

Appendix C

Properties of Water

Water is occasionally used as a damper fluid in special applications, but is mainly of interest as a cooling medium for severe duty applications or testing.

In liquid or gaseous form (steam), the molecular formula is H_2O , with a relative molecular mass ('molecular weight') of 18.015 kg/kmol.

Avogadro's number is 6.0225×10^{26} molecules/kmol, so the mass of one water molecule is 29.9×10^{-27} kg.

At a reference temperature of 15°C, the following values are applicable:

$$\rho = 999.1 \text{ kg/m}^3$$

$$\mu = 1.139 \times 10^{-3} \text{ N s/m}^2$$

$$\nu = 1.140 \times 10^{-6} \text{ m}^2/\text{s}$$

$$k = 0.596 \text{ W/m K}$$

$$c_p = 4186 \text{ J/kg K}$$

$$Pr = 7.82$$

$$B = 2.15 \text{ GPa (bulk modulus)}$$

$$\sigma = 73.5 \text{ mN/m}$$

At an average cooling temperature of 50°C, the values are:

$$\rho = 988.0 \text{ kg m}^{-3}$$

$$\mu = 0.547 \times 10^{-3} \text{ N s/m}^2$$

$$\nu = 0.553 \times 10^{-6} \text{ m}^2/\text{s}$$

$$k = 0.644 \text{ W/m K}$$

$$c_p = 4186 \text{ J/kg K}$$

$$Pr = 3.56$$

$$B = 2.29 \text{ GPa}$$

$$\sigma = 67.9 \text{ mN/m}$$

The commonly quoted density of water of 1000 kg m^{-3} is the value at 4°C only, reducing by about 4% at 100°C to 996 kg m^{-3} , and to 864 kg m^{-3} at 200°C (under pressure), in a highly nonlinear

manner, the value at 4°C being a maximum. Hence a simple constant thermal expansion coefficient is not applicable over any significant temperature range. For cooling purposes an average value of

$$\rho = 998 \text{ kg/m}$$

can be used (2% accuracy for 0–100°C). Where a more accurate value is desired

$$\rho = 1001.3 - 0.155 T_C - 2.658 \times 10^{-3} T_C^2$$

where T_C is celsius (centigrade), has 0.2% accuracy from 0 to 200°C. Above 80°C of course, pressurisation of a water cooling circuit becomes necessary to prevent evaporation or boiling, but this has little effect on the density.

The dynamic viscosity μ reduces considerably with temperature according to:

$$\log_{10} \mu = -2.750 - 0.0141 T_C + 91.9 \times 10^{-6} T_C^2 - 311 \times 10^{-9} T_C^3$$

for μ in Pa s (N s/m²), which is 0.5% accurate for 3–100°C.

The specific thermal capacity c_P varies slightly from 0 to 100°C, but for cooling may generally be considered constant at

$$c_P = 4200 \text{ J/kgK}$$

with accuracy 0.05% for 0–100°C but 7% error at 200°C. For better accuracy above 100°C,

$$c_P = 4209 - 1.31 T_C + 0.014 T_C^2 \text{ J kg}^{-1} \text{ K}^{-1}$$

which is within 0.2% for 3–200°C.

The thermal conductivity k of water varies significantly, with

$$k = 0.5706 + 1.756 \times 10^{-3} T_C - 6.46 \times 10^{-6} T_C^2$$

which is within 0.3% from 1 to 200°C.

The Prandtl number may best be found from its definition:

$$Pr = \frac{c_P \mu}{k}$$

It varies considerably, reducing sharply with temperature.

The bulk modulus B at 15°C is 2.15 GPa. This constant value is within 8% from 0 to 100°C. The variation with temperature is given by

$$B = 2.29 \times 10^9 (1 - 48 \times 10^{-6} (T_C - 53)^2)$$

which is within 1% for 0–100°C.

The surface tension σ of water against air is 73.5 mN/m at 15°C. A constant value of 68 mN/m is within 12% from 0 to 100°C. The expression

$$\sigma = 0.0760 - 1.677 \times 10^{-4} T_C$$

is within 0.6% from 0 to 100°C.