Fuels – Incomplete and complete combustion

1. A mass of 0.560 grams of CH_4 reacts completely, in the right stoichiometric ratio, with oxygen gas at SLC. The volume and mass of the product gas formed is measured.
   a. The volume of the product gas is 0.496 litres and weighs 0.560 grams. Identify the gas

      We can identify the gas by its molar mass.
      molar mass = mass / mol

      Step 1 find the mol of gas
      => 0.496 / 24.8 = 0.0200

      Step 2 find the molar mass
      => 0.560 / 0.0200 = 28 g/mol

      Step 3 identify the gas
      => CO

   b. Give the balanced chemical equation for the combustion reaction of methane and oxygen gas under these conditions. States required.

      $2CH_4(g) + 3O_2(g) \rightarrow 2CO(g) + 4H_2O(l)$

   c. Is this a complete or incomplete combustion reaction? Justify your reasoning with reference to oxidation states.
      Incomplete. C in CH_4 has an oxidation state of -4. It can have a maximum oxidation state of +4 as in CO_2 but in CO it only has an oxidation state of +2, so it is only partially oxidised.
2. An amount of 1.60 grams of pure methane gas burns in oxygen to raise the temperature of 2.00 litres of distilled water by 7.26 °C.
   a. If the water was originally at 25°C, calculate the amount of energy produced, assuming all energy was absorbed by the water.
      Step 1 Find the mass of the water, given that the stem of the question stated that 2.00 litres of water was at 25°C.
      => 0.997 X 2000 = 1994 grams.
      Step 2 Find the amount of energy, in kJ, absorbed by the water.
      => E(J) = 4.18 X 1994 X 7.26 = 60.5 kJ
   b. Write the balanced chemical equation for the combustion of methane gas and oxygen under these conditions given that 1.60 grams of methane reacts with 4.80 grams of oxygen gas. States required.
      Considering that 0.10 mol of methane (1.60 grams) produces 4.80 grams of oxygen (0.15 mol of O_2) we can identify the gas as CO and hence the reaction would be written as
      $$2CH_4(g) + 3O_2(g) \rightarrow 2CO(g) + 4H_2O(l)$$
   c. Write the balanced thermochemical equation for the reaction.
      Step 1 find the molar heat of combustion according to the data given in the question.
      => mol of methane = 1.60 / 16.0 =0.100 mol
      Step 2 molar heat of combustion
      => 60.5 kJ / 0.100 = 605 kJ mol^{-}
      Step 3 write the balanced thermochemical equation
      => $2CH_4(g) + 3O_2(g) \rightarrow 2CO(g) + 4H_2O(l)$ $\Delta H = -1210$ kJ mol^{-}

3. Propane gas reacts with oxygen gas in a combustion reaction at SLC to produce 22.0 grams of a gaseous product. This gaseous product occupies a volume of 12.4 litres.

   a. Write a balanced thermochemical equation for the combustion of propane gas under these conditions.

      $C_3H_8(g) + 5O_2(g) \rightarrow 3CO_2(g) + 4H_2O(l)\ \Delta H = -2220\ kJ\ mol^{-}$

   b. Propane gas is used to heat 200 litres of water in a hot water tank. The water, originally at 30.0 °C, is heated to 50.0°C. A mass of 0.4000 kg of propane was used to heat the water.

      i. Calculate the amount, in kJ, of energy absorbed by the water. Assume water density 1.00 g /mL.

         => Energy(J) = 4.18 X 200000 X 20.0 = 16720 kJ

      ii. Calculate the theoretical amount of heat energy, in kJ, delivered by 0.400 kg of propane. Use the thermochemical equation given in question a. above.

         According to the equation above, one mol of propane delivers 2220 kJ of heat energy.
         Step 1 find the mol of propane
         => 400 / 44.0 = 9.10
         Step 2 find the total theoretical amount of heat energy delivered.
         => 9.10 X 2220 = 2.02×10^4 kJ

      iii. Consider the energy efficiency formula of an appliance shown on the right, diagram 1.

         Calculate the energy efficiency of the hot water tank.

$$\%\ \text{Energy efficiency} = \frac{\text{Useable energy}}{\text{Total energy supplied}} \times 100$$

Diagram 1

         % energy efficiency = (useful energy / total energy delivered) X 100
         => (16720 / 20200) X 100 = 82.8%

      iv. Under the conditions at which propane gas burns, in another hot water tank, energy efficiency is low at around 35%. During the combustion reaction in this tank a toxic, diatomic gas is given off as well as unburnt propane.
         Give the balanced chemical equation for this reaction and provide an explanation as to how this toxic gas can be avoided.

         Low energy efficiency is the result of a multitude of factors some of which are:
         - *Poor insulation*
         - *Incomplete combustion of the fuel due to poor oxygen supply*
         - *Contaminants in the fuel.*

           The gas is most likely CO.
           $2C_3H_8(g) + 7O_2(g) \rightarrow 6CO(g) + 8H_2O(l)$
           Adding excess oxygen gas to the combustion mixture will prevent the production of CO gas and ensure complete combustion of the propane.