The ABW vs. ABV Relationship

In early 2007, I began researching the relationship between alcohol by weight (ABW) and alcohol by volume (ABV). While the terms are explicit, the mathematical relationship between the parameters is somewhat less so. As I searched about the 'net, I saw various conversion formulae – some divide ABW by a constant that varies between 0.757 to 0.80, another method multiplies the difference between the original gravity (OG) & final gravity (FG) by a constant ranging from 125 to 133.

So which method is correct, and why is there so much variation in the constants? Inquiring minds would like to know…  The answer is that both methods are correct – to a point. Also, please keep in mind that what follows is highly condensed and will get a bit detailed in places.

It all starts with the reaction between a fermentable solution and yeast, which converts much of the dissolved sugars (glucose, sucrose, etc.) into ethyl alcohol (EtOH) and carbon dioxide (CO_2). When a must (wort) finishes fermenting, its specific gravity is always less than when it started because some of the sugars have been converted into EtOH (CH_3CH_2OH), which is less dense than water (SG=0.789 kg/L):

$$C_6H_{12}O_6 \implies 2(CH_3CH_2OH) + 2(CO_2)$$

We begin by calculating the gram molecular weights (GMW) of EtOH (46.0688g) and CO_2 (44.0098g).

If you look at the reaction equation, you see that each glucose molecule ($C_6H_{12}O_6$) is converted into 2 molecules of EtOH (CH_3CH_2OH) and 2 molecules of carbon dioxide (CO_2). This means for each carbon dioxide molecule that leaves the fermentation vessel, one EtOH molecule must be formed inside the vessel. Thus, you can say that for every 44.0098 grams of CO_2 that leaves the vessel 46.0688 grams of EtOH are formed – In other words for each gram of CO_2, 1.04678 grams of EtOH are produced.

During the fermentation process most of the CO_2 that forms bubbles out of solution and leaves the primary by way of a vent / airlock. We will assume that all of it leaves because the amount that remains in the must is very small compared to the amount that leaves – for those who have degassed their musts you might not think so...

Assume the OG is 1.100 and the FG is 1.020. The difference in these SGs represents the weight of CO_2 that leaves the primary - 0.080 kg/L. If we multiply that value by 1.04678, we get the weight of the alcohol remaining in the container - 0.08374 kg/L. Now we know both the mass of the solution (1.020 kg/L) and the mass of the alcohol (0.08374 kg/L) and can calculate the percentage of alcohol by mass (ABW) by dividing the two values. This gives 0.0821, or 8.1% ABW.

To calculate the ABV one often sees this relationship: ABV = ABW / 0.79. Well (without going through another derivation) the 0.79 is actually the EtOH SG (0.789) rounded-off, making this example's ABV = 10.3%.

So where does the number 133 come from? Summarizing the above discussion, we have:

$$\%ABV = 100 * [ABW / 0.789]$$
$$\%ABV = 100 * [(FG – OG) * 1.04678 / 0.789]$$
$$\%ABV = 100 * (FG – OG) * 1.3267$$
$$\%ABV = 132.6 (FG – OG)$$

While a more accurate number is 132.6, we see it stated as values from 125 to 133. We also see the EtOH SG stated as 0.8, and 0.79.

Does this answer all the initial questions? Some, but not all… The discussion above assumes only ethyl alcohol was produced, and did not take into account that negative volumes are created when water & alcohol are mixed. These effects (and perhaps some others) will alter the basic relationships shown above and result in variations in the value of the "constant" 0.79 (which I will call **Ka**) and the true values of ABW & ABV.

Empirical testing reveals that **Ka is also a function of the must FG**. The ProMash software program shows this relationship via the **%Alc** calculator. I have plotted the results of several of these calculations and performed a curve-fit to derive the formula shown on the following chart – ABV Conversion Factor.

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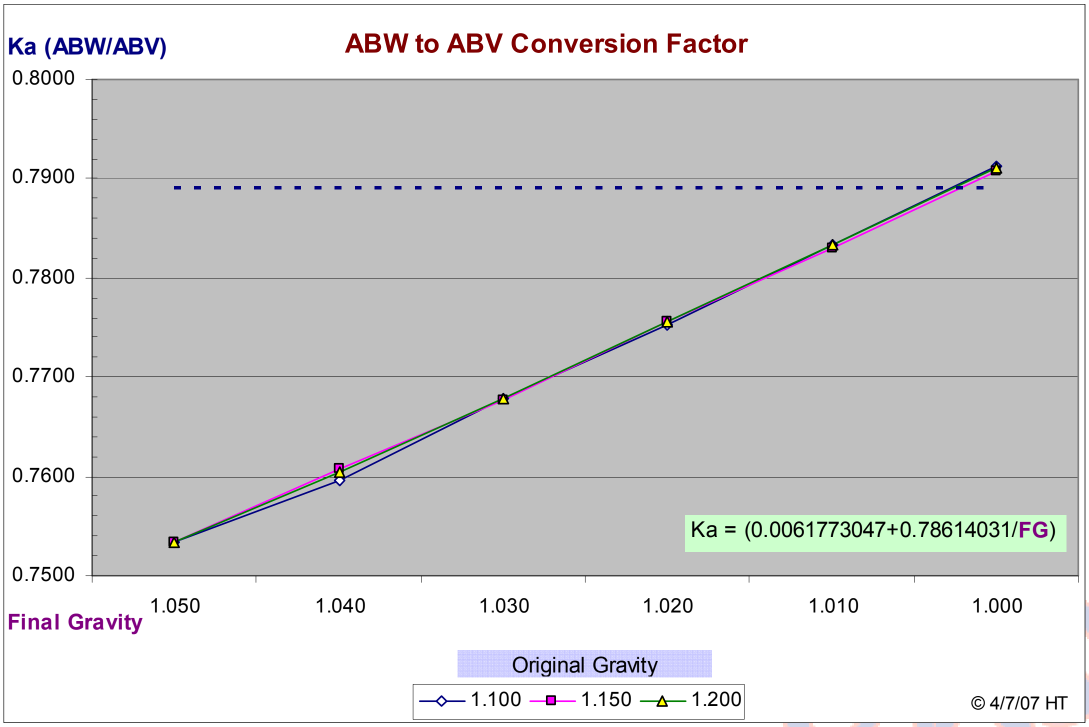

Presently, all my ABV calculations use this empirical formula:

$$ABV = \frac{(OG - FG)(1.04678)}{(0.0061773047 + 0.78614031/\text{FG})}$$

Admittedly, it is more complex than existing “rule of thumb” conversion methods. However, once entered into a spreadsheet, the calculation becomes straightforward.

It should be noted that the truly accurate way to determine the ABV of a solution is to measure the ethanol content using gas chromatography. But as home brewers typically don’t have the resources or need for such a device, the methods above will suffice.