What is the theoretical maximum of MMW?

Ver. 1.1.

05/25/11

This report was prepared by HHO Research, a work group for the purpose of promoting better quality research in the science and technology of HHO gas.

The term MMW refers to milliliters per minute per watt. It is a convenient way for an experimenter to measure the output of an HHO cell. This serves as an approximate way to gauge the performance of an HHO cell. A common figure given for maximum theoretical MMW is 6.182 [1]. The source of this figure is probably a calculation found on page 131 of the book, *The Chemistry and Manufacture of Hydrogen* by P. L. Teed [2]. Based on Faraday's law and the assumption that the voltage across the plates of the electrolytic cell will be 1.69 volts, this book states that 1000 watt hours will generate 8.7 cubic feet of hydrogen. To convert to MMW:

1000 watt hours equal 60,000 watt minutes.

The amount of HHO gas would be two volumes of hydrogen to one volume of oxygen.

Therefore, this output would be 1.5 x 8.7 = 13.05 cubic feet.

There are 28,316.8 milliliters in a cubic foot. 13.05 x 28,316.8 = 369,534.24 milliliters.

Finally, MMW is equal to 369,534.24 / 60,000 = 6.159.

That is only 0.37 % below the estimate cited above, probably close enough to be equivalent. The problem with this estimate is that the voltage across the plates of an HHO cell will not necessarily be 1.69 volts. Major Teed provides almost no information about this value except that it was measured by someone named Le Blanc. No reference is given. He does not explain why minimum voltage needed to sustain electrolysis would necessarily correspond to maximum theoretical output, especially since the cell used to make an empirical measurement would not be 100% efficient.

In this article, we obtain an estimate based on thermodynamics in which voltage is completely irrelevant. The value obtained is **9.28 milliliters per watt per minute.** This would explain why it is common for HHO cells to exceed the 6.16 MMW figure.

The chemical equation for the dissociation of water is:

$$H_2O \longrightarrow \tfrac{1}{2} O_2 + H_2 \qquad \text{Eqn.1}$$
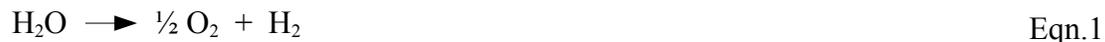
Two variables directly affect the basic thermodynamics of this equation. They are temperature and pressure. These are taken into account by means of the concept of Gibbs free energy.

The change in Gibbs free energy [3], denoted as ΔG is given by the equation:

$$\Delta G = \Delta H - T\Delta S \qquad \text{Eqn. 2}$$

where ΔH equals net enthalpy change, ΔS equal net entropy change and T equals temperature in degrees Kelvin. Room temperature, 25 deg. C equals 298 degrees Kelvin[1].

---

1 Kelvin is simply Celsius plus 273. Absolute zero is approximately -273 deg. C. For purposes of thermodynamics, Celsius temperatures must be offset by this amount.

The net change in entropy for Eqn. 1 is calculated from the molar entropies for water, hydrogen gas, and oxygen gas.

Quantity	Entropy J/K
H_2O	69.91
½ O_2	0.5 x 205.14
H_2	130.68

Net entropy is, therefore, 61.91 - 130.68 - 102.57 (205.14 / 2) = - 163.34 J/K.

The enthalpy includes the internal energy of dissociation: 282.1 kJ   Also, it includes the amount of work needed to expand 1.5 moles of gas under standard pressure and temperature: 3.72 kJ.
This amount: - 285.83 kJ takes into account gas pressure and temperature as long as it is at 1 atm and 298 deg. K.

Therefore, Gibbs free energy of this dissociation is:

  - 285.83 kJ - (- 163.34 x 298) = 48.7 kJ - 285.83 kJ   =   - 237.1 kJ   Eqn. 3

Now that we have the amount of energy needed to produce 1.5 gram moles of oxyhydrogen gas, we shall calculate the volume of 1.5 moles of gas according to the ideal gas equation.

Units for the gas constant used are cubic meters atmospheres per degree K per gram mole. The ideal gas equation is given as:

$$PV = nRT$$

Eqn. 4

where P = pressure in atmospheres, i.e., 1
n = number of gram moles of gas, 1.5
R = the ideal gas constant, about 8.205×10^{-5}
T = 298 degrees Kelvin.

Volume would be:

$$V = nRT / P$$ Eqn. 5

The numerical evaluation would be:

8.205×10^{-5} x 1.5 x 298 = 0.0366797 cubic meters per gram mole of water   Eqn. 6

There are 10^6 milliliters in a cubic meter. Therefore, this quantity represents 36,680 milliliters. To convert kJ into watt minutes, a joule is a watt second. Seconds x 60 equal minutes. If we multiply:

$$\text{watt seconds} \times 60 / 60 = \text{watt minutes} / 60 \qquad \text{Eqn. 7}$$

Therefore,

$$237100 \text{ J} / 60 = 3952 \text{ watt minutes per gram mole of water} \qquad \text{Eqn. 8}$$

So finally, maximum MMW is given as milliliters of gas divided by watt minutes. Both of these quantities have gram moles water in the denominator. These cancel to give:

$$36680 / 3952 = \textbf{9.28 milliliters per watt per minute} \qquad \text{Eqn. 9}$$

This may be off a bit due to humidity of the gas and the fact that gasses do not conform perfectly to the ideal gas equation. MMW measurements are rather approximate anyway.

The above calculation indicates that MMW would increase with temperature. This may be relevant because most HHO cells operate at an equilibrium temperature considerably higher than room temperature which is commonly taken to be 77 deg. F, 25 deg. C, and 298 deg. K. What if the temperature were elevated to 110 deg. F, 43.3 deg. C, and 316.3 deg. K ?

The work component of enthalpy described above is given as:

$$W = P\Delta V = (101.3 \times 10^3 \text{ Pa})(1.5 \text{ moles})(22.4 \times 10^{-3} \text{ m}^3/\text{mol})$$
$$(298K/273K) = 3715 \text{ J} \qquad \text{Eqn. 10}$$

Substituting 316 deg. K instead of 298 deg. K gives 3944 J. Therefore, negative enthalpy would increase to -286.04 kJ. The entropy component shown on Eqn. 3 would also increase to 51.67 kJ. The Gibbs free energy is now reduced to 234.37 kJ. This is only about a 1% reduction.

Should 316 deg. K be substituted into Eqn. 6? Well, probably not. Most experimenters measure volume by collecting the gas in a eudiometer apparatus. Such an arrangement would allow the gas to cool down quite a bit. Also, generated gas would be cooled somewhat by evaporation of water as it fizzes off the HHO cell. So, the volume will be roughly the same regardless of electrolyte temperature in the HHO cell. Therefore, an approximate MMW measurement is not significantly affected by temperature.

The MMW rationale for evaluating HHO cells seems to imply that the HHO output for all cells is equivalent. However, the energy yields calculated in tests described in other articles on our web site are many times greater than the MMW. This has never been explained using a rigorous theory and the energy yields of various kinds of HHO cells have never been evaluated. It may be that there is little correlation between MMW and energy yield for various types of HHO cells. This represents an area of unexplored potential that may result in a significant advancement in HHO technology.

References

1. http://www.hhoforums.com/showthread.php?t=1231

2. Teed, P Litherland, *The Chemistry and Manufacture of Hydrogen.* University of California Libraries. (February 18, 2011), ISBN: 1125246340. This book was originally published in 1919. This particular edition has been digitized and reprinted from the collections of the University of California Libraries.

3. A similar discussion of water electrolysis can be found on the Hyperphysics website hosted by the Department of Astronomy and Physics, Georgia State University at: http://hyperphysics.phy-astr.gsu.edu/Hbase/thermo/electrol.html