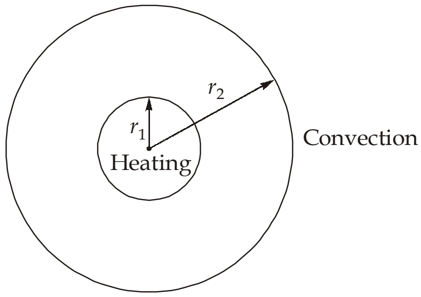
$q = 10^5 \text{ W/m}^2$, $r_1 = 0.04$ m, $r_2 = 0.06$ m,

$k = 20 \text{ W/mK}$

for sphere, $R_{th} = \left[\dfrac{r_2 - r_1}{4\pi r_1 r_2 k}\right]$

$$R_{th} = \frac{0.06 - 0.04}{4\pi \times 0.06 \times 0.04 \times 20} = 0.0332 \text{ K/W}$$

$\therefore$ $Q = \dfrac{\Delta T}{R_{th}}$



$$Q = 4\pi r_1^2 \times q = \frac{T_i - T_0}{0.0332}$$

$$4\pi \times 0.04^2 \times 10^5 \times 0.0332 = T_i - T_0$$

$$T_i = 266.75°\text{C}$$

or $T_i = 539.75$ K

12. (b)

Given

$U_0 = 3000$ W/m²K

$d_i = 2.5$ cm, $d_0 = 3$ cm, $k = 50$ W/mK

$h_0 = 31000$ W/m²K

$\nu = 0.365 \times 10^{-6}$ m²/s

$k = 700 \times 10^{-3}$ W/mK

$Pr = 2.2$

$$\frac{1}{A_0 U_0} = \frac{1}{A_i h_i} + \frac{1}{A_o h_o} + \frac{\ln(r_2/r_1)}{2\pi k L}$$

for unit length, $l = 1$ m

$A_i = \pi d_i = \pi \times 0.025$

$A_0 = \pi d_0 = \pi \times 0.03$

$$\frac{1}{\pi \times 0.03 \times 3000} = \frac{1}{\pi \times 0.025 \times h_i} + \frac{1}{\pi \times 0.03 \times 31000} + \frac{\ln(3/2.5)}{2\pi \times 50 \times 1}$$

$h_i = 4870$ W/m²K $\Rightarrow$ 4.87 kW/m²K

13. (c)

$T_1 = 1000$ K, $T_2 = 600$ K

$$\left(\frac{q_{12}}{A}\right) = \frac{\sigma\left(T_1^4 - T_2^4\right)}{\left(\frac{2}{\varepsilon} - 1\right)(n+1)}$$ with similar shields

Now $$\left(\frac{q_{12}}{A}\right)_5 = \frac{\sigma\left(T_1^4 - T_2^4\right)}{\left(\frac{2}{\varepsilon} - 1\right)(5+1)}$$

when 5 more shields are applied

$$\left(\frac{q_{12}}{A}\right)_{10} = \frac{\sigma\left(T_1^4 - T_2^4\right)}{\left(\frac{2}{\varepsilon} - 1\right)(10+1)}$$

$$\frac{\left(\frac{q_{12}}{A}\right)_{10}}{\left(\frac{q_{12}}{A}\right)_{5}} = \frac{1/11}{1/6} = \frac{6}{11}$$

% reduction,

$$\left[1 - \frac{(q_{12}/A)_{10}}{(q_{12}/A)_{5}}\right] \times 100 = \left[1 - \frac{6}{11}\right] \times 100 = 45.45\%$$

14. (a)

Given: d_0 = 30 cm, L = 170 cm, h = 8 W/m^{2}K, k = 7 W/mK

$$s = \frac{\pi r_0^2 L}{2\pi r_0 L + 2\pi r_0^2}$$

$$s = \frac{\pi \times 0.15^2 \times 1.7}{2\pi \times 0.15 \times 1.7 + 2\pi \times 0.15^2}$$

$$s = 0.0689 \text{ m}$$

$$Bi = \frac{hs}{k} = \frac{8 \times 0.0689}{7} = 0.0787$$

lumped analysis is valid,

$$\frac{ht}{\rho sc} = \ln\left[\frac{37-20}{26-20}\right]$$

$$t = \frac{1.0414 \times 1000 \times 0.0689 \times 4180}{8} = 37492 \text{ second}$$

or t = 10.41 hours = 10 hours 25 minutes before

i.e. died at 12 : 00 – (10 : 25 – 6 : 00) PM = 7 : 35 pm yesterday

15. (a)

Statement 1 is correct but statement 2 is incorrect, it depends on matter which type of phenomenon is taking place.

Volumetric phenomenon = gas, semi transparent solids

Surface phenomenon = solids and liquids

16. (a)

Given: d = 30 mm, L = 700 mm,

T_∞ = 25°C, T_0 = 600°C

h = 20 W/m^{2}K, k = 132.3 W/mK

$$m = \sqrt{\frac{hP}{kA}} = \sqrt{\frac{4h}{kd}} \quad \text{(for cylinder)}$$

$$m = \sqrt{\frac{4\times 20}{132.3\times 0.03}} = 4.49$$

Steady state rate of heat lost,

$$q = \sqrt{hPkA} \times \theta_0 \times \tanh(\text{mL})$$

$$\sqrt{hPkA} = \sqrt{20\times(\pi\times 0.03)\times 132.3\times(\pi\times 0.25\times 0.03^2)} = 0.4199$$

$$\tanh(mL) = \tanh(4.49 \times 0.7) = 0.9963$$

$$\dot{q} = 0.4199 \times 0.9963 \times (600 - 25)$$

$$\dot{q} = 240.57 \text{ W}$$

$$\text{Heat lost in one minute} = \dot{q}\,.t = 240.57 \times 60 \times 10^{-3} \text{ kJ} = 14.43 \text{ kJ}$$

17. (a)

$$D = 20 \text{ mm}, \rho = 978 \text{ kg/m}^3, \mu = 4 \times 10^{-4} \text{ kg/m-s}, \text{Pr} = 2.54,$$

$$\text{Re} = \frac{\rho VD}{\mu} = \frac{978\times 2\times 0.02}{4\times 10^{-4}} \Rightarrow \text{Re} = 97800$$

$\therefore$ Re > 2300 flow is turbulent

Using Dittus Boltier equation,

$$\text{Nu} = 0.023(\text{Re})^{0.8}(\text{Pr})^{0.4}$$

$$\frac{h_i d}{k} = 0.023(97800)^{0.8}(2.54)^{0.4}$$

$$h_i = 328.04\times\frac{0.332}{0.02} = 5445.5 \text{ W/m}^2\text{K}$$

$$\frac{1}{U} = \frac{1}{h_i}+\frac{1}{h_0} = \frac{1}{5445.5}+\frac{1}{10000}$$

$$U = 3525.6 \text{ W/m}^2\text{K}$$

18. (b)

$$F_{12} = 0.12$$

$$F_{12} + F_{11} + F_{13} = 1$$

$$F_{13} = 1 - F_{12} = 1 - 0.12 = 0.88$$

$$A_3F_{31} = A_1F_{13}$$

$$F_{31} = \frac{\pi}{4}\times\frac{d^2}{\pi\times d\times h}\times 0.88$$

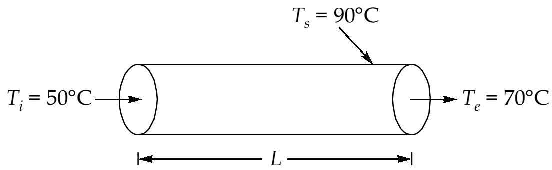
$$F_{31} = \frac{d}{4\times h}\times 0.88 = 0.165$$

$$q_{3\text{-surrounding}} = 2 \times F_{31} \times A_3 \times \sigma(T_3^4 - T_0^4)$$

$$= 2 \times 0.165 \times \pi \times 0.075 \times 0.1 \times 5.67 \times 10^{-8} \times (700^4 - 310^4)$$

$$= 102 \text{ W}$$

19. (a)



We know that for constant temperature wall :

$$\frac{T_e - T_s}{T_i - T_s} = e^{\frac{-hPL}{\dot{m}C_P}}$$

$$\dot{m} = \rho \times A \times V = \rho \times \frac{\pi}{4} \times d^2 \times V$$

$$= 1000 \times \frac{\pi}{4} \times (0.02)^2 \times 1.2 = 0.377 \text{ kg/s}$$

$$\frac{70-90}{50-90} = e^{-\frac{6.5\times10^3 \times \pi \times 0.02 \times L}{0.377 \times 4.2 \times 10^3}} = e^{-0.258L}$$

$$0.69314 = 0.258L$$

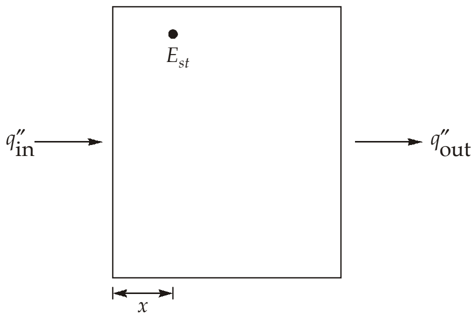
$$L = 2.686 = 2.7 \text{ m}$$

20. (c)

$$T_{(x)} = a + bx + cx^2$$

By Fourier law,

$$q''_x = -k\frac{\partial T}{\partial x}$$



So,
$$q''_{in} = -k\frac{\partial T}{\partial x}\bigg|_{x=0}$$

$$= -k(b + 2cx)\big|_{x=0} = -1(-200 + 2 \times 30 \times 0)$$

$$q''_{in} = 200 \text{ W/m}^2$$

$$q''_{out} = -k(b + 2cx)\big|_{x=0.3} = -1(-200 + 2 \times 30 \times 0.3)$$

$$= 182 \text{ W/m}^2$$

Applying on energy balance to control volume about the wall

$$E''_{in} - E''_{out} = E''_{st}$$

$$E''_{st} = 200 - 182 = 18 \text{ W/m}^2$$

21. (d)

The center temperature of the wire (cylinder) is given by

$$T_o = T_s + \frac{\dot{e}_{gen} r_0^2}{4k}$$

Given :

$$T_s = 110°C$$

$$\dot{e}_{gen} = \frac{2.5 \times 10^3}{\pi \times r^2 \times l} = \frac{2.5 \times 10^3}{\pi \times (3 \times 10^{-3})^2 \times 1}$$

$$\dot{e}_{gen} = 88.419 \times 10^6 \text{ W/m}^3$$

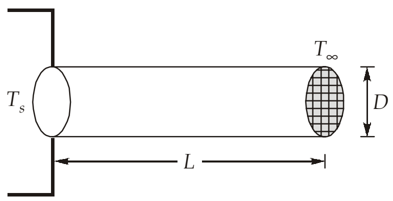
$$k = 21 \text{ W/m°C}$$

So,

$$T_o = 110 + \frac{88.419 \times 10^6 \times (3 \times 10^{-3})^2}{4 \times 21}$$

$$T_o = 119.473°C$$

22. (b)



Fin effectiveness,

$$\varepsilon_f = \frac{\text{Heat transfer rate with fin}}{\text{Heat transfer rate without fin}}$$

$$\varepsilon_f = \frac{Q_f}{hA\theta_o}$$

$$Q_f = \sqrt{hPkA}\,(\tan hml)\theta_o$$

$$m = \sqrt{\frac{hP}{kA}} = \sqrt{\frac{12 \times \pi \times 4 \times 10^{-2} \times 4}{237 \times \pi \times (4 \times 10^{-2})^2}} = 2.25 \text{ m}^{-1}$$

$$Q_f = \sqrt{12 \times \pi \times 4 \times 10^{-2} \times 237 \times \frac{\pi}{4} \times (4 \times 10^{-2})^2}\,(\tan h(2.25 \times 0.1))\theta_o$$

$$Q_f = 0.6701 \times 0.2212 = 0.1482\theta_o$$

$$\varepsilon_f = \frac{0.1482\,\theta_o}{12 \times \frac{\pi}{4} \times (4 \times 10^{-2})^2 \times \theta_o} = 9.83$$

23. (c)

Given,

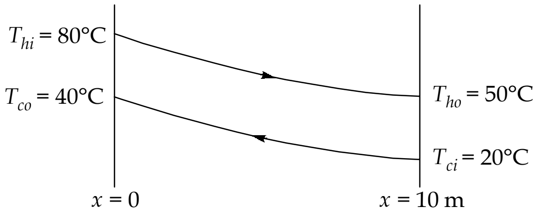
$$T_s = 30°C$$
$$T_\infty = 25°C$$
$$A = 1.5 \text{ m}^2$$
$$h = 7 \text{ W/m}^2\text{ K}$$
$$\varepsilon = 0.9$$

$$\dot{Q}_{convection} = h \times A\,(T_s - T_\infty)$$
$$= 7 \times 1.5\,[30 - 25] = 52.5 \text{ W}$$

$$\dot{Q}_{radiation} = \varepsilon \times \sigma \times A\,(T_s^4 - T_\infty^4)$$
$$= 0.9 \times 5.67 \times 10^{-8} \times 1.5 \times [303^4 - 298^4] = 41.54 \text{ W}$$
$$\dot{Q}_{total} = 52.5 + 41.54 = 94.04 \text{ W}$$

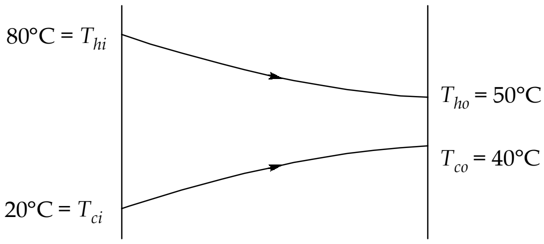
24. (b)

Assume counter,



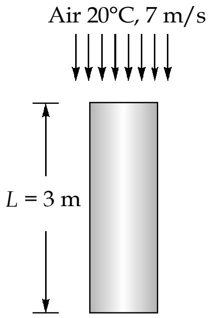
$$\Delta T_1 = 80°C - 40°C = 40°C$$
$$\Delta T_2 = 50°C - 20°C = 30°C$$
$$\text{LMTD} = \frac{\Delta T_1 - \Delta T_2}{\ln\left(\frac{\Delta T_1}{\Delta T_2}\right)} = \frac{40°C - 30°C}{\ln\left(\frac{40}{30}\right)} = 34.7°C$$

Assume parallel,



$$\Delta T_1 = 80°C - 20°C = 60°C$$
$$\Delta T_2 = 50°C - 40°C = 10°C$$
$$(\text{LMTD})_{\text{parallel HE}} = \frac{\Delta T_1 - \Delta T_2}{\ln\left(\frac{\Delta T_1}{\Delta T_2}\right)} = \frac{60°C - 10°C}{\ln\left(\frac{60}{10}\right)} = 27.9°C$$

25. (b)



The flow is along 3 m side of the plate, and thus the characteristic length is L = 3 m. Both sides are exposed to air flow,

$$A = 2 \times w \times L$$
$$= 2 \times 2 \times 3 = 12 \text{ m}^2$$

For flat plates, drag force is equivalent to friction force.

$$F_f = C_f A_s \frac{\rho V^2}{2}$$

$$C_f = \frac{F_f}{\frac{1}{2}\rho A_s V^2} = \frac{0.86}{1.204 \times 12 \times \frac{1}{2} \times (7)^2} = 0.00243$$

From Reynolds Analogy,

$$St \times (\Pr)^{2/3} = \frac{C_f}{2} = \frac{0.00243}{2}$$

$$St = \frac{h}{\rho V c_p}$$

$$h = 0.00149 \times 1.204 \times 7 \times 1007$$

$$= 12.64 \text{ W/m}^2\text{K}$$

26. **(b)**

Since fluid properties will be same at same temperature so Prandtl number will be same

$$Nu \propto (\text{Re})^m$$

$$\frac{Nu_2}{Nu_1} = \frac{(VL_C)_2^m}{(VL_C)_1^m} = \left(\frac{V_2 L_{C_2}}{V_1 L_{C_1}}\right)^m$$

$$= \left(\frac{25}{50} \times \frac{12}{6}\right)^m = 1$$

$$Nu_2 = Nu_1$$

$$\frac{h_1 L_{C_1}}{K} = \frac{h_2 L_{C_2}}{K}$$

$$\Rightarrow \quad h_2 = \frac{h_1 L_{C_1}}{L_{C_2}} = \frac{120 \times 6}{12} = 60 \text{ W/m}^2\,°\text{C}$$

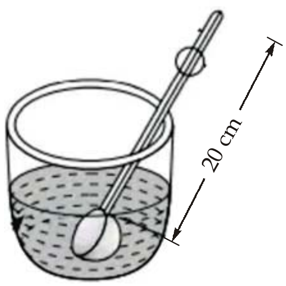
Heat flux from the second airfoil

$$= h_2 (T - T_\infty)$$

$$= 60 \times (80 - 15)$$

$$= 3900 \text{ W/m}^2$$

27. **(b)**



Given : $h = 16$, $k = 15$, $P = 2 \times (0.25 + 1.25) = 3$ cm

$$A = 0.25 \times 1.25 \text{ cm}^2$$

$$m = \sqrt{\frac{hP}{kA}} = \sqrt{\frac{16}{15}\times\frac{3\times100}{0.25\times1.25}} = 32$$

$$mL = 32 \times 0.20 = 6.4$$

$$mL > 5 \text{(So can assume infinitely long fin)}$$

$$\frac{T_L - T_\infty}{T_0 - T_\infty} = e^{-mL}$$

$$\frac{T_L - 25}{70} = e^{-6.4}$$

$$\Rightarrow \quad T_L = 25 + 70\, e^{-6.4}$$

Temperature difference across the exposed surface

$$T_0 - T_L = 95 - (25 + 70\, e^{-6.4})$$
$$= 70(1 - e^{-6.4})$$

28. (c)

$$Q = -kA\left(\frac{dT}{dx}\right)_{x=0}$$

$$\frac{dT}{dx} = 10x - 4$$

$$\left(\frac{dT}{dx}\right)_{x=0} = -4$$

$$Q = -0.15 \times 3 \times (-4) = 1.8 \text{ W}$$

29. (c)

$$\dot{m}_h = \frac{1000}{3600} = 0.277 \text{ kg/s}$$

Hot fluid, $T_{hi} = 70°C$

$T_{ho} = 40°C$

$c_{ph} = 2$ kJ/kgK

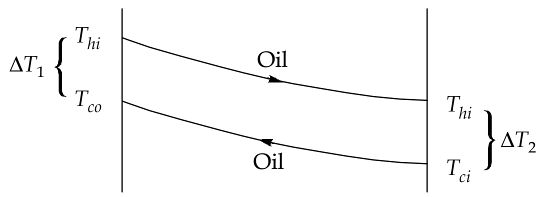
Cold fluid, $T_{ci} = 25°C$

$T_{co} = 40°C$

$c_{pc} = 4.2$ kJ/kgK

$U = 0.2$ kW/m^{2}K

Counter flow temperature profile



$$\Delta T_1 = 70°C - 40°C = 30°C$$
$$\Delta T_2 = 40°C - 25°C = 15°C$$

$$\text{LMTD} = \frac{\Delta T_1 - \Delta T_2}{\ln\left(\frac{\Delta T_1}{\Delta T_2}\right)} = \frac{30°\text{C} - 15°\text{C}}{\ln\left(\frac{30°\text{C}}{15°\text{C}}\right)}$$

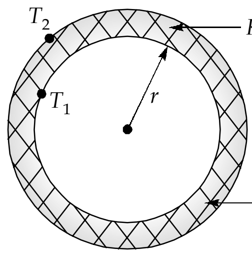
$$\text{LMTD} = 21.64°\text{C}$$

$$\text{Heat transfer} = \dot{m}_h c_{ph}(T_{hi} - T_{ho}) = U.A(\text{LMTD})$$

$$10^3 \times 0.277 \times 2 \times (70 - 40) = 0.2 \times 1000 \times A \times 21.64$$

$$A = 3.84 \text{ m}^2$$

30. (a)



$$\text{Heat conducted} = \text{Heat convected}$$

$$\frac{T_1 - T_2}{\frac{\ln\left(\frac{r_2}{r_1}\right)}{2\pi KL}} = h \times 2\pi r_2 \times L \times (T_2 - T_\infty)$$

$$r_1 = 1 \text{ m}, r_2 = 1.1 \text{ m}$$

$$\Rightarrow \frac{(200 - T_2) \times 2\pi \times 0.05 \times L}{\ln(1.1/1)} = h \times \pi \times 2.2 \times L \times (T_2 - 20)$$

$$\Rightarrow \frac{(200 - T_2)}{\ln(1.1/1)} \times 0.1 = h \times 2.2 \times (T_2 - 20)$$

$$\Rightarrow 200 - T_2 = 2.097 \times 10 \times (T_2 - 20)$$

$$\Rightarrow 200 - T_2 = 20.97 \times (T_2 - 20)$$

$$\Rightarrow 200 - T_2 = 20.97 T_2 - 419.4$$

$$\Rightarrow T_2 = 28.19°\text{C}$$

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