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:

$$\begin{aligned}
\rho &= 999.1\,\mathrm{kg/m^3} \\
\mu &= 1.139 \times 10^{-3}\,\mathrm{N\ s/m^2} \\
\nu &= 1.140 \times 10^{-6}\,\mathrm{m^2/s} \\
k &= 0.596\,\mathrm{W/m\ K} \\
c_\mathrm{P} &= 4186\,\mathrm{J/kg\ K} \\
Pr &= 7.82 \\
B &= 2.15\,\mathrm{GPa}\ \text{(bulk modulus)} \\
\sigma &= 73.5\,\mathrm{mN/m}
\end{aligned}$$

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

$$\begin{aligned}
\rho &= 988.0\,\mathrm{kg\ m^{-3}} \\
\mu &= 0.547 \times 10^{-3}\,\mathrm{N\ s/m^2} \\
\nu &= 0.553 \times 10^{-6}\ \mathrm{m^2/s} \\
k &= 0.644\,\mathrm{W/m\ K} \\
c_\mathrm{P} &= 4186\,\mathrm{J/kg\ K} \\
Pr &= 3.56 \\
B &= 2.29\,\mathrm{GPa} \\
\sigma &= 67.9\,\mathrm{mN/m}
\end{aligned}$$

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

The Shock Absorber Handbook, Second Edition John C. Dixon
 ISBN: 978-0-470-51020-9

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

$$\rho = 998\,\mathrm{kg/m}$$

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/m^2), 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

$$c_P = 4200\,\mathrm{J/kgK}$$

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

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

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.