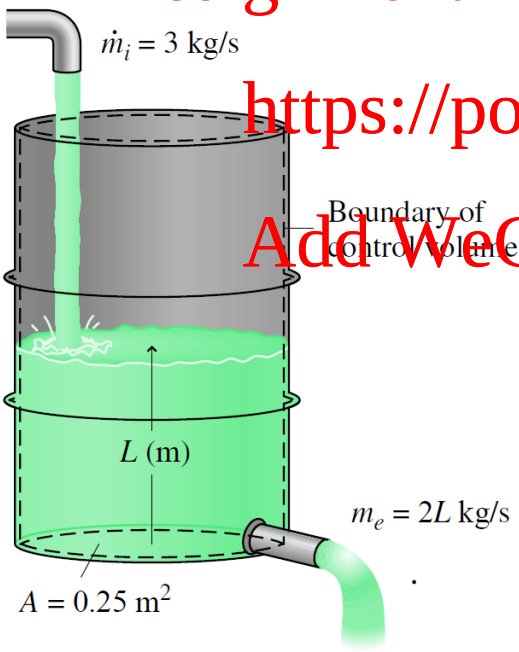
Workshop R2: Material & Energy Balancing

LEARNING OUTCOMES

- Use a material balance on a tank of water to model the time take to reach steady state
- Write balanced equations for the combustion of carbonaceous fuels, and calculate the heating value and CO_2 emissions for complete reaction
- Compare different fuel resources to meet the energy requirement of heating a tank of water

ACTIVITY 1: Material Balancing with Excel (45 minutes)

Water flows into the top of an open tank at a constant mass flow rate of 3 kg/s. Water exits through a pipe near the base with a mass flow rate proportional to L is the instantaneous liquid height, in m. The area of the base is 0.25 m^2, and the density of water is 1000 kg/m^3. If the barrel is initially empty, plot the variation of liquid height with time. Use your plot to find the time taken to reach steady state.



For the control volume (tank), the **material balance** can be written as:

$$\frac{dm_{cv}}{dt} = \dot{m}_i - \dot{m}_e$$

The mass of the water in the tank is a function of time t, and can be written as:

$$m_{cv} = \rho \times V = \rho \times AL$$

Or more accurately as, as L varies with time t:

$$m_{cv}(t) = \rho \times AL(t)$$

Therefore, the material balance above can be re-written as:

$$\frac{d(\rho AL)}{dt} = 3 - 2L$$

(a) What are the variables in this equation, and what are the constants?

(b) The solution of this differential equation yields:

$$L = 1.5 + C.exp\,(-\frac{2t}{\rho A})$$

Using the boundary condition that initially, the tank is empty, find the value of the constant C.

(c) Plot the liquid height L vs time t using an Excel spreadsheet, and use this plot to find how long it took to reach steady state, and the height of liquid in the tank at steady state.

Copy and paste your Excel graph here:

Height of liquid at steady state = _____

Time taken to reach steady state = _____

(d) What is the meaning of “steady state”? Referring to the material balance on page 1, confirm your result obtained graphically in part (c).

ACTIVITY 2: What does an Equation Say? (10 minutes)

Methane, hydrogen and coal are common fuels used to provide energy. Write balanced equations for the complete combustion of each of the fuels below, stating your assumptions:

Methane CH_4:

Hydrogen H_2:

Ethanol C_2H_5OH:

ACTIVITY 3: “Which Fuel is Best?” (30 minutes)

(a) Assuming your tank of water in Activity 1 has reached a steady level, and the water flow rate in and out of the tank has stopped, use the specific heat capacity of water Cp to calculate the energy (kJ) required to heat up the volume of water in the tank from 25°C to 55°C. Cp for water is 4.184 kJ/kg.K.

Assumption (s):

Mass of water (kg) =

Energy required (kJ) =

(b) Using the Table of heating values below, calculate how many kg of each fuel is required to heat the water in your tank.

SAMPLE CALCULATION FOR **Ethanol (C_2H_5OH) to heat up water in tank**

Assumption(s):

Mass of fuel needed = _____ kg

(c) Using your balanced equations in Activity 2, calculate the CO_2 emissions for methane, hydrogen and ethanol in the table below. The molecular weights are 16, 2 and 46 respectively.

SAMPLE CALCULATION FOR CO_2: **Per kg of C_2H_5OH used**

Moles ethanol per kg =

Moles CO_2 produced per kg fuel =

Mass CO_2 emitted, per kg of fuel = _____ kg

FUEL	HHV*, *MJ/kg*	Mass of fuel needed, *kg*	CO_2 emitted, *kg per kg of fuel*
Methane	55.5		
Hydrogen	141.7		
Ethanol	29.7		
Anthracite Coal	32.6		2.86
Wood	16.2		3.67
Diesel fuel	45.6		3.16

*HHV = high heating value

ACTIVITY 4: Decision-Making (10 MINUTES)

Based on your answers for Activity 3, discuss within your group what other factors would impact your choice of fuel.

Each group will present their choice of fuel, and the reason for their choice.