Calibration of Hot-wires allowing for Ambient Temperature Compensation.

Paul Nathan 03/11/2023

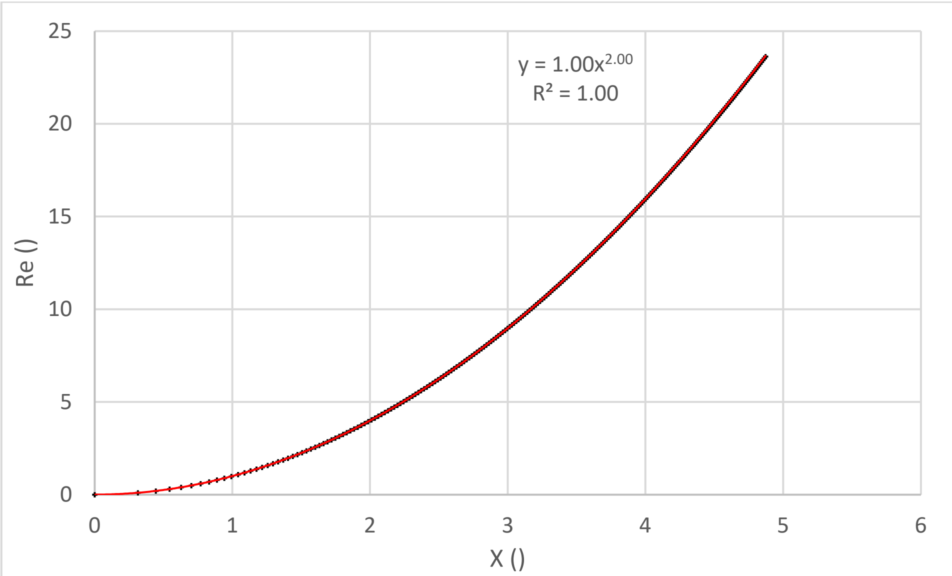

Figure 1: Simulated ideal calibration from U = 0 to 120 m/s.

$$\mathrm{Re} = f(X)$$

$$X = \frac{C\dfrac{V_s^2}{k(T_w - T_a)} - A}{B \cdot g(\mathrm{Pr})}$$

$$A = 0.3$$
$$B = 0.62$$
$$C = \frac{1}{\Omega R_0 \pi L\left((1+n)\left(1+\dfrac{R_L}{\Omega R_0}\right)\right)^2}$$
$$g(\mathrm{Pr}) = \frac{\mathrm{Pr}^{\frac{1}{3}}}{\left(1+\left(\dfrac{0.4}{\mathrm{Pr}}\right)^{\frac{2}{3}}\right)^{\frac{1}{4}}}$$

The fluid properties, ν, k and Pr are evaluated at the film temperature $T_f = \frac{1}{2}(T_w + T_a)$ with $T_w = T_0 + \frac{\Omega - 1}{\alpha_0}$

In practice the coefficients and offset can be dropped and incorporated into the function $f(\;)$ to give

$$X = \frac{V_s^2}{g(\mathrm{Pr})k(T_w - T_a)}$$

$$\mathrm{Re} = \frac{Ud}{\nu} \text{ Reynolds number}$$
$$\mathrm{Pr} = \text{Prandtl number}$$
$$\Omega = \frac{R_w}{R_0} \text{ overheat ratio}$$
$$n = \text{bridge ratio}$$
$$R_0 = \text{wire resistance at } T_0 \ (\Omega)$$
$$R_L = \text{probe leads resistance } (\Omega)$$
$$L = \text{wire length } (m)$$
$$d = \text{wire diameter } (m)$$
$$\alpha_0 = \text{wire temperature coefficient of resistance } \left(K^{-1}\right)$$
$$k = \text{air thermal conductivity } \left(Wm^{-1}K^{-1}\right)$$
$$\nu = \text{air kinematic viscosity } \left(m^2 s^{-1}\right)$$
$$\mathrm{V_s} = \text{bridge supply voltage } (V)$$
$$T_w = \text{wire temperature } (^\circ C \text{ or } K)$$
$$T_f = \text{film temperature } (^\circ C \text{ or } K)$$
$$T_a = \text{ambient temperature } (^\circ C \text{ or } K)$$
$$T_0 = \text{reference temperature } (20^\circ C \text{ or } 293.15K)$$

For an overheat ratio around 1.7 and ambient temperatures spanning the range 0…100°C, the following formulae can be used to evaluate the fluid properties (based on CRC Handbook data tables), with T_f having units °C:

$$k = 2.447763E-02 + T_f\left(7.399136E-05 + T_f\left(-2.570032E-08\right)\right) \qquad W/mK$$
$$\nu = 1.339409E-05 + T_f\left(9.152291E-08 + T_f\left(9.218673E-11\right)\right) \qquad m^2/s$$
$$\mathrm{Pr} = 7.096338E-01 + T_f\left(-1.268923E-04 + T_f\left(3.452048E-07\right)\right)$$
$$g(\mathrm{Pr}) = 7.832041E-01 + T_f\left(-5.664919E-05 + T_f\left(1.541017E-07\right)\right)$$