Q: Combustion of natural gas (Answered, 2 Comments)

Question

Subject: **Combustion of natural gas**
Category: Science
Asked by: **benhogan-ga**
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How many lbs of water is released into the atmosphere when burning 100,000 btu of natural gas or when burning the same of propane. Another way to ask is how much water is in a cubic meter of natural gas or a gallon of propane.

Answer

Subject: **Re: Combustion of natural gas**
Answered By: **bikerman-ga** on 18 Oct 2003 06:39 PDT

Hello, Benhogan.

This was a fun question to answer! I'm sorry it took so long, but I got started and had to go to bed...I find that math calculations and sleep depravation usually result in the wrong answer. :) But having had a good night's sleep, I have confidence in the veracity of these figures. I am going to answer your question using the second form in which you asked it--that is, by using the volumes instead of BTU. I feel that the answer will be more accurate that way. I assume that you already have data which states that 1 gallon of liquid propane equals approximately 100,000 BTU, and 1 cubic meter of natural gas equals the same. I didn't verify that information since you already have it. It isn't too hard to calculate the number of BTU produced by these reactions using the standard enthalpies of formation of the products and reactants, but I won't go through that unless you specifically request it.

Note that my calculations will probably look crummy unless you view this page with a fixed width font in your browser! Viewed with a fixed width font (for example, Courier), the calculations should line up nicely.

Here are the facts we need to solve the problem:

Propane

Density: 585.3 g/L (liquid)
Molar Mass: 44.094 g/mol
Chemical Formula: C3H8
Chemical reaction: C3H8 + 5O2 --> 3C02 + 4H20 + heat
One mole of Propane produces 4 moles of water.

Water

Density: 1 g/cm^3
Molar Mass: 18.016 g/mol

Methane (natural gas)

Chemical Formula: CH4
Chemical reaction: CH4 + 2O2 --> CO2 + 2H2O + heat
Molar Mass: 16.042 g/mol
One mole of Methane produces 2 moles of water.

Conversions and constants
----
1 gal = 3.7854 L
1 lb = 2205 g
0 deg C = 273.15 K
25 deg C = 298.15 K
R = 0.0821 L*atm/(mol*K)

Since the propane is in liquid state, the procedure we will follow

is to go from volume of propane --> mass of propane --> moles of propane --> moles of water --> mass of water:

$$\frac{1\text{ gal } C_3H_8}{1} \times \frac{3.785\text{ L}}{1\text{ gal}} \times \frac{585.3\text{ g}}{1\text{ L}} \times \frac{1\text{ mol}}{44.09\text{ g}} = 50.25\text{ mol } C_3H_8$$

$$\frac{50.25\text{ mol } C_3H_8}{1} \times \frac{4\text{ mol } H_2O}{1\text{ mol } C_3H_8} = 201.0\text{ mol } H_2O$$

$$\frac{201.0\text{ mol } H_2O}{1} \times \frac{18.016\text{ g}}{1\text{ mol } H_2O} \times \frac{1\text{ lb}}{2205\text{ g}} = 1.642\text{ lb } H_2O$$

So one gallon of propane burns to produce 1.64 pounds of water (three significant figures).

Natural gas (methane) is a little different because it is in a gaseous state. The number of gas molecules present (and therefore the amount of water which can be produced) depends on the temperature and pressure. I'll assume standard temperature (25 deg C) and pressure (1 atm) in this case because those are the most commonly used figures (e.g., if you look up how many BTU are contained in 1 cubic meter of methane, it will probably be given at 25 deg C and 1 atm--also referred to as STP). The procedure to follow in this case is to go from volume of methane --> moles of methane --> moles of water --> mass water. The formula we need to use to convert from volume to moles is the ideal gas law, PV=nRT. But first we need to convert 1 m^3 to liters.

$$1\text{ cubic meter} \times \frac{1000000\text{ cm}^3}{1\text{ m}^3} \times \frac{1\text{ L}}{1000\text{ cm}^3} = 1{,}000\text{ L}$$

$$n = \frac{PV}{RT} = \frac{1 * 1000}{0.0821 * 298.15} = 40.85\text{ moles}$$

$$\frac{40.85\text{ mol } CH_4}{1} \times \frac{2\text{ mol } H_2O}{1\text{ mol } CH_4} = 81.71\text{ mol } H_2O$$

$$\frac{81.71\text{ mol } H_2O}{1} \times \frac{18.016\text{ g}}{1\text{ mol } H_2O} \times \frac{1\text{ lb}}{2205\text{ g}} = 0.6676\text{ lb } H_2O$$

So when 1 cubic meter of methane gas at STP burns, it produces 0.668 pounds of water (three significant figures).

Additional Links:

These pages contain some information on the two compounds:
http://elifritz.members.atlantic.net/compounds/propane.htm
http://elifritz.members.atlantic.net/compounds/methane.htm

This page gives the chemical formulas for the combustion reactions:
http://home.att.net/~lfretzin/notes08.html

Search Strategy:

Google Search:
chemical reaction propane combustion
://www.google.com/search?hl=en&lr=&ie=UTF-8&q=chemical+reaction+propane+combustion&spell=1

Google Search:
heat OR energy obtained OR produced combustion propane
://www.google.com/search?hl=en&lr=&ie=ISO-8859-1&q=heat+OR+energy+obtained+OR+produced+combustion+propane

Google Search:
water produced combustion propane
://www.google.com/search?q=water+produced+combustion+propane

Used my college chemistry and physics books to find the necessary constants, formulas, and conversion factors.

I hope this is a satisfactory answer. If you have any questions, please feel free to ask for clarification.

Best regards,
Bikerman

Clarification of Answer by bikerman-ga on 18 Oct 2003 06:47 PDT

Hi,

I just wanted to clarify that this is the amount of water produced when burning 1 gallon and 1 cubic meter of propane and methane respectively. Technically speaking, there is no water contained in either propane or methane--the water is formed by the combination of the hydrogen in the gases and oxygen in the air. I think that is what you meant by "...how much water is in a cubic meter of natural gas or a gallon of propane", but I just wanted to make it clear...in case my chemistry professor ever looks at this. :-)

Thanks,
Bikerman

Clarification of Answer by bikerman-ga on 18 Oct 2003 09:07 PDT

Thank you racecar-ga! I am very sorry--I checked my work several times and still missed that. Indeed it should read 1 kg = 2.205 lb and therefore 1 lb = 453.5 g.

That does change the answers to

$$\frac{201.0 \text{ mol } H_2O}{1} \times \frac{18.016 \text{ g}}{1 \text{ mol } H_2O} \times \frac{1 \text{ lb}}{453.5 \text{ g}} = 7.985 \text{ lb } H_2O$$

for the propane and

$$\frac{81.71 \text{ mol } H_2O}{1} \times \frac{18.016 \text{ g}}{1 \text{ mol } H_2O} \times \frac{1 \text{ lb}}{453.5 \text{ g}} = 3.246 \text{ lb } H_2O$$

for natural gas.

I didn't, however, miss the step of converting from volume to BTU. As I stated at the beginning of my answer, my assumption is that benhogan-ga already has that data, and that is why he picked 1 gallon and 1 cubic meter. However, if it turns out that I didn't understand properly, I can calculate that figure from the standard enthalpies of formation as stated above.

I apologize for the error, and thanks for pointing it out, racecar-ga.
Bikerman

Clarification of Answer by bikerman-ga on 18 Oct 2003 11:11 PDT

Hello,

I apologize once again for the above error, and I decided to go ahead and calculate the BTU/volume for you in case you did in fact need it. It isn't that difficult, so there's no point in not going ahead and doing it.

The total heat of the reaction is the sum of the enthalpies of formation of the products minus the sum of the enthalpies of the reactants. Here is the relevant data:

Standard enthalpies of formation

C3H8(g) : -103.8 kJ/mol
CH4(g) : -74.8 kJ/mol
O2(g) : 0.0 kJ/mol
CO2(g) : -393.5 kJ/mol
H20(g) : -241.8 kJ/mol
H20(l) : -285.8 kJ/mol

Conversions
---
1 BTU = 1.055 kJ

NB: when methane or propane burn, it is actually water vapor that is produced in the exothermic reaction. However, under normal circumstances the water condenses into it's liquid state, which gives off even more heat. Because of this, I'm going to give two figures for each gas: one is the BTU produced before condensation occurs, and the other is the total ending BTU. Which you need depends on exactly what you are doing.

For propane, burning one mole produces:
sum of products - sum of reactants =
3*(-393.5)+4*(-241.8)-[-103.8+5(0)] = -2043.9 kJ

If the water condenses, you have
3*(-393.5)+4*(-285.8)-[-103.8+5(0)] = -2219.9 kJ

(The negative sign indicates that this was an exothermic reaction--heat was given off.)

$$-2043.9\ \text{kJ} \times \frac{1\ \text{BTU}}{1.055\ \text{kJ}} = -1937.3\ \text{BTU}$$

$$-2219.9\ \text{kJ} \times \frac{1\ \text{BTU}}{1.055\ \text{kJ}} = -2104.2\ \text{BTU}$$

Now we have already established that one gallon of propane is equal to 50.25 moles. So, before the water vapour condenses, we have (I'm dropping the minus signs):

$$\frac{1937.3\ \text{BTU}}{1\ \text{mol}} \times \frac{50.25\ \text{mol}}{1\ \text{gal}} = 97300\ \text{BTU/gal}\ \ (3\ \text{significant figs})$$

After condensation:

$$\frac{2104.2\ \text{BTU}}{1\ \text{mol}} \times \frac{50.25\ \text{mol}}{1\ \text{gal}} = 106{,}000\ \text{BTU/gal}\ (3\ \text{significant figs})$$

Burning one mole of methane produces:
sum of products - sum of reactants =
-393.5+2*(-241.8)-[-74.8+2(0)] = -802.3 kJ

If the water condenses, that becomes:
-393.5+2*(-285.8)-[-74.8+2(0)] = -890.3 kJ

Converting to BTU:

$$-802.3\ \text{kJ} \times \frac{1\ \text{BTU}}{1.055\ \text{kJ}} = -760.5\ \text{BTU}$$

$$-890.3\ \text{kJ} \times \frac{1\ \text{BTU}}{1.055\ \text{kJ}} = -843.9\ \text{BTU}$$

1.055 kJ

From my answer, we know that 1 cubic meter of methane contains 40.85 moles of the gas. So, before condensation,

760.5 BTU 40.85 mol
--------- x ----------- = 31,100 BTU/m^3 (3 significant figs)
1 mol 1 m^3

and after condensation occurs,

843.9 BTU 40.85 mol
--------- x ----------- = 34,500 BTU/m^3 (3 significant figs)
1 mol 1 m^3

Combining these figures with those from my answer, we get the following:

Hydrocarbon	Before Condensation	After Condensation
propane	8.21E-5 lb/BTU	7.53E-5 lb/BTU
methane	1.04E-4 lb/BTU	9.41E-5 lb/BTU

So 100,000 BTU worth of propane with the BTU measurement being taken before condensation produces 8.21 pounds of water. If the water is allowed to condense before measuring the BTU, you only get 7.53 pounds of water.

Likewise, 100,000 pre-condensation BTU of methane produces 10.4 pounds of water, while that many post-condensation BTU produces 9.41 pounds of water.

I hope this is to your satisfaction. If not, please ask for clarification. I hope the pre/post condensation issue isn't too confusing, but it has to be dealt with...the exact figures depend on whether your water vapour becomes a part of the system you are dealing with, or gets exhausted before it is allowed to condense. This is easy to see if you consider that the steam produced contains heat--if the steam is removed, so is the heat it contains. If the steam is allowed to condense, it will give off it's heat in turning back to liquid and this becomes part of your system.

Best regards,
Bikerman

Comments

Subject: **Re: Combustion of natural gas**
From: **racecar-ga** on 18 Oct 2003 08:56 PDT

There are about 2.205 pounds in a kilogram.
There are about 454 grams in a pound (not 2205).

This changes the answers above to 7.98 pounds of water from a gallon of propane, and 3.25 pounds of water from a cubic meter of natural gas.

In addition, there is one more step required--how many gallons of propane/cubic meters of natural gas are required to produce 100,000 btu?

Subject: **Re: Combustion of natural gas**
From: **benhogan-ga** on 20 Oct 2003 08:10 PDT

I am astonished with the quality of the answer and the effort that went it this question. We actually used this to confirm our own estimates and your answer was very consistitent with our own estimates. By the way: One gallon of propane produces 90,000 BTU and one Cubic meter of Natural gas produces 35,000 btu. Thanks for the effort

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