The following copyrighted article appeared as a note entitled “Rule of Thumb” in essentially the same form in *FC (Flow Control)* **6** (6) p. 33 (June 2000). It is reproduced here with *Flow Control’s* permission.

UR-232: Rule of Thumb for Quick Conversion of Molecular Weight to Density in lb/m^3 (Pounds Per Cubic Meter) for Ideal Gases at Standard Conditions

Most designers or testers of flowmeters know that one of the most accurate ways of calibrating a flowmeter is the *gravimetric* method. Water, or other calibration fluid, passes through the flowmeter under test. Let’s assume the flowmeter is intended for water service, and the calibration fluid is water. The calibration stand operator determines the weight of water passing through, in a given time. Let’s say, for example, that during a one minute water calibration interval an empty collection vessel increased in weight by 1000 kg or 2200 pounds. The water mass flow rate M_f is simply (2200 lb)/(60 sec) = 36.67 lb/sec, or 16.67 kg/sec, right?

Wrong! The amount of water collected, apparently weighing one metric ton, occupied essentially one cubic meter. The metric ton of collected water displaced one cubic meter of air, whose buoyant force (1.3 kg or 2.9 lb) needs to be taken into account. Actually, the mass of water collected in the test was 2200 + 2.9 = 2202.9 lb, and M_f = (2202.9)/(60) = 36.72 lb/sec. The fractional error would be about 1/8% if air’s buoyancy were neglected. The 1/8% buoyancy correction has to be applied whether the amount of collected water weighed an ounce or a ton.

The buoyancy of air is of course well known to operators of gravimetric flow apparatus, to designers of dirigibles, and to anyone who has let go of a helium-filled balloon. Is there an easy way to quickly estimate the buoyancy, or density, of *ideal* gases other than air, if you know the molecular weight of the gas?

In 2000 the writer noticed that if the molecular weight of an ideal gas is divided by ten, the result yields, to a good approximation, the gas *density* at 0EC and 760 mm Hg pressure, provided one can accept the strange density unit of *pounds per cubic meter*. The approximation is high by 1.6%. The 1.6% error is a consequence of one-tenth of the gram molecular volume (22.4 liters) 10) numerically exceeding by 1.6% the conversion factor or converting kg to lb (2.2046). Numerical examples, based on data listed in [1], are given in Table 1.

Extending this)10 rule of thumb to *non*-ideal gases introduces errors beyond the 1.6% error mentioned above, to the extent that experimental (actual) gas density even at atmospheric pressure differs from the ideal gas value at 0EC. A 1998 tabulation of measured density at atmospheric pressure and roughly room temperature, for seventy-nine gases from acetylene to xenon, appears in [2]. That article’s tabulated entries are not identified as to source and many of them, like those in column 2 above, taken from [1], apparently are from sources dating back to the 1940s. Readers interested in this topic, particularly accuracy aspects, are advised to consult the latest references on gas density for real gases at standard conditions (0EC, 760 mm Hg), to determine whether the)10 rule of thumb is sufficiently accurate for gases and conditions of interest. [Example: http://webbook.nist.gov]

For *real* gases, the Non-Ideal Gas Law, according to [3], is $PV = nZRT$ where n = number of moles, Z = gas compressibility factor, P = absolute pressure, V = volume, T = absolute temperature, and R = universal gas constant. In [3], graphs comprising Figures 3-4 to 3-7 plot Z vs P_r where $P_r = P/P_c$. Here P_c = critical pressure and P_r is the reduced pressure. These four graphs cover P_r from low range to very high range, i.e., zero to 0.25, to 1.0, to 5 and to 50, respectively.

If Z < 1 then the true (non-ideal) gas density of molecular weight *MW* is *greater* than the value *P(MW)/RT* predicted by the ideal gas law. According to [3], $?_{\mathrm{TRUE}} = P(MW)/ZRT$. Numerical example: if Z = 0.90, then $?_{TRUE} / ?_{IDEAL\ GAS\ LAW}$ = 1.11.

Readers interested in explanations of *why* or *how* real gases differ from the ideal, may find useful discussions of molecular size and interactions in texts such as [4].

Table 1. Illustration of converting gas molecular weight to density in lb/m^3. Values are rounded off to three decimal places (.xxx) or to one decimal place (.x)

Gas	Weight of one liter in grams, @ 0EC and 760 mm, according to [1], to three places .xxx	Weight of one cubic meter, in pounds, @ 0EC and 760 mm		Molecular weight divided by ten	
		.xxx	**.x**	.xxx	**.x**
Hydrogen	0.090	0.198	**0.2**	0.202	**0.2**
Oxygen	1.429	3.150	**3.2**	3.200	**3.2**
Chlorine	3.166	6.980	**7.0**	7.092	**7.1**
Hydrogen chloride	1.628	3.589	**3.6**	3.647	**3.6**
Carbon dioxide	1.965	4.332	**4.3**	4.400	**4.4**
Water	0.805	1.774	**1.8**	1.802	**1.8**
Mercury	8.957	19.747	**19.7**	20.060	**20.1**
Mercuric chloride	12.121	26.722	**26.7**	27.152	**27.2**
Air (dry)	1.293	2.851	**2.9**	2.896	**2.9**

References

[1] W. F. Ehret, *Smith's College Chemistry*, Sixth Edition, page 104, D. Appleton-Century (1947).

[2] R. Gilmont, Correlations for the Density and Viscosity of Fluids for Flowmeter Calculations, Part 1 - Density of Gases, *m&c* (*Measurements and Control*) **32** (6) 92-97 (Dec. 1998).

[3] Buzzard, Bill, Chap. 3, Physical Properties of Fluids, pp. 27-50 in: D. W. Spitzer (Ed.), *Flow Measurement*, ISA (1991), or pp. 29-52 in *ibid*, 2nd Edition (2001).

[4] Roy, B. N., *Principles of Modern Thermodynamics*, IOP Publishing (1995).

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