Fire Dynamics
Units

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Objectives

- Knowing fundamental units in fire engineering
- Understanding the concept of non-dimensional numbers

Units (SI)

- Fire dynamics in SI units !!!
  - Almost all equations in SI units
- Conversion of English units to SI units
  - Length: 1 inch =<u>0.0254</u> m
  - Mass: 1 lbm =<u>0.4536</u> kg
  - Energy: 1 BTU = 1.0551 kJ
  - Vol: 1 gal = 3.785 L

Units (SI)

- $N = kg \cdot m/s^2$
- $J = N \cdot m$
- $W = J/s$
- $L = (0.1\ m)\ (0.1\ m)\ (0.1\ m) = 0.001\ m^3$
- Kg = 1000 g, kW = 1000 W
- 1 kW -> _____ (kg, m, and s)

Units (SI)

- Conservation units
  - Mass [kg], Momentum [kg-m/s], Energy [J = N-m]
- For mass: $\underline{\mathbf{m} = \boldsymbol{\rho V}}$ [kg]
- For momentum: $\underline{\mathbf{F} = \mathbf{ma}}$ [N = kg-m/s^2]
  - This is force, not momentum!
- For Energy: $\underline{\mathbf{Q} = \mathbf{cmT}}$ [J, or kJ]
  - Unit of “c” ?

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One more thing to remember

- Ideal gas law: **PV = nRT**

$$PV = nRT = \frac{m}{MW} RT$$

$$\Rightarrow P = \frac{m}{V(MW)} RT = \frac{\rho}{MW} RT = \rho \frac{R}{MW} T = \rho R' T$$

where,

P = pressure [Pa], V = gas volume [m^3], n = number of moles [mole],

m = mass [g], MW = molecular weight [g/mole],

R = universal gas constant [=8.314 J/mole-K],

R' = specific gas constant [J/g-K], T = gas tempeature [K]

Notation

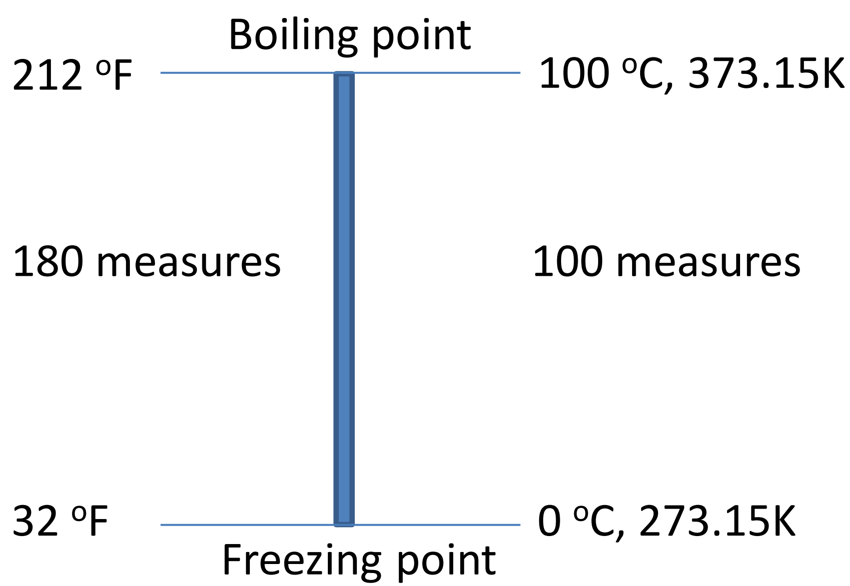
- **Rate of change of energy** (Q),
  - $\dot{Q}\ [\frac{J}{s}] = W$
- Per unit length ($\dot{\mathrm{Q}}'\,[\frac{J}{s}\frac{1}{m} = \frac{W}{m}]$)
- **Per unit area ($\dot{\mathbf{Q}}''$)**
- Per unit volume ($\dot{\mathrm{Q}}'''$)
  - Units of $\dot{\mathrm{Q}}''$ and $\dot{\mathrm{Q}}'''$ $=$?

Common terms in Fire Dynamics

- **Temperature [^oC, K]**
- **Heat release rate [kW]**
- **Heat flux [kW/m^2]**
- Heat of combustion, vaporization, … [kJ/g]
- Heat transfer coefficient [kW/m^2-k]
- Thermal conductivity [kW/m-k]
- Specific heat [J/kg-k]

Temperature

- Fahrenheit [^oF], Celsius [^oC], and [K]



$$[^\circ F] = \frac{180}{100}[^\circ C] + 32 = \frac{9}{5}[^\circ C] + 32$$

$$[^\circ C] = \frac{100}{180}\left([^\circ F] - 32\right) = \frac{5}{9}\left([^\circ F] - 32\right)$$

$$[K] = [^\circ C] + 273.15$$

Temperature

- Thermocouples
  - Various types (J, K, T, E, N, S, R and B)
  - In fire tests, type K is mostly used.
  - Type K
    - Chromel for + (yellow) and alumel for – (red)
    - -270 ^{o}C to 1260 ^{o}C

Figures from https://www.thermoworks.com/PRB-K-440 and https://www.coleparmer.com/i/digi-sense-traceable-workhorse-thermocouple-thermometer-with-calibration/9121045

Heat release rate

- Heat release rate [kW=kJ/s]
  - https://www.youtube.com/watch?v=Ld3xbFwno0Q

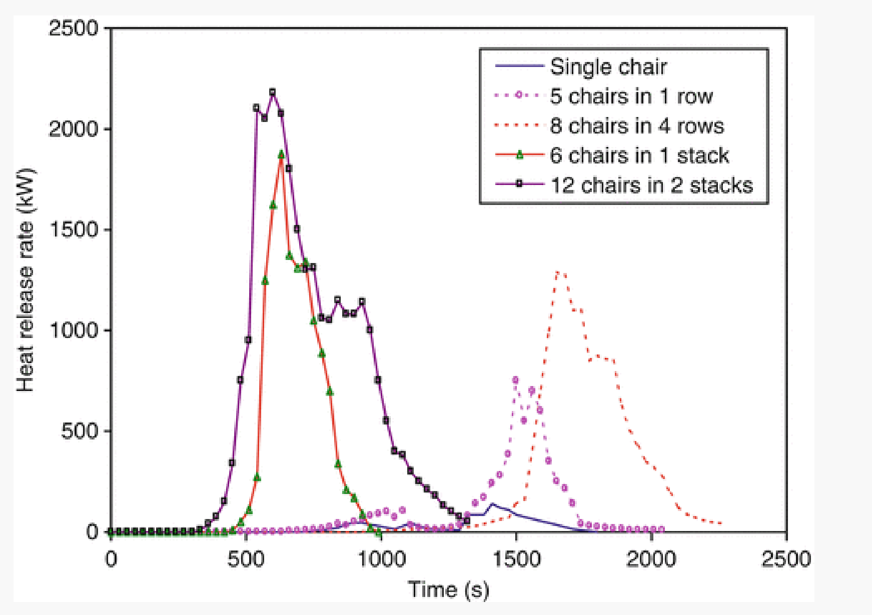
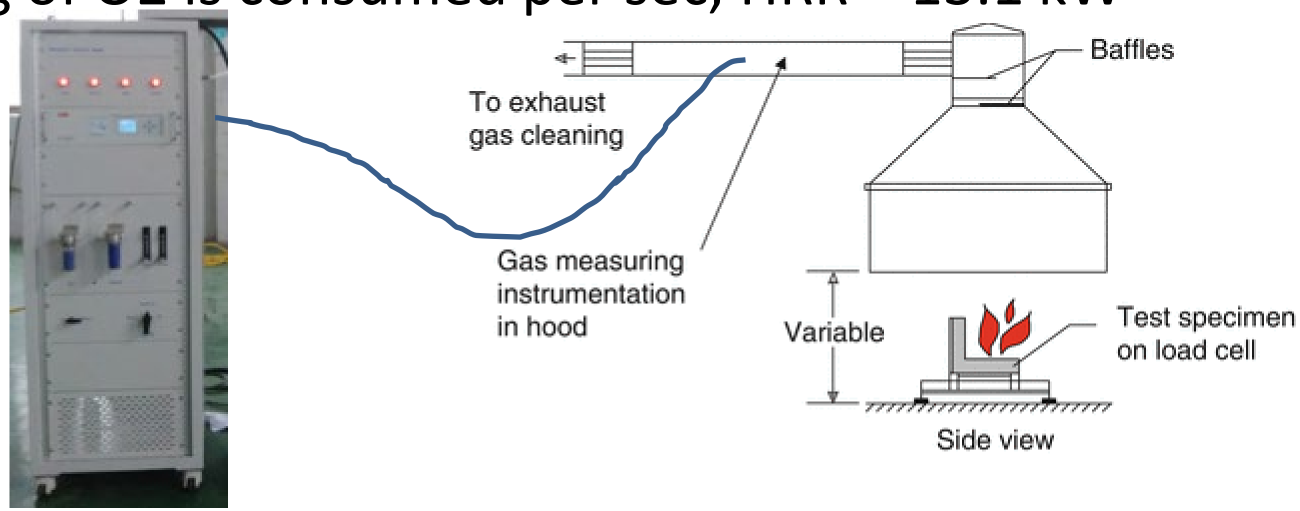


Figure from https://link.springer.com/chapter/10.1007/978-1-4939-2565-0_26

Heat release rate

- Heat release rate [kW]
  - Oxygen consumption calorimeter [13.1 kJ/g of O_2]
    - If 1 g of O2 is consumed per sec, HRR = 13.1 kW



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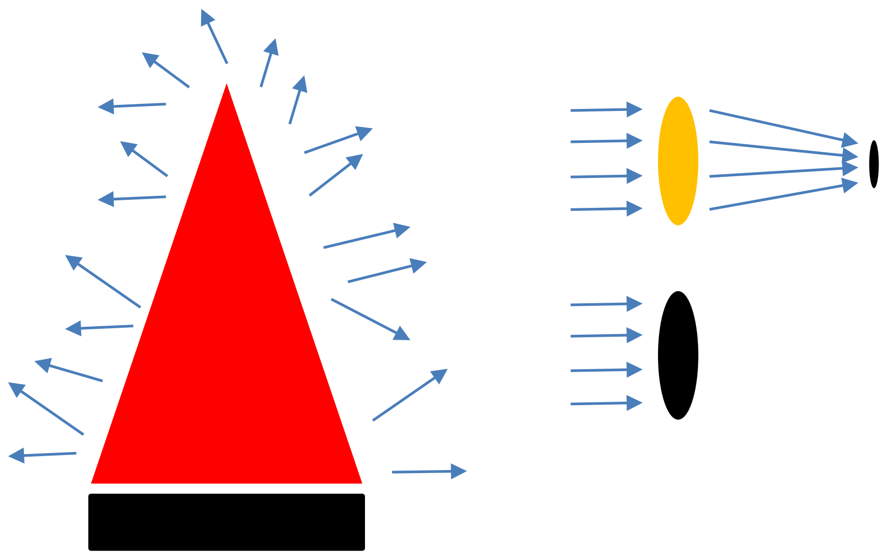
Heat flux

- Heat flux [kW/m^2]
  - https://www.youtube.com/watch?v=Kfxj50rI8BU



$$\dot{q}''_{target\_2} = \frac{0.4kW}{0.02m^2} = 20\ \mathrm{kW/m^2}$$

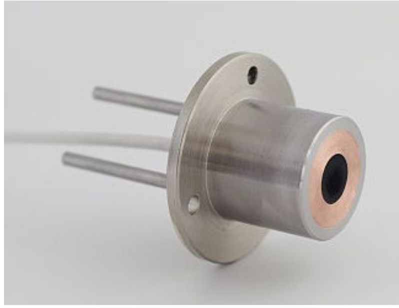
A_{target_2} = 0.02 m^2

$$\dot{q}''_{target\_1} = \frac{0.4kW}{0.1m^2} = 4\ \mathrm{kW/m^2}$$

A_{target_1} = 0.1 m^2

Heat flux

- Heat flux [kW/m^2]
  - Water-cooled heat flux gauge



  - Plate thermometer

Unit conversion

- 36 km/hour to cm/s?

- 3412 BTU/hr to kW?