

Conversion of Wet Flow Rate to Dry Flow Rate



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The thermal anemometer measures the cooling effect due to all gas constituents passing by the sensor pulling heat away. In air we have N₂, O₂, Ar, H₂O, CO₂ etc. It is the H₂O component which is of interest for this note because it is often required to know what the flow rate is in a system without the water. The raw reading from a thermal anemometer is the wet flow rate or WSCFM. If the water vapor component is removed, this flow rate is the dry flow rate or DSCFM.

This method is based on the assumption that changes in the air thermal properties are small due to the moisture, and that the thermal anemometer reads the WSCFM correctly. This is valid within 1% for specific humidity levels up to 5%. At higher specific humidity levels, the conversion is more involved that described here.

Based on a humidity measurement, one can obtain the dew point temperature and look up the specific humidity ratio (ω) from the Psychrometric chart for Air. Specific humidity is defined as the mass fraction of water vapor compared to the dry air component.

$$\omega \equiv (\text{Mass H}_2\text{O Vapor})/(\text{Mass Dry Air}) \quad (1)$$

On a typical day in Monterey, the dew point is 14 °C which is 70 grains/lb of air based on the Psychrometric chart. Since there are 7000 grains per pound, this is 1% specific humidity. The relative humidity reported by weather forecasters is a different parameter, not of interest for this note.

One is tempted to take the WSCFM number and convert to mass flow rate using the air density. Then use ω to do the conversion on a mass basis. The problem with this method is that the gas density changes with ω . As we increase water vapor, the total air density drops. To avoid this problem we will work with volumetric flow.

The Gibbs-Dalton or Dalton's law says that the partial pressure ratio (p), volume fraction ratio (v_f) and molar fraction χ of each gas component are equal for mixtures of ideal gases like water vapor and air.

Let v_{f_a} be the volume fraction which is air (dry air) in a duct.

$$\text{WSCFM} = \text{DSCFM} + \text{H}_2\text{O SCFM}$$

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$$\text{WSCFM} = \text{WSCFM} * v_{f_a} + \text{WSCFM} * (1 - v_{f_a}) \quad (2)$$

Where the term

$$\text{WSCFM} * v_{f_a} = \text{DSCFM} \quad (3)$$

is the dry component flow rate and the term

$$\text{WSCFM} * (1 - v_{f_a}) = \text{H}_2\text{O SCFM} \quad (4)$$

is the water vapor component flow rate.

Since the molar fraction and the volume fraction are the same, we can convert equation 1 for specific humidity to a volume fraction using the atomic weight of water and air.

$$\omega = (M_{\text{H}_2\text{O}} * (1 - v_{f_a})) / (M_{\text{air}} * v_{f_a}) \quad (5)$$

where $M_{\text{H}_2\text{O}} = 18.016$ and $M_{\text{air}} = 28.96$.

Solving equation 5 for the dry air fraction we get

$$v_{f_a} = 1 / (\omega / (M_{\text{H}_2\text{O}} / M_{\text{air}}) + 1) \quad (6)$$

Substituting the molar values of air and H₂O we get:

$$v_{f_a} = 0.622 / (\omega + 0.622) \quad (7)$$

Substituting equation 7 into 3, the conversion from wet SCFM to dry based on specific humidity ratio is:

$$\text{DSCFM} = \text{WSCFM} * 0.622 / (\omega + 0.622) \quad (8)$$

*Using our 1% wexample in Monterey, the conversion from WSCFM to DSCFM is :
 $0.622 / (0.01 + 0.622) = 98.4 \%$. This is means that 1.6 % by volume was water vapor.*