Program Record (EERE Office of Transportation)		
Record #: 14007	**Date:** 7/14/2014	
Title: Water Emissions from Light-Duty Vehicles		
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Approved by: Pat Davis Sunita Satyapal	**Date:** July 14, 2014	

Item

This record documents an estimate of the amounts of water emitted per km and per mile from a gasoline vehicle with an internal combustion engine (ICEV) and a fuel cell electric vehicle (FCEV), respectively. The analysis shows that the amount of water emitted by FCEVs ranges from approximately 10% less water to approximately 10% more water per mile (or per km) than today's average ICEV: 150 g per mile (93 g per km) for the ICEV, and 132 to 167 g per mile (82 to 103 g per km) for the FCEV.

Approach

Gasoline is a mixture of alkanes (e.g., C_6H_{12}, C_8H_{18}, etc.), alkenes (e.g., C_3H_6, C_5H_{10}, etc.), aromatics (e.g., C_6H_6,C_7H_8, etc.), and trace amounts of other compounds. Alkanes form the bulk of gasoline, followed by aromatics (less than 20% of gasoline), alkenes (a few percent), and very small amounts of other compounds (http://www.turborick.com/gsxr1127/gasoline.html, http://www.atsdr.cdc.gov/toxprofiles/tp72-c3.pdf).

From Bishop et al, 1996, the basic "building block" for the combustion reaction in an engine is:

$$CH_2 + 1.5\ (O_2 + 4\ N_2) \longrightarrow CO_2 + H_2O + 6\ N_2$$

Multiplying by 8 and neglecting N_2:

$$8\ CH_2 + 12\ O_2 \longrightarrow 8\ CO_2 + 8\ H_2O \qquad (1)$$

Alternatively, assume stoichiometric combustion of one gallon of gasoline and assume gasoline to be composed of octane (C_8H_{18}):

$$C_8H_{18} + 12.5\ O_2 \longrightarrow 8\ CO_2 + 9\ H_2O \qquad (2)$$

Comparing Equations 1 and 2, one sees that they are fairly close to each other, and octane can be used as an approximate average compound in gasoline in describing the combustion process.

From the Hydrogen Data Book (http://hydrogen.pnl.gov/cocoon/morf/hydrogen/article/716), one gallon of gasoline weighs 6.27 lb, or 2,845 g. Writing the above equation in terms of mass,

and using the molecular weights: C_8H_{18}: 114 g/mole, O_2: 16 g/mole, CO_2: 44 g/mole, H_2O: 18 g/mole,

$$2{,}845 \text{ g fuel} + 9{,}975 \text{ g } O_2 \longrightarrow 8{,}780 \text{ g } CO_2 + 4{,}040 \text{ g } H_2O \quad (3)$$

So, 4,040 g of water is emitted per combusted gallon of gasoline.

The U.S. Environmental Protection Agency (EPA) and the Department of Transportation assume that a gallon of gasoline emits 8,887 g CO_2, from http://www.epa.gov/cleanenergy/energy-resources/refs.html.

The CO_2 emission amount of 8,780 g in Equation (3) is close to the EPA/DOT assumption for gasoline, further justifying the choice of octane as the "average" hydrocarbon compound for gasoline.

From fueleconomy.gov, the on-road fuel economy of new midsize gasoline ICEVs ranges from 22 to 32 miles per gallon (mpg). Assuming 27 mpg, the water given off by an ICEV per mile is:

(4,040 g H_2O/gal) / (27 mi/gal) = 150 g H_2O per mile (this is 93 g per km).

For the FCEV, the reaction in the fuel cell is:

$$H_2 + 1/2\ O_2 \longrightarrow H_2O + \text{electricity} \quad (4)$$

One kg of hydrogen has an energy content (heating value) equivalent to one gallon of gasoline (1 kg of hydrogen = 1 gge, from the Hydrogen Data Book). Writing Equation (4) in terms of mass:

$$1{,}000 \text{ g } H_2 + 8{,}000 \text{ g } O_2 \longrightarrow 9{,}000 \text{ g } H_2O \quad (5)$$

So, in a FCEV, 9 kg of water is emitted per gge of hydrogen fuel.

FCEVs are approximately twice as efficient as their gasoline counterparts (National Research Council 2013). Assuming a fuel economy of 54 mi/gge, an FCEV would emit:

(9,000 g H_2O /gge) / (54 mi/gge) = 167 g/mi (this is 103 g per km)

Using a fuel economy of 68 mi/gge as validated for one FCEV model (Wipke et al., 2009), the resulting water emission would be:

(9,000 g H_2O /gge) / (68 mi/gge) = 132 g/mi (this is 82 g per km)

This is approximately 10% less water than today's ICEV.

As both ICEVs and FCEVs become more efficient, the amount of water emitted per mile (or per km) will decrease.

References

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