Pascal's Sinking Feeling…
LinkedIn Article
March 8, 2016
Caoimhín P. Connell
Forensic Industrial Hygienist

A very common myth we encounter is the issue of gases that are "heavier than air." Many people (including those who should know better) believe these gases will "settle" to lower areas and "lighter than air gases" will rise.

Whereas this would theoretically occur in a closed vertical column tens of thousands of feet tall, where the temperature is maintained at a constant level; in practical terms, even in a static cell (a completely sealed container), no such gradient is observed.

I think the most common occurrence of this myth is when a "radon tester" tells an home owner they are "testing radon" in the lowest levels of the home because radon is an heavy gas that "settles" in the lowest portion of a home.

We also see this counterproductive myth appear in laboratories with adjustable laboratory fume hoods which often have a lever to adjust for "lighter than air gases" and "heavier than air gases" (a *completely* useless adjustment that should be corrected with an hacksaw upon arrival of the new fume hood).

Consider an helium-filled balloon that rises in a room – it rises only because it is a sealed system; sealed by the walls of the balloon and therefore, the density of the sealed system as an whole is less than the surrounding air - therefore the balloon rises until it reaches and altitude where the air density equals the density of the whole balloon system.

If you pop the balloon, then for a very brief moment, the helium gas will remain as a fluid "ball" and continue to rise, but within just a second or two, the helium begins to immediately diffuse into the surrounding air via molecular velocity, density convection, thermal convection (as you already noted) and mechanical agitation.

In dynamic cells, such as a home or confined space where a material is constantly being introduced <u>in large quantities</u>, (such as during a fire, or during a large spill of a rapidly evaporating solvent), concentration gradients based on molecular weight may well be seen. And if the dynamics of the system are stable, then predictable gradients may also be seen. But those would be the rare exception, not the rule.

Even in a static cell, such as a sealed tank, the velocity of a particular species of gas will have a slightly different diffusion velocity (that is its velocity relative to the molar average velocity of the system as a whole), it will nonetheless eventually equilibrate in all parts of the headspace regardless of the vapor density of the gas.

That is, due to molecular diffusion, in a very short time, there will be no concentration gradient due to density of the pure species. Eventually, the concentration of the component gases will all be identical in all parts of the space in which the gas is contained. That equilibrium will occur even in a sealed container with no convection and no mechanical agitation, and it will occur within seconds to minutes.

The intuitive idea that heavier than air gases "sink" and lighter than air gases "rise" is just a failure of human intuition.

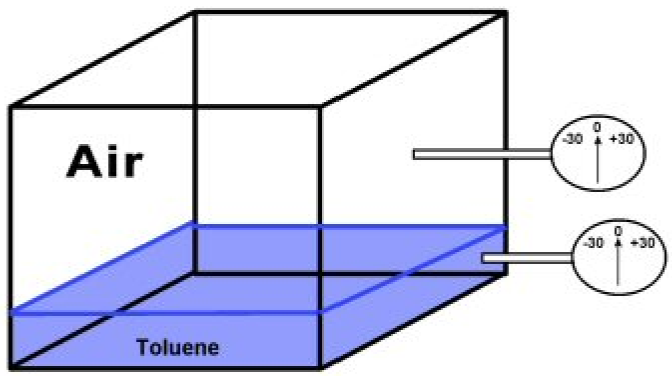
To illustrate, let's do a mind experiment and use two common gases: "air" and toluene vapor. "Air" is a complex mixture containing roughly 80% nitrogen and 20% oxygen (good enough rough values for the purposes of the example).

Toluene is heavier than air, in fact, it is immensely heavier than air; about three times heavier than air.

So let's take a large chamber (such as a large underground electrical vault) and pretend the vault is filled with air and into which is installed a tap at the bottom of the tank. Now, let's carefully tap fill the bottom portion with just toluene gas, allowing the air at the top to escape as necessary to maintain static pressure. Now, we have a one foot deep layer of toluene in the bottom of the tank. Now, if we hook up a manometer and read the pressure differential across the shell of the chamber, we would see that the gases in the chamber are at equilibrium – no net pressure between the top and the bottom, and since the chamber is not pressurized (it's just holding the gases, like a cup holds water), there is no net pressure differential across

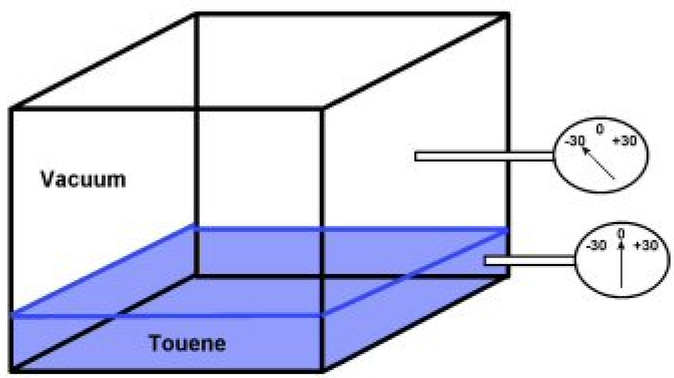
the wall of the chamber.

See below:



Now, let's carefully remove the air above the layer of toluene. If the toluene is resting on the bottom of the chamber because it has settled there (since it is heavy), it should just remain there, right?

See the chamber below:



But look what has happened to the pressure differentials. The toluene is still exerting the same pressure as before, as expected, but now, there is a vacuum in the top part of the chamber. How could one possibly have a pressurized chamber at the bottom, and a perfect vacuum at the top?

Answer: You can't.

The toluene will expand into the top layer to fill the vacuum. In fact, the toluene doesn't "know" what the pressure is, rather, like all perfect gases, will perfectly fill any volume in which it is placed and it will exert the EXACT same pressure on the walls of the container regardless of the original pressure in the container – this is known as Pascal's Law.

The actual pressure in the chamber is described by an equation known as the ideal gas law: PV=nRT (pressure times volume equals the number of moles of gas times the ideal gas constant times the temperature).

In a perfectly still container with no mixing, one gas will diffuse perfectly into another gas and will ultimately be at equal concentrations at all points in the container. "Perfect" containers don't exist, and thermal buoyancy, mechanical mixing, drafts, and movement in an area dramatically accelerate the mixing process.

For a contaminant being introduced into an existing space, one can expect lognormally distributed concentrations in a given area. For example, if one were to layout a 3-dimensional array of real-time air sampling devices at a factory wherein using a piece of equipment or a processes that generates a specific contaminant, one would observe a spatial lognormal distribution of contamination concentrations. The mixtures are spatially complex, and predictable only over larger volumes of space, and over longer periods of time.

If this were not the case, then remember this: "Air" itself is a mixture of gases that are lighter-than-air, and heavier-than-air: Taken as an whole, "air" would have an equivalent gram molecular weight of about 28; diatomic oxygen (heavier than air at 32 gmw) is 20.9%; CO2 (44 gmw, at 0.03%); diatomic nitrogen is 28 gmw at 78%, and argon at 40 gmw contributes about 1%.

So if a chamber was filled with "air," and gases separated out according to their "weights," an enclosed chamber would quickly partition out in layers, with CO2 settling to the bottom, upon which a layer of argon would rest; which would be covered by a layer of oxygen, capped by a layer of nitrogen.

So when it comes to even radon, even when it is introduced into the structure from cracks in the basement, molecular velocity, thermal gradients, mechanical agitation, stack effect, infiltration– exfiltration, leakage and other air movement issues will result in extremely rapid dispersion throughout the structure. Indeed, several studies have shown that the basement is not even necessarily the location with the highest radon concentrations.

The myth is not useful – nor practical. I have taught several firefighting classes in regard to illegal drug laboratories, and my Brothers the firefighters, cling to the heavier than air myth with the tenacity of a firefighter. And although it is important to understand the spatial concentration gradients that can occur in structures, it is also important to understand the dynamics governing those gradients for what they are, and, what they are not.

> ***Belief is a wise wager. Granted that faith cannot be proved, what harm will come to you if you gamble on its truth and it proves false? If you gain, you gain all; if you lose, you lose nothing. Wager, then, without hesitation, that He exists. -*** **Blaise Pascal**