ME 405 Fall 2006 Professor John M. Cimbala Lecture 11 09/29/2006

Today, we will:

- Continue our discussion of **Thermal Comfort and Heat Stress** in **Section 3.5**
- Do some example problems
- Discuss **Odors** in **Section 3.6**
- Finish the rest of Chapter 3
- Do Candy Questions for Candy Friday

Continuation from last time – Thermodynamics of the human body:

First law of thermo becomes $\boxed{\dot{M} + \dot{Q} = 0}$, where $\dot{M}$ is the body's metabolic rate, which includes any work (exercise or activity) being done by the body, and $\dot{Q}$ is the net rate of heat transfer to the body. Note: Since $\dot{M}$ is always positive, $\dot{Q}$ must always be negative.

Various ways to gain or lose heat from the body:

- Conduction $\dot{Q}_{\text{cond}}$: can be + or -, but usually is negligible
- Convection $\dot{Q}_{\text{conv}}$: can be + or -, but usually negative unless outside air > 98.6°F
- Radiation $\dot{Q}_{\text{rad}}$: can be + or -, depending on temperature of walls, etc.
- Respiration $\dot{Q}_{\cancel{\text{cond}}\ \text{res}}$: can be + or -, but usually negative unless outside air > 98.6°F
- ~~Conduction~~ Evaporation $\dot{Q}_{\cancel{\text{cond}}\ \text{evap}}$: always negative (can't gain heat by sweating)

(+) into body

Sum must be (−)

First law becomes

$$\dot{M} + \underbrace{\cancel{\dot{Q}_{cond}}}_{\text{ignore}} + \underbrace{\dot{Q}_{conv} + \dot{Q}_{res} + \dot{Q}_{rad}} + \dot{Q}_{evap} = 0$$

hardest to calculate

See eqs for these $\dot{Q}$ terms (empirical or semi-empirical eqs)

See Eqs 3.40, 41, 43

required

Solve for $\dot{Q}_{evap}$ & call it $\dot{Q}_{evap,req}$.

$$\boxed{\dot{Q}_{evap,\,req.} = -\dot{M} - \dot{Q}_{conv} - \dot{Q}_{res} - \dot{Q}_{rad}} \qquad 3.44$$

We will calculate $\underline{\underline{\dot{Q}_{evap,\,max}}}$ ← Maximum possible under given conditions

Define

$$\boxed{HSI = \underline{\underline{\text{Heat Stress Index}}} \equiv \frac{\dot{Q}_{evap,\,req.}}{\dot{Q}_{evap.,\,max}} \times 100\%} \; ☆$$

See Table 3.8 for the consequences of HSI

☆ THESE ARE FOR 8-hr WORK DAYS

Table 3.8 Heat stress index (adapted from ASHRAE, 1997).

HSI (%)	**consequence of 8-hr exposure**
< 0	Indicates varying degrees of stress due to hypothermia.
0	No thermal strain.
10-30	Mild to moderate heat stress. Manual dexterity and mental alertness may suffer but there is little impairment to perform heavy work.
40-60	Severe heat stress. Health may be threatened unless physically fit. This condition should be avoided by people with cardiovascular or respiratory impairment or chronic dermatitis.
70-90	☆ Very severe heat stress. Only specially selected people are capable of sustaining these conditions for 8 hrs. Special care must be taken to replace water and salt.
100	Maximum heat stress. Only acclimated, physically fit young people can withstand this for 8-hrs.
>100	Indicates varying degrees of stress due to hyperthermia.

Example

Given: Pete is playing basketball out in the sun on a hot day:

- T_a = 86°F = 30°C (ambient air temperature, also dry bulb air temperature)
- Φ_a = 60% (relative humidity of ambient air)
- T_G = 120°F = 48.89°C (globe temperature due to radiation)
- U_a = 4.0 m/s (average ambient air velocity)
- A_s = 1.8 m^2 (skin surface area)
- K = 0.75 (fraction of exposed skin)

To do: Calculate Pete's heat stress index. Is it dangerous for Pete to play basketball under these conditions?

HSI

Solution:

Table 3.6 → basketball → $\dot{M} = 565 \text{ kcal/hr} = 9.417 \frac{\text{kcal}}{\text{min}}$

Table A-17 → @ $T_a = 30°C$, $P_{v_{H_2O}} = 4.246$ kPa

@ $T_s = 35°C$, $P_{v_{H_2O}} = 5.628$ kPa

Radiation:

Eq 3.42

$$T_w = \left[T_G^4 + \left(0.248 \times 10^9\, U_a^{0.5}\right)\left(T_G - T_a\right)\right]^{0.25}$$

use K not °C!

$$T_w = 376.64 \text{ K}$$

Eq 3.43

$$\dot{Q}_{rad} = 0.0728\, A_s\, K\left(T_w - T_s\right) = 6.732 \frac{\text{kcal}}{\text{min}}$$

Convection:

Eq. 3-40

$$\dot{Q}_{conv} = K A_s\left(0.0325 + 0.1066\, U_a^{0.67}\right)\left(T_a - T_s\right)$$

$$= -2.041 \text{ kcal/min}$$

Respiration:

Eq. 3.41

$$\dot{Q}_{res} = \sim\sim = -0.594 \frac{\text{kcal}}{\text{min}}$$

$\dot{Q}_{evap,max}$ = max possible heat transfer due to sweating

Eq 3-46 $\rightarrow$ $\dot{Q}_{evap,max} = \underline{-14.788 \ kcal/min}$

Eq. 3-44 $\rightarrow$ Required $\dot{Q}_{evap,req} = \underline{-\dot{M} - \dot{Q}_{conv} - \dot{Q}_{res} - \dot{Q}_{rad}}$

$= \underline{-13.514 \ kcal/min}$

$$HSI = \frac{\dot{Q}_{evap,req.}}{\dot{Q}_{evap,max}} \times 100\% = \boxed{91.4\% = HSI}$$

Pete can play basketball, but drink lots of water

Sec. 3.6 <u>ODORS</u> <u>OSHA does not regulate odors</u>

- Two odor thresholds published:
  - <u>Detection threshold</u> – you smell something, but cannot describe it
  - <u>Recognition "</u> – you smell it & can describe it

See Table 3.9 (detection thresholds) & TABLE 3.10 – compare to PEL

✱ Just because you smell something does not mean it is harmful
If you can't smell anything, it doesn't mean that it is not harmful

✱ Odor thresholds are not necessarily related to health effects.

Table 3.10 Comparison of odor recognition threshold and OSHA PEL for various chemicals (maximum value of odor threshold to two significant digits, abstracted from Appendix A.20).

material	**odor recognition threshold (PPM)**	**PEL (PPM)**
n-butyl acetate	20.	150
n-butyl mercaptan	9.0×10^{-4}	<< 10
carbon monoxide	no odor	50
ethylene oxide	780	>> 1
hydrogen cyanide	4.5	~ 10
methyl alcohol	20,000	>> 200
methyl bromide	1,000	>> 5
methyl formate	2,800	> 100
methyl methacrylate	0.34	< 100
methylene chloride	620	> 25
nickel carbonyl	30.	0.001
triethylamine	0.27	25
xylidene	0.0049	<< 5

Sec. 3.7 Radiation

Sec. 3.8 General Safety

Sec. 3.9 Engr. Economics

Browse

Next week – Start Chap. 4