| Length | Volume |
|---|---|
| 1 ft = 12 in = 0.3048 m<br>1 mi = 5280 ft = 1609.344 m<br>1 nautical mile (nmi) = 6076 ft = 1852 m<br>1 yd = 3 ft = 0.9144 m<br>1 angstrom (Å) = 1.0 E-10 m | 1 $ft^3$ = 0.028317 $m^3$<br>1 U.S. gal = 231 $in^3$ = 0.0037854 $m^3$<br>1 L = 0.001 $m^3$ = 0.035315 $ft^3$<br>1 U.S. fluid ounce = 2.9574 E-5 $m^3$<br>1 U.S. quart (qt) = 9.4635 E-4 $m^3$ |
| **Mass** | **Area** |
| 1 slug = 32.174 lbm = 14.594 kg<br>1 lbm = 0.4536 kg<br>1 short ton = 2000 lbm = 907.185 kg<br>1 tonne = 1000 kg | 1 $ft^2$ = 0.092903 $m^2$<br>1 $mi^2$ = 2.78784 E7 $ft^2$ = 2.59 E6 $m^2$<br>1 acre = 43,560 $ft^2$ = 4046.9 $m^2$<br>1 hectare (ha) = 10,000 $m^2$ |
| **Velocity** | **Acceleration** |
| 1 ft/s = 0.3048 m/s<br>1 mi/h = 1.466666 ft/s = 0.44704 m/s<br>1 kn = 1 nmi/h = 1.6878 ft/s = 0.5144 m/s | 1 $ft/s^2$ = 0.3048 $m/s^2$ |
| **Mass flow** | **Volume flow** |
| 1 slug/s = 14.594 kg/s<br>1 lbm/s = 0.4536 kg/s | 1 gal/min = 0.002228 $ft^3/s$ = 0.06309 L/s<br>1 $\times 10^6$ gal/day = 1.5472 $ft^3/s$ = 0.04381 $m^3/s$ |
| **Pressure** | **Force** |
| 1 $lbf/ft^2$ = 47.88 Pa<br>1 $lbf/in^2$ = 144 $lbf/ft^2$ = 6895 Pa<br>1 atm = 2116.2 $lbf/ft^2$ = 14.696 $lbf/in^2$ = 101,325 Pa<br>1 inHg (at 20°C) = 3375 Pa<br>1 bar = 1.0 E5 Pa | 1 lbf = 4.448222 N = 16 oz<br>1 kgf = 2.2046 lbf = 9.80665 N<br>1 U.S. (short) ton = 2000 lbf<br>1 dyne = 1.0 E-5 N<br>1 ounce (avoirdupois) (oz) = 0.27801 N |

| Energy | Power |
|---|---|
| 1 ft · lbf = 1.35582 J<br>1 Btu = 252 cal = 1055.056 J = 778.17 ft · lbf<br>1 kilowatt hour (kWh) = 3.6 E6 J | 1 hp = 550 ft · lbf/s = 745.7 W<br>1 ft · lbf/s = 1.3558 W |
| **Specific weight** | **Density** |
| 1 lbf/ft$^3$ = 157.09 N/m$^3$ | 1 slug/ft$^3$ = 515.38 kg/m$^3$<br>1 lbm/ft$^3$ = 16.0185 kg/m$^3$<br>1 g/cm$^3$ = 1000 kg/m$^3$ |
| **Viscosity** | **Kinematic viscosity** |
| 1 slug/(ft · s) = 47.88 kg/(m · s)<br>1 poise (P) = 1 g/(cm · s) = 0.1 kg/(m · s) | 1 ft$^2$/h = 0.000025806 m$^2$/s<br>1 stokes (St) = 1 cm$^2$/s = 0.0001 m$^2$/s |

**Temperature scale readings**

$T_F = \frac{9}{5}T_C + 32$ $\quad T_C = \frac{5}{9}(T_F - 32)$ $\quad T_R = T_F + 459.69$ $\quad T_K = T_C + 273.16$

where subscripts F, C, R, and K refer to readings on the Fahrenheit, Celsius, Kelvin, and Rankine scales, respectively

| Specific heat or gas constant* | Thermal conductivity* |
|---|---|
| 1 ft · lbf/(slug · °R) = 0.16723 N · m/(kg · K)<br>1 Btu/(lb · °R) = 4186.8 J/(kg · K) | 1 Btu/(h · ft · °R) = 1.7307 W/(m · K) |

*Although the absolute (Kelvin) and Celsius temperature scales have different starting points, the intervals are the same size: 1 kelvin = 1 Celsius degree. The same holds true for the nonmetric absolute (Rankine) and Fahrenheit scales: 1 Rankine degree = 1 Fahrenheit degree. It is customary to express temperature differences in absolute-temperature units.

$$1 \text{ newton of force} = 1 \text{ N} \equiv 1 \text{ kg} \cdot \text{m/s}^2$$

$$1 \text{ pound of force} = 1 \text{ lbf} \equiv 1 \text{ slug} \cdot \text{ft/s}^2 = 4.4482 \text{ N}$$

| Primary dimension | SI unit | BG unit | Conversion factor |
|---|---|---|---|
| Mass $\{M\}$ | Kilogram (kg) | Slug | 1 slug = 14.5939 kg |
| Length $\{L\}$ | Meter (m) | Foot (ft) | 1 ft = 0.3048 m |
| Time $\{T\}$ | Second (s) | Second (s) | 1 s = 1 s |
| Temperature $\{\Theta\}$ | Kelvin (K) | Rankine (°R) | 1 K = 1.8°R |

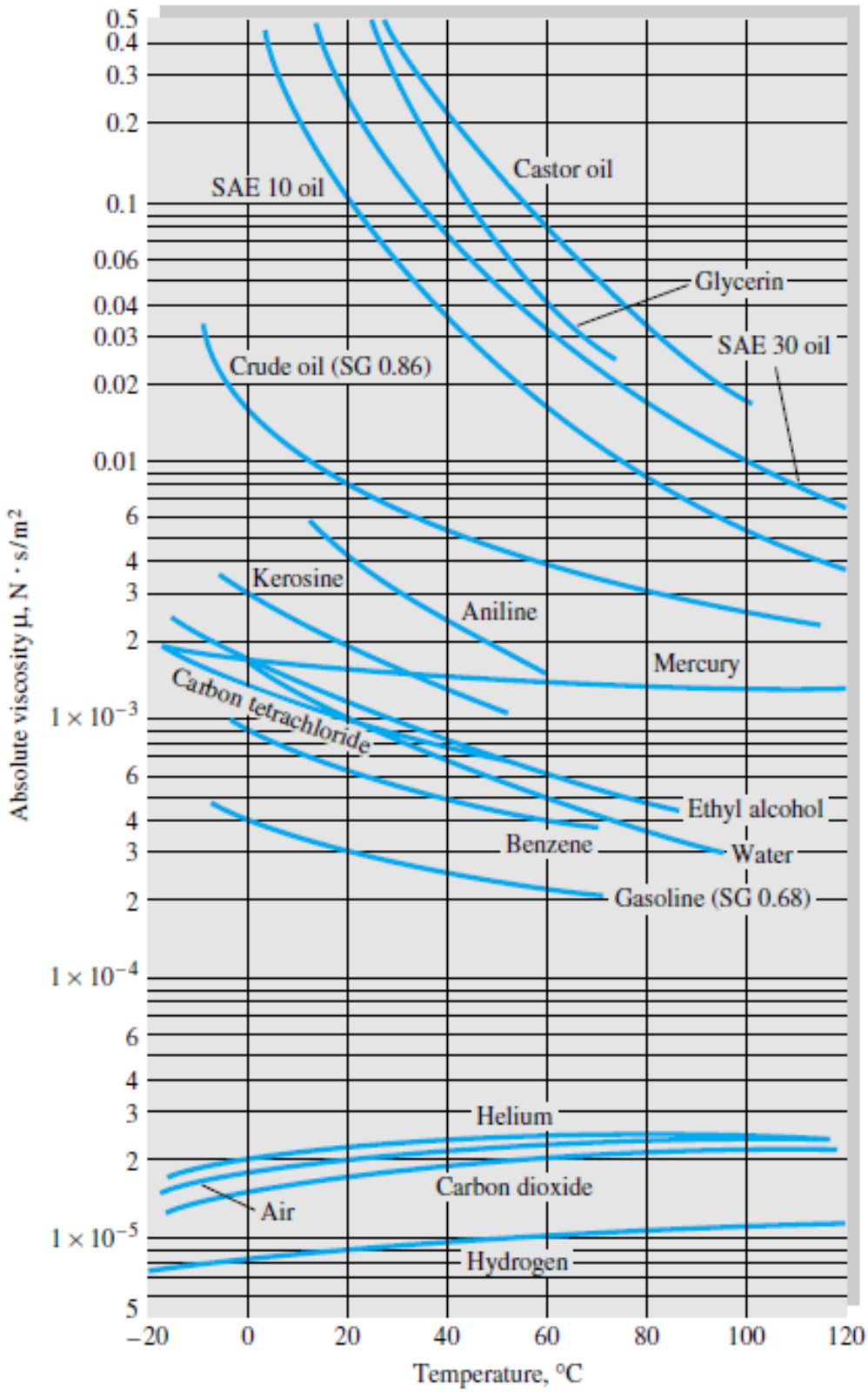
| Secondary dimension | SI unit | BG unit | Conversion factor |
|---|---|---|---|
| Area $\{L^2\}$ | $m^2$ | $ft^2$ | $1\ m^2 = 10.764\ ft^2$ |
| Volume $\{L^3\}$ | $m^3$ | $ft^3$ | $1\ m^3 = 35.315\ ft^3$ |
| Velocity $\{LT^{-1}\}$ | m/s | ft/s | 1 ft/s = 0.3048 m/s |
| Acceleration $\{LT^{-2}\}$ | $m/s^2$ | $ft/s^2$ | $1\ ft/s^2 = 0.3048\ m/s^2$ |
| Pressure or stress $\{ML^{-1}T^{-2}\}$ | $Pa = N/m^2$ | $lbf/ft^2$ | $1\ lbf/ft^2 = 47.88\ Pa$ |
| Angular velocity $\{T^{-1}\}$ | $s^{-1}$ | $s^{-1}$ | $1\ s^{-1} = 1\ s^{-1}$ |
| Energy, heat, work $\{ML^2T^{-2}\}$ | $J = N \cdot m$ | $ft \cdot lbf$ | $1\ ft \cdot lbf = 1.3558\ J$ |
| Power $\{ML^2T^{-3}\}$ | W = J/s | $ft \cdot lbf/s$ | $1\ ft \cdot lbf/s = 1.3558\ W$ |
| Density $\{ML^{-3}\}$ | $kg/m^3$ | $slugs/ft^3$ | $1\ slug/ft^3 = 515.4\ kg/m^3$ |
| Viscosity $\{ML^{-1}T^{-1}\}$ | $kg/(m \cdot s)$ | $slugs/(ft \cdot s)$ | $1\ slug/(ft \cdot s) = 47.88\ kg/(m \cdot s)$ |
| Specific heat $\{L^2T^{-2}\Theta^{-1}\}$ | $m^2/(s^2 \cdot K)$ | $ft^2/(s^2 \cdot {}^\circ R)$ | $1\ m^2/(s^2 \cdot K) = 5.980\ ft^2/(s^2 \cdot {}^\circ R)$ |

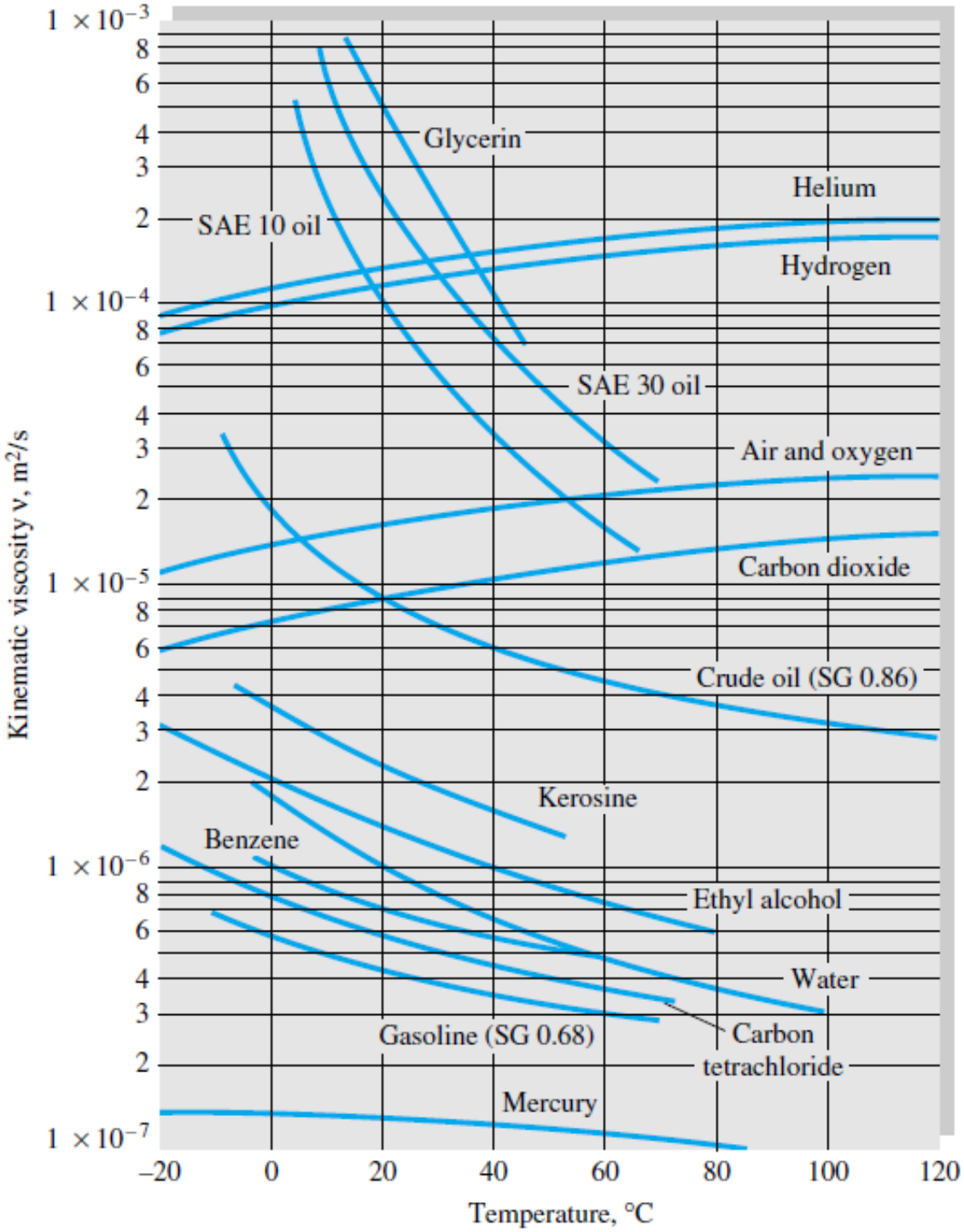
$$^\circ R = {}^\circ F + 459.69$$
$$K = {}^\circ C + 273.16$$

| Multiplicative factor | Prefix | Symbol |
|---|---|---|
| $10^{12}$ | tera | T |
| $10^9$ | giga | G |
| $10^6$ | mega | M |
| $10^3$ | kilo | k |
| $10^2$ | hecto | h |
| 10 | deka | da |
| $10^{-1}$ | deci | d |
| $10^{-2}$ | centi | c |
| $10^{-3}$ | milli | m |
| $10^{-6}$ | micro | $\mu$ |
| $10^{-9}$ | nano | n |
| $10^{-12}$ | pico | p |
| $10^{-15}$ | femto | f |
| $10^{-18}$ | atto | a |

| Fluid | $\mu$, kg/(m · s)† | Ratio $\mu/\mu(H_2)$ | $\rho$, kg/m$^3$ | $\nu$ m$^2$/s† | Ratio $\nu/\nu$(Hg) |
|---|---|---|---|---|---|
| Hydrogen | 8.8 E–6 | 1.0 | 0.084 | 1.05 E–4 | 920 |
| Air | 1.8 E–5 | 2.1 | 1.20 | 1.51 E–5 | 130 |
| Gasoline | 2.9 E–4 | 33 | 680 | 4.22 E–7 | 3.7 |
| Water | 1.0 E–3 | 114 | 998 | 1.01 E–6 | 8.7 |
| Ethyl alcohol | 1.2 E–3 | 135 | 789 | 1.52 E–6 | 13 |
| Mercury | 1.5 E–3 | 170 | 13,580 | 1.16 E–7 | 1.0 |
| SAE 30 oil | 0.29 | 33,000 | 891 | 3.25 E–4 | 2,850 |
| Glycerin | 1.5 | 170,000 | 1,264 | 1.18 E–3 | 10,300 |

†1 kg/(m · s) = 0.0209 slug/(ft · s); 1 m$^2$/s = 10.76 ft$^2$/s.


Absolute viscosity μ, N · s/m²
Temperature, °C
0.5
0.4
0.3
0.2
0.1
0.06
0.04
0.03
0.02
0.01
6
4
3
2
1 × 10⁻³
6
4
3
2
1 × 10⁻⁴
6
4
3
2
1 × 10⁻⁵
5
−20
0
20
40
60
80
100
120
SAE 10 oil
Castor oil
Glycerin
SAE 30 oil
Crude oil (SG 0.86)
Kerosine
Aniline
Mercury
Carbon tetrachloride
Ethyl alcohol
Benzene
Water
Gasoline (SG 0.68)
Helium
Carbon dioxide
Air
Hydrogen


Kinematic viscosity ν, m²/s
1 × 10⁻³
8
6
4
3
2
1 × 10⁻⁴
8
6
4
3
2
1 × 10⁻⁵
8
6
4
3
2
1 × 10⁻⁶
8
6
4
3
2
1 × 10⁻⁷
–20
0
20
40
60
80
100
120
Temperature, °C
Glycerin
SAE 10 oil
Helium
Hydrogen
SAE 30 oil
Air and oxygen
Carbon dioxide
Crude oil (SG 0.86)
Kerosine
Benzene
Ethyl alcohol
Water
Carbon tetrachloride
Gasoline (SG 0.68)
Mercury

## جدول تغییرات چگالی و لزجت دینامیکی آب

| $T$, °C | $\rho$, kg/m$^3$ | $\mu$, N · s/m$^2$ | $\nu$, m$^2$/s | $T$, °F | $\rho$, slug/ft$^3$ | $\mu$, lb · s/ft$^2$ | $\nu$, ft$^2$/s |
|---|---|---|---|---|---|---|---|
| 0 | 1000 | 1.788 E-3 | 1.788 E-6 | 32 | 1.940 | 3.73 E-5 | 1.925 E-5 |
| 10 | 1000 | 1.307 E-3 | 1.307 E-6 | 50 | 1.940 | 2.73 E-5 | 1.407 E-5 |
| 20 | 998 | 1.003 E-3 | 1.005 E-6 | 68 | 1.937 | 2.09 E-5 | 1.082 E-5 |
| 30 | 996 | 0.799 E-3 | 0.802 E-6 | 86 | 1.932 | 1.67 E-5 | 0.864 E-5 |
| 40 | 992 | 0.657 E-3 | 0.662 E-6 | 104 | 1.925 | 1.37 E-5 | 0.713 E-5 |
| 50 | 988 | 0.548 E-3 | 0.555 E-6 | 122 | 1.917 | 1.14 E-5 | 0.597 E-5 |
| 60 | 983 | 0.467 E-3 | 0.475 E-6 | 140 | 1.908 | 0.975 E-5 | 0.511 E-5 |
| 70 | 978 | 0.405 E-3 | 0.414 E-6 | 158 | 1.897 | 0.846 E-5 | 0.446 E-5 |
| 80 | 972 | 0.355 E-3 | 0.365 E-6 | 176 | 1.886 | 0.741 E-5 | 0.393 E-5 |
| 90 | 965 | 0.316 E-3 | 0.327 E-6 | 194 | 1.873 | 0.660 E-5 | 0.352 E-5 |
| 100 | 958 | 0.283 E-3 | 0.295 E-6 | 212 | 1.859 | 0.591 E-5 | 0.318 E-5 |

## جدول تغییرات چگالی و لزجت دینامیکی هوا

| $T$, °C | $\rho$, kg/m$^3$ | $\mu$, N · s/m$^2$ | $\nu$, m$^2$/s | $T$, °F | $\rho$, slug/ft$^3$ | $\mu$, lb · s/ft$^2$ | $\nu$, ft$^2$/s |
|---|---|---|---|---|---|---|---|
| −40 | 1.52 | 1.51 E-5 | 0.99 E-5 | −40 | 2.94 E-3 | 3.16 E-7 | 1.07 E-4 |
| 0 | 1.29 | 1.71 E-5 | 1.33 E-5 | 32 | 2.51 E-3 | 3.58 E-7 | 1.43 E-4 |
| 20 | 1.20 | 1.80 E-5 | 1.50 E-5 | 68 | 2.34 E-3 | 3.76 E-7 | 1.61 E-4 |
| 50 | 1.09 | 1.95 E-5 | 1.79 E-5 | 122 | 2.12 E-3 | 4.08 E-7 | 1.93 E-4 |
| 100 | 0.946 | 2.17 E-5 | 2.30 E-5 | 212 | 1.84 E-3 | 4.54 E-7 | 2.47 E-4 |
| 150 | 0.835 | 2.38 E-5 | 2.85 E-5 | 302 | 1.62 E-3 | 4.97 E-7 | 3.07 E-4 |
| 200 | 0.746 | 2.57 E-5 | 3.45 E-5 | 392 | 1.45 E-3 | 5.37 E-7 | 3.71 E-4 |
| 250 | 0.675 | 2.75 E-5 | 4.08 E-5 | 482 | 1.31 E-3 | 5.75 E-7 | 4.39 E-4 |
| 300 | 0.616 | 2.93 E-5 | 4.75 E-5 | 572 | 1.20 E-3 | 6.11 E-7 | 5.12 E-4 |
| 400 | 0.525 | 3.25 E-5 | 6.20 E-5 | 752 | 1.02 E-3 | 6.79 E-7 | 6.67 E-4 |
| 500 | 0.457 | 3.55 E-5 | 7.77 E-5 | 932 | 0.89 E-3 | 7.41 E-7 | 8.37 E-4 |

## جدول خصوصیات سیالات در فشار یک اتمسفر و دمای ۲۰ درجه سانتیگراد (۶۸ درجه فارنهایت)

| Liquid | $\rho$, kg/m$^3$ | $\mu$, kg/(m · s) | Y, N/m* | $p_v$, N/m$^2$ | Bulk modulus, N/m$^2$ | Viscosity parameter $C$† |
|---|---|---|---|---|---|---|
| Ammonia | 608 | 2.20 E-4 | 2.13 E-2 | 9.10 E+5 | — | 1.05 |
| Benzene | 881 | 6.51 E-4 | 2.88 E-2 | 1.01 E+4 | 1.4 E+9 | 4.34 |
| Carbon tetrachloride | 1,590 | 9.67 E-4 | 2.70 E-2 | 1.20 E+4 | 9.65 E+8 | 4.45 |
| Ethanol | 789 | 1.20 E-3 | 2.28 E-2 | 5.7 E+3 | 9.0 E+8 | 5.72 |
| Ethylene glycol | 1,117 | 2.14 E-2 | 4.84 E-2 | 1.2 E+1 | — | 11.7 |
| Freon 12 | 1,327 | 2.62 E-4 | — | — | — | 1.76 |
| Gasoline | 680 | 2.92 E-4 | 2.16 E-2 | 5.51 E+4 | 9.58 E+8 | 3.68 |
| Glycerin | 1,260 | 1.49 | 6.33 E-2 | 1.4 E-2 | 4.34 E+9 | 28.0 |
| Kerosine | 804 | 1.92 E-3 | 2.8 E-2 | 3.11 E+3 | 1.6 E+9 | 5.56 |
| Mercury | 13,550 | 1.56 E-3 | 4.84 E-1 | 1.1 E-3 | 2.55 E+10 | 1.07 |
| Methanol | 791 | 5.98 E-4 | 2.25 E-2 | 1.34 E+4 | 8.3 E+8 | 4.63 |
| SAE 10W oil | 870 | 1.04 E-1‡ | 3.6 E-2 | — | 1.31 E+9 | 15.7 |
| SAE 10W30 oil | 876 | 1.7 E-1‡ | — | — | — | 14.0 |
| SAE 30W oil | 891 | 2.9 E-1‡ | 3.5 E-2 | — | 1.38 E+9 | 18.3 |
| SAE 50W oil | 902 | 8.6 E-1‡ | — | — | — | 20.2 |
| Water | 998 | 1.00 E-3 | 7.28 E-2 | 2.34 E+3 | 2.19 E+9 | Table A.1 |
| Seawater (30%) | 1,025 | 1.07 E-3 | 7.28 E-2 | 2.34 E+3 | 2.33 E+9 | 7.28 |

*In contact with air.

†The viscosity-temperature variation of these liquids may be fitted to the empirical expression

$$\frac{\mu}{\mu_{20^\circ\mathrm{C}}} \approx \exp\left[C\left(\frac{293\ \mathrm{K}}{T\ \mathrm{K}} - 1\right)\right]$$

with accuracy of $\pm 6$ percent in the range $0 \le T \le 100^\circ\mathrm{C}$.

‡Representative values. The SAE oil classifications allow a viscosity variation of up to $\pm 50$ percent, especially at lower temperatures.

## جدول خصوصیات گازها در فشار یک اتمسفر و دمای ۲۰ درجه سانتیگراد (۶۸ درجه فارنهایت)

| Gas | Molecular weight | $R$, $m^2/(s^2 \cdot K)$ | $\rho g$, $N/m^3$ | $\mu$, $N \cdot s/m^2$ | Specific-heat ratio | Power-law exponent $n^\dagger$ |
|---|---|---|---|---|---|---|
| $H_2$ | 2.016 | 4124 | 0.822 | 9.05 E-6 | 1.41 | 0.68 |
| He | 4.003 | 2077 | 1.63 | 1.97 E-5 | 1.66 | 0.67 |
| $H_2O$ | 18.02 | 461 | 7.35 | 1.02 E-5 | 1.33 | 1.15 |
| Ar | 39.944 | 208 | 16.3 | 2.24 E-5 | 1.67 | 0.72 |
| Dry air | 28.96 | 287 | 11.8 | 1.80 E-5 | 1.40 | 0.67 |
| $CO_2$ | 44.01 | 189 | 17.9 | 1.48 E-5 | 1.30 | 0.79 |
| CO | 28.01 | 297 | 11.4 | 1.82 E-5 | 1.40 | 0.71 |
| $N_2$ | 28.02 | 297 | 11.4 | 1.76 E-5 | 1.40 | 0.67 |
| $O_2$ | 32.00 | 260 | 13.1 | 2.00 E-5 | 1.40 | 0.69 |
| NO | 30.01 | 277 | 12.1 | 1.90 E-5 | 1.40 | 0.78 |
| $N_2O$ | 44.02 | 189 | 17.9 | 1.45 E-5 | 1.31 | 0.89 |
| $Cl_2$ | 70.91 | 117 | 28.9 | 1.03 E-5 | 1.34 | 1.00 |
| $CH_4$ | 16.04 | 518 | 6.54 | 1.34 E-5 | 1.32 | 0.87 |

$^\dagger$The power-law curve fit, Eq. (1.27), $\mu/\mu_{293K} \approx (T/293)^n$, fits these gases to within $\pm 4$ percent in the range $250 \leq T \leq 1000$ K. The temperature must be in kelvins.

**جدول تغییرات کشش سطحی، فشار بخار و سرعت صورت در آب نسبت به درجه حرارت**

| T, °C | Y, N/m | $p_v$, kPa | $a$, m/s |
|---|---|---|---|
| 0 | 0.0756 | 0.611 | 1402 |
| 10 | 0.0742 | 1.227 | 1447 |
| 20 | 0.0728 | 2.337 | 1482 |
| 30 | 0.0712 | 4.242 | 1509 |
| 40 | 0.0696 | 7.375 | 1529 |
| 50 | 0.0679 | 12.34 | 1542 |
| 60 | 0.0662 | 19.92 | 1551 |
| 70 | 0.0644 | 31.16 | 1553 |
| 80 | 0.0626 | 47.35 | 1554 |
| 90 | 0.0608 | 70.11 | 1550 |
| 100 | 0.0589 | 101.3 | 1543 |
| 120 | 0.0550 | 198.5 | 1518 |
| 140 | 0.0509 | 361.3 | 1483 |
| 160 | 0.0466 | 617.8 | 1440 |
| 180 | 0.0422 | 1,002 | 1389 |
| 200 | 0.0377 | 1,554 | 1334 |
| 220 | 0.0331 | 2,318 | 1268 |
| 240 | 0.0284 | 3,344 | 1192 |
| 260 | 0.0237 | 4,688 | 1110 |
| 280 | 0.0190 | 6,412 | 1022 |
| 300 | 0.0144 | 8,581 | 920 |
| 320 | 0.0099 | 11,274 | 800 |
| 340 | 0.0056 | 14,586 | 630 |
| 360 | 0.0019 | 18,651 | 370 |
| 374* | 0.0* | 22,090* | 0* |

*Critical point.