

The Effect of Molecular Weight on Plume Rise

The forgotten component

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Background

Plume rise is due to the buoyancy of the exhaust due to density difference of emitted air and the heat released or absorbed due to changes of state or chemical reactions

In regulatory models density is approximated by the temperature difference only. I.e. they assume all buoyancy is due to temperature and assumes that the plume molecular weight is approximately equal to that of ambient air. This is true if the emissions are from a combustion source, but it does not necessarily hold for other sources.

In the derivation of buoyancy plume rise, Briggs (1975) states that with regards to the effect of molecular weight on the density.

If $|mw_a - mw_p| / mw_p$ is less than 10% of $|T_p - T_a| / T$, we can neglect the molecular weight term. This is true of the emissions from most combustion processes, unless they have cooled considerably.

Note, taking T_p 373 K, T_a 293 K, $|T_p - T_a| / T$ is 0.21. To be < 0.021
 $|mw_a - mw_p| < 0.61$ g/mol

For standard plume rise equations where the temperature difference is used to define the density difference, Briggs suggested a first order correction for molecular weight by multiplying T_p by mw_a / mw_p

Examples (Based on Real Cases)

Source	Temp (deg K)	Molecular Weight (g/mol)	MW Correction (MW _a /MW _p)	Adjusted T _{plume} (K)	Plume Rise for 1m/s @ 10m Neutral Original (adj.)	Percentage Change (%)
Water Vapour Plume	371	18	1.61	597	28 (50)	+79
Process with high CO ₂ content	335	33	0.876	293	21 (15)	-29

Calculations based on Diam = 0.5m, vel =10 m/s, ambient temp =293 K, MW_a = 28.9 g/mol

Note for the water vapour plume the release of latent heat when the water vapour condenses immediately after release is neglected.

The above two real examples show that the molecular weight can have a considerable affect. This is due to the increase in plumes buoyancy being larger than the decrease in the plumes momentum.

Conclusion

- 1) *The issue of accounting for the molecular weight should be flagged in the standard modelling documents/advice given. At the moment it appears to that there is no guidance given with perhaps the Briggs criteria used to determine cut off.*
- 2) *More comprehensive plume rise modules should be incorporated (an option) in regulatory models as the exhaust types neglected are not that uncommon. We can approximate the MW effects (as shown) but we still neglect the latent heat effects.*