CH365 Chemical Engineering Thermodynamics

Lesson 2
Fundamentals 2

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Work

When a force acts over a distance, work is force times displacement:

force is F and displacement is dl

Eq. 1.2 $$dW = F\,dl$$

positive (+) if F and dl are in the same direction
negative (-) if F and dl are in the opposite direction

Change in volume of a fluid in a cylinder ("frictionless" piston):

F is performing work on the gas in the piston

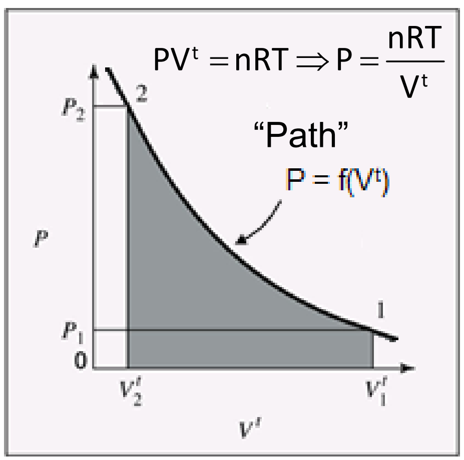


Figure 1.3, page 11

$$dW = \overbrace{PA}^{\text{force}}\, d\overbrace{\left(\frac{V^t}{A}\right)}^{\text{Length, l (height)}}$$ Eq. 1.3

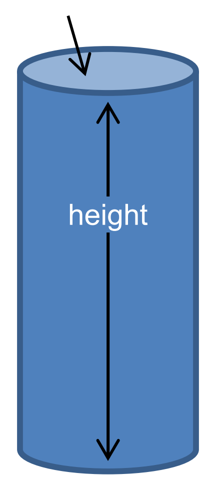
force = pressure · area = P·A

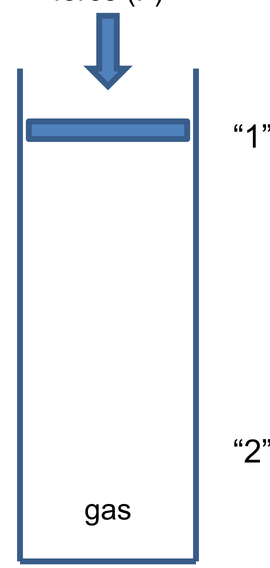
length = total volume · area = V^t / A

Area is a constant for a cylindrical piston (it cancels out)

$$dW = -PdV^t$$ Eq. 1.3

$$W = -\int_{V_1^t}^{V_2^t} PdV^t$$ Eq. 1.4





volume = area · height

height = volume ÷ area

Units of work:

Newton-meter (SI) and foot-pound-force (English Engineering)

Energy and Work Overview

$$dW = F\,dl = ma\,dl$$ Eq. 1.2

$$dW = m\frac{du}{dt}dl = m\frac{dl}{dt}du = m\,u\,du$$

u = velocity

$$a \equiv \frac{du}{dt}$$

$$u \equiv \frac{dl}{dt}$$

$$W = m\int_{u_1}^{u_2} u\,du = m\left(\frac{u_2^2}{2} - \frac{u_1^2}{2}\right)$$

work done on a body to accelerate it

$$W = \Delta E_K = \Delta\left(\frac{mu^2}{2}\right)$$ Eq. 1.5

$$E_K = \frac{mu^2}{2}$$ Eq. 1.6

Lord Kelvin, 1856

$$dW = F\,dl = mg\,dz$$ Eq. 1.2

work done on a body to elevate it

$$W = \Delta E_P = mg\Delta z$$ Eq. 1.7

$$E_P = mzg$$ Eq. 1.8

units are (kg m^2 s^{-2}) or (ft lb_f)

(kg m^2 s^{-2}) is (N m)

Conservation: $\Delta E_K + \Delta E_P = 0$

$$\frac{mu_2^2}{2} - \frac{mu_1^2}{2} + mz_2 g - mz_1 g = 0$$

Heat

"Flows" from region of higher T to region of lower T

Temperature difference is the "driving force" for the flow of energy as heat

$$I = \tfrac{1}{R} V$$

Ohm's Law

$$Q_x = -k\,a\,\frac{dT}{dx}$$

Fourier's First Law
CH485, p.16

$$Q = U\,a(T_1 - T_2)$$

Rate of Heat Transfer
CH485, p.16

The driving force analogy comes from physics:

- voltage difference drives current flow in an electrical circuit
- gravitational potential drives free fall of an object
- pressure difference drives fluid flow in a horizontal pipe
- concentration difference drives molecular diffusion

<u>Heat exists only in transit</u> between the system and its surroundings.

Stored as E_p and E_k of atoms and molecules in the system

1 calorie raises the temperature of 1 gram of water 1 deg C

1 Btu raises the temperature of 1 lb_m of water 1 deg F

$$1\,J = 1\,Nm \quad \Rightarrow \quad 1\,cal = 4.1840\,J \qquad 1\,Btu = 1055.04\,J$$

Lesson 2 Problems

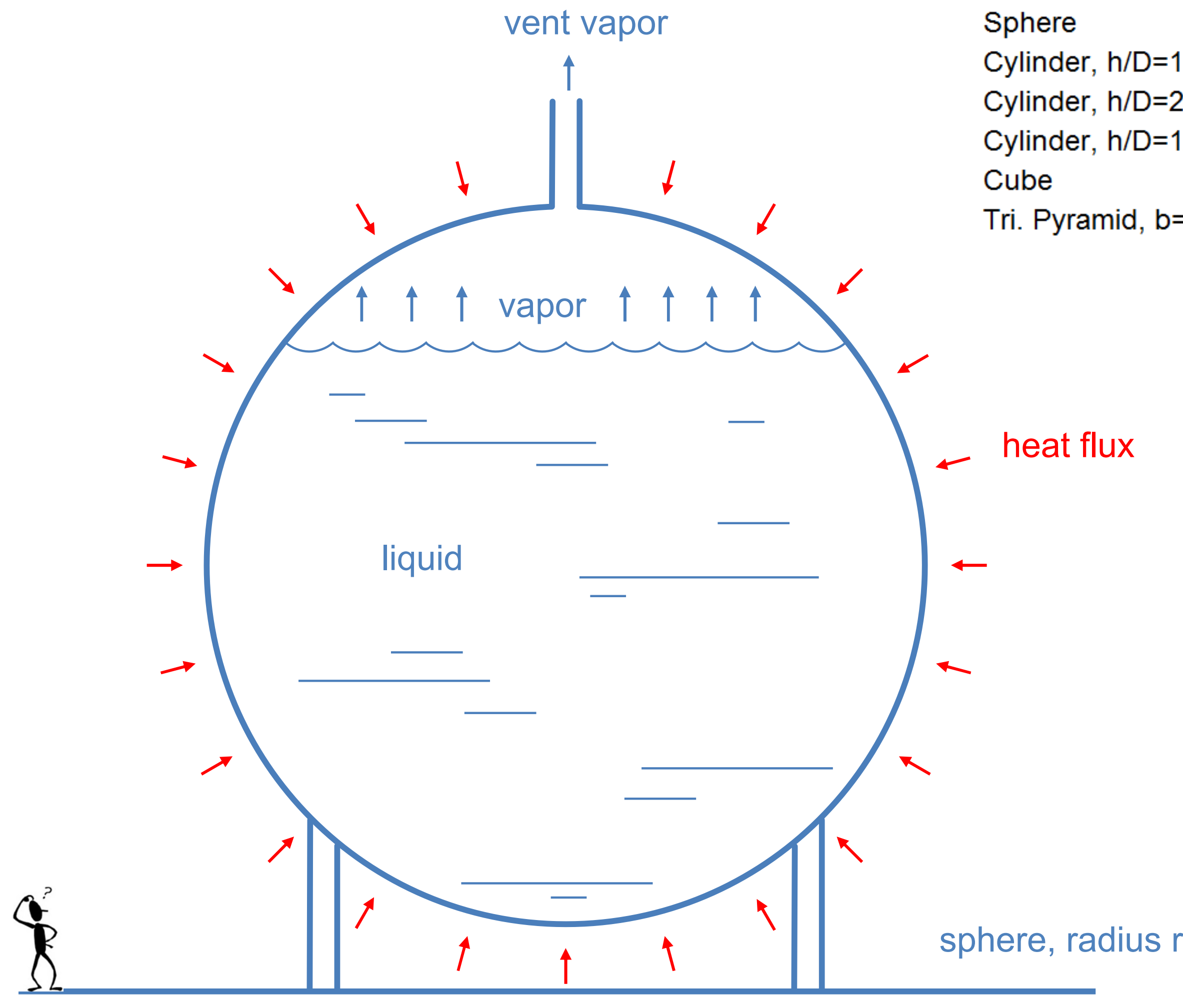
Problem 1.11

Liquids that boil at relatively low temperatures are often stored as liquids under their vapor pressures, which at ambient temperature can be quite large. Thus, n-butane stored as a liquid/vapor system is at a pressure of 2.581 bar for a temperature of 300 K. Large-scale storage (>50m^3) of this kind is sometimes done in spherical tanks. Suggest two reasons why.

Illustration for Problem 1.11 for Spherical, Cylindrical, and Cubical Tank

Results (m^2 per 50 m^3):

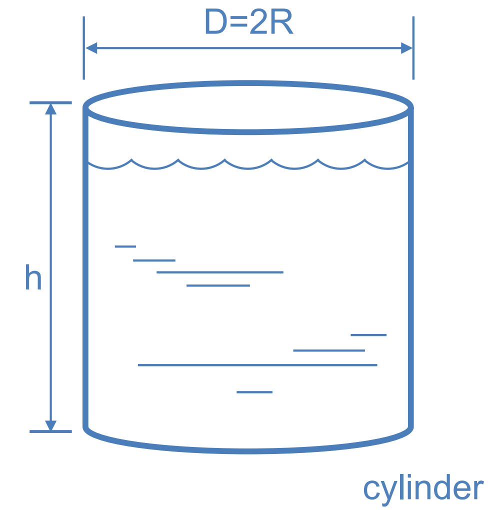
Sphere	65.6348
Cylinder, h/D=1	75.1346
Cylinder, h/D=2	78.8840
Cylinder, h/D=1/2	79.5104
Cube	81.4325
Tri. Pyramid, b=h	89.6128

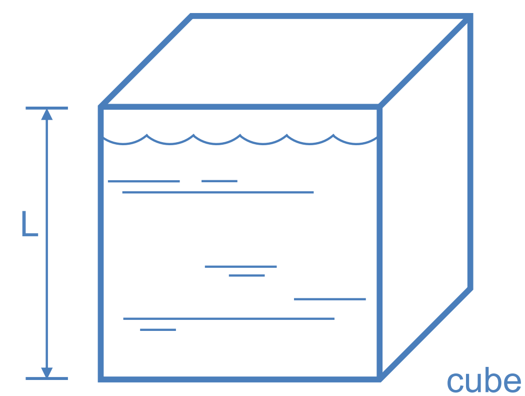


Heat flux is proportional to temperature difference,
Rate of heat transfer, CH485, RRW, Table 1.5 p.16

$$\frac{Q}{a} = U\left(T_{outside} - T_{inside}\right) \Rightarrow Q = Ua\left(T_{outside} - T_{inside}\right)$$

$$flux = \frac{Q}{a} = \frac{flow}{area} = \frac{J/s}{m^2}$$





If each vessel has a max capacity of 50 m^3 of liquid, what is the area of each vessel?

$$50m^3 = \frac{4}{3}\pi r^3 = \underset{(h=D)}{2\pi R^3} = L^3$$

Once r, R, and L are known, area for each shape can be calculated.

Problem 1.12

The first accurate measurements of the properties of high-pressure gases were made by E.H. Amagat in France between 1869 and 1893. Before developing the dead-weight gauge, he worked in a mine shaft, and used a mercury manometer for measurements of pressure to more than 400 bar. Estimate the height of the manometer required.

Émile Hilaire Amagat (2 January 1841 – 15 February 1915) was a French physicist, famous for his work on isotherms and pressure measurement. Amagat's Law, named in his honor, states that the volume of an ideal gas mixture is equal to the sum of the component volumes of each individual component in the gas mixture at the same temperature and total pressure of the mixture

Problem 1.18

A gas is confined in a 1.25-ft-diameter cylinder by a piston, on which rests a weight. The mass of the piston and weight together is 250lb_m. The local acceleration of gravity is 32.169 (ft/s^2),and the atmospheric pressure is 30.12 inches of Hg.

(a) What is the force in lb_f exerted on the gas by the atmosphere, the piston, and the weight, assuming no friction between the piston and the cylinder?

(b) What is the pressure of the gas in psia?

(c) If the gas in the cylinder is heated, it expands, pushing the piston and weight upward. If the piston and weight are raised 1.7 ft, what is the work done by the gas in ft*lb_f? What is the change in potential energy of the piston and the weight?