# 10 Conversion Factors and Other Tables

Despite the existence of SI units and standards (ISO, DIN, etc), the literature contains a multitude of dimensional units. The units cited in the literature have, in most cases, been retained in this book in order to make comparison with the original source easier. The tables given in this chapter enable the reader to perform the conversions. In the man-made fiber and textile industry, many other non-standard units, are used, e.g., m/min, dtex = den : 0.9, Nm or Ne. Some of these have once again been officially adopted in various countries. For specific (i.e., linear density based) tenacity alone, one finds more than twelve different units in the literature. The differences are not only country-specific, but also depend on the author and the topic discussed. In many cases, the material density (mostly in $g/cm^3$) is involved in the tenacity calculation, thereby introducing a variation of $\pm 2\%$, depending on source.

This chapter provides a collection of conversion formulas for spinning data, solution viscosities and stoichiometric formulas, as well as the Mollier i, x diagram for air conditioning calculations and physical and chemical properties of important monomers, solvents and polymers. Sometimes the data cited in the literature contains significant discrepancies; in such cases, two values or ranges are quoted here.

**Table 10.1** Decimal Definitions and SI Units [1]

**Prefixes for SI Units**

| Factor | Prefix | Symbol | Usual name Germany/England | Usual name USA/France |
|---|---|---|---|---|
| $10^{18}$ | exa | E | trillion | quintillion |
| $10^{15}$ | peta | P | billard | quadrillion |
| $10^{12}$ | tera | T | billion | trillion |
| $10^{9}$ | giga | G | milliard | billion |
| $10^{6}$ | mega | M | million | million |
| $10^{3}$ | kilo | k | thousand | thousand |
| $10^{2}$ | hekto | h | hundred | hundred |
| $10^{1}$ | deka | da | ten | ten |
| $10^{-1}$ | deci | d | tenth | tenth |
| $10^{-2}$ | centi | c | hundredth | hundredth |
| $10^{-3}$ | milli | m | thousandth | thousandth |
| $10^{-6}$ | micro | μ | millionth | millionth |
| $10^{-9}$ | nano | n | milliardth | billionth |
| $10^{-12}$ | pico | p | billionth | trillionth |
| $10^{-15}$ | femto | f | billiardth | quadrillionth |
| $10^{-18}$ | atto | a | trillionth | quintillionth |

**SI Units**

| Physical unit Symbol | Physical unit Name | Name | Physical unit Symbol |
|---|---|---|---|
| *Basic units* | | | |
| $l$ | length | meter | m |
| $m$ | mass | kilogram | kg |
| $t$ | time | second | s |
| $I$ | electrical current | ampere | A |
| $T$ | thermodynamic temperature | kelvin | K |
| $I_V$ | luminous intensity | candela | cd |
| $n$ | reaction quantity | mole | mol |
| *Supplementary units* | | | |
| $\alpha, \beta, \gamma$ | plane angle | radian | rad |
| $\omega, \Omega$ | solid angle | steradian | sr |
| *Derived units* | | | |
| $F$ | force | newton | $N = J \cdot m^{-1} = kg \cdot m \cdot s^{-2}$ |
| $E$ | energy, work, heat | joule | $J = Nm = kg \cdot m^2 \cdot s^{-2}$ |
| $P$ | power | watt | $W = VA = J \cdot s^{-1}$ |
| $p$ | pressure, stress | pascal | $Pa = Nm^{-2} = J \cdot m^{-3}$ |
| $\nu$ | frequency | hertz | $Hz = s^{-1}$ |
| $Q$ | electric charge | coulomb | $C = A \cdot s$ |
| $U$ | electrical potential difference, voltage | volt | $V = JC^{-1} = WA^{-1}$ |
| $R$ | electrical resistance | ohm | $\Omega = VA^{-1}$ |
| $G$ | electrical conductance | siemens | $S = AV^{-1}$ |
| $C$ | electrical capacitance | farad | $F = As\ V^{-1}$ |
| $\varepsilon$ | relative permittivity | — | 1 |
| $\Phi$ | magnetic flux | weber | $Wb = Vs$ |
| $L$ | electrical self-inductance, magnetic conductance | henry | $H = Wb\ A^{-1}$ |
| $B$ | magnetic flux density | tesla | $T = Wbm^{-2}$ |
| $\Phi_v$ | luminous flux | lumen | $lm = cd\ sr$ |
| $E_v$ | illumination | lux | $lx = lm\ m^{-2}$ |
| – | radioactivity | becquerel | $Bq = s^{-1}$ |
| – | radiation dose | gray | $Gy = Jkg^{-1}$ |

**Table 10.2** Dimensional Conversion Factors

| | |
|---|---|
| *Length* | 1 m = $10^3$ mm = $10^6$ μm = $10^9$ nm = $10^{10}$ Å |
| | 1 mile = 1609.3 m |
| | 1 yd = 0.9144 m (= 3ft = 36 inches) |
| | 1 ft = 12′ = 0.3048 m |
| | 1 inch = 1″ = 25.4 mm |
| | 1 mil = 0.0254 mm |
| *Area* | 1 $m^2$ = $10^4$ $cm^2$ = $10^6$ $mm^2$ = $10^{-4}$ ha |
| | 1 sq.mi = 2.590 · $10^6$ $m^2$ |
| | 1 acre = 4.047 · $10^3$ $m^2$ |
| | 1 sq.yd. = 0.8361 $m^2$ |
| | 1 sq.ft. = 92903 · $10^{-2}$ $m^2$ |
| | 1 sq.inch = 6.4516 $cm^2$ |
| *Volume* | 1 $m^3$ = $10^3$ $dm^3$(= l) = $10^6$ $cm^3$ = $10^9$ $mm^3$ |
| | 1 cb.yd. = 0.7646 $m^3$ |
| | 1 US barrel = 0.119 $m^3$ |
| | 1 cb.ft = 28.317 = 0.028317 $m^3$ |
| | 1 US gal. = 3.7854 |
| | 1 US qt.( = quart) = 0.9463 l |
| | 1 US ounce = 29.574 $cm^3$ |
| | 1 cb.inch = 16.387 $cm^3$ (US) |
| *Mass (weight)* | 1 kg = $10^3$ g = $10^{-3}$ t (also) = 1 kp;kilopond) |
| | 1 short ton = 907.2 kg (US) |
| | 1 long ton = 1016.05 kg (GB) |
| | 1 lb. = 0.45359 kg = 16 oz. |
| | 1 oz.( = ounce) = 28.350 g |
| | 1 ct.( = carat) = 0.2 g |
| *Force* | 1 N = 100 cN = $10^{-3}$ kN = 0.102 kg (kp) |
| | 1 oz( = ounce) = 27.80 cN = 28.35 g |
| | 1 lb. = 444.8 cN = 0.4536 kg (kp) |
| | 1 dyn = $10^{-5}$ N |
| *Pressure* | 1 Pa = 0.0102 kg/$m^2$ = 0.01 mbar |
| | 1 MPa = 1 MN/$m^2$ = 1 N/$mm^2$ |
| | 1 bar = 1000 mbar = $10^5$ Pa = 0.1 MPa |
| | 1 phys.atm. = 1 atm = 0.1083 MPa |
| | 1 techn.atm. = 1 at = 0.09807 MPa |
| | 1 bar = 1000 mbar = $10^5$ Pa = 0.1 MPa |
| | 1 Torr = 1 mm Hg = 1.3332 MPa |
| | 1 inch Hg = 3.386 · $10^{-3}$ MPa = 3.386 · $10^{-2}$ bar = = 3.453 · $10^{-2}$ at (kg/$cm^2$) |
| | 1 lb./sq.inch = 0.06895 bar = 1 psi. (1 bar = 14.504 psi.) |
| | 1 lb./sq.ft. = 1.48865 MPa |
| | 1 mm w.g. = 0.0980 mbar = 0.0397 inch w.g. |
| *Work, energy, heat* | 1 J = 1 Nm = 1 Ws |
| | 1 kWh = 3.6 · $10^6$ J = 860 kcal |
| | 1 mkg = 9.804 J |
| | 1 BTU = 1055 J = 107.6 kgm |
| | 1 kcal = 426.9 kgm = 4187 J |
| | 1 eV = 1.6021 · $10^{-19}$ J |
| *Power* | 1 W = 1 J/s = $10^{-3}$ kW |
| | 1 PS (German hp) = 735.5 W |
| | 1 hp = 745.7 W = 1.0137 PS |
| | 1 kcal/h = 1.162 W |
| | 1 BTU/h = 0.2929 W |
| | 1 erg/s = $10^{-7}$ W |
| | 1 kW = 1.3596 PS |
| *Density* | 1 g/$cm^3$ = 1 kg/$dm^3$ = 1000 kg/$m^3$ |
| | 1 lb./cb.inch = 27.680 g/$cm^3$ |
| | 1 oz./cb.inch = 1.7300 g/$cm^3$ |
| | 1 lb./cb.ft. = 1.60185 · $10^{-2}$ g/$cm^3$ |
| | 1 lb./gal. (US) = 7.4892 · $10^{-3}$ g/$cm^3$ |
| *Time* | 1 a (annum) = 1 y (year) = 3.1558 · $10^7$ s |
| | 1 mo (month) = 2.630 · $10^6$ s |
| | 1 d (day) = 86 400 s |
| | 1 h = 3600 s |
| | 1 min = 60 s |
| | 1 working year ≙ 340 working days or ≙ 240 day shifts, each 8 h |
| *Specific heat* | 1 kcal/kg K = 4187 J/kg K = = 4.187 · $10^3$ BTU/lb. °F |
| *Velocity, speed* | 1 m/s = 60 m/min = 3.6 km/h |
| | 1 ft./min = 5.080 · $10^{-3}$ m/s |
| | 1 ft./s = 0.3048 m/s |
| | 1 knot = 0.5144 m/s |

*Flow rate*

1 cb.ft./s = 0.02832 $m^3/s$
1 cb.ft./min = $4.720 \cdot 10^{-4}$ $m^3/s$
1 gal (US)/min = $6.31 \cdot 10^{-5}$ $m^3/s$

*Thermal conductivity*

1 kcal/m h °C = 1.1628 W/m K
1 BTU/ft. h°F = 1.7295 W/m K
1 cal/cm s °C = 418.41 W/m K

*Heat transfer coefficient*

1 kcal/$m^2$ h °C = 1.1628 W/$m^2$ K
1 BTU/sq.ft. h °F = 5.682 W/$m^2$ K
1 cal/$cm^2$ s °C = $4.1868 \cdot 10^4$ W/$m^2$ K

*Linear density (fineness, titer)*

1 tex = $10^{-6}$ kg/m = 10 dtex = g/1000 m
1 den = g/9000 m = 0.9 dtex
1 Nm = 1000/tex = 9000/den
(= metric count)
$s' \approx 150/\sqrt{\text{dtex}}$ (= English unit for wool fineness: see tables for exact values)
1 Ne = 0.5905 · Nm(= English cotton count)
1 $Ne_L$ = 1.6535 · Nm(= English linen lea (count))
1 $Ne_K$ = 0.8858 · Nm(= English worsted count)
Comments: 1 Ne = 1 hank of 840 yd./1 lb.
1 $Ne_L$ = 1 · 300 yd./1 lb.
1 $Ne_K$ = 1 · 300 yd./1 lb.

*Dynamic viscosity*

1 P(oise) = 0.1 Pa · s = $1.020 \cdot 10^{-2}$ kg s/$m^2$
1 lb./sq.ft. s = 0.2089 N/$m^2$

*Kinematic viscosity*

1 St(oke) = $10^{-4}$ $m^2/s$

*Specific tenacity, elastic modulus*

1 g/tex = 0.1 g/dtex = 1 kg/$mm^2$
(for $\gamma = 1$ g/$cm^3$) = 0.1111 g/den
1 GPa = $10^9$ N/$m^2$ = $10^3$ N/$mm^2$ =
= 11.33 · g/den/$\gamma$ = 102 · g/tex/$\gamma$ =
= 10.2 · g/dtex/$\gamma$
1 N/$m^2$ = $1.02 \cdot 10^{-7}$ g/tex/$\gamma$
1 N/$mm^2$ = 0.102 g/tex/$\gamma$ = 0.0102 g/dtex/$\gamma$
1 cN/tex = 0.102 g/dtex
1 PSI = $7.04 \cdot 10^{-2}$ g/dtex/$\gamma$
1 g/den = 0.901 g/dtex
($\gamma$ = density, g/$cm^3$)

*Breaking length under own weight* (= Rkm)

1 Rkm ≈ 10 · $(g/dtex)_{Tenacity}$

*Filament diameter (round only)*

d (µm) = $10\sqrt{4\ dtex\ \pi/\gamma} = \text{km}\sqrt{dtex}$

| for | PA | PET | PP |
|---|---|---|---|
| km | 10.57 | 9.71 | 11.89 |

*Production capacity (in the fiber industry): 340 days/y × 24 × h/d*

1 kg/h ≙ 8.2 t/y ≙ 18 000 lbs./y
1 t/24 h ≙ 750 000 lbs./y
$10^6$ lbs./y = 1 mio. lbs./y = 450 t/y = 1.3 t/d =
= 55 kg/h

*Temperature*

K = °C + 273.16 °C
°C = 5 (°F − 32)/9

*Leakage rate*

1 mbar 1/s = T(K) · 0.363 lbs.(air)/h

*Square-woven wire mesh*

Free area: $F_o = w^2/(w + d)^2 \cdot 100$ (%)
w = aperture
d = wire diameter
Mesh = $2.54\sqrt{M_F}$ = mesh/inch
$M_F = 100/(w + d)^2$ = mesh/$cm^2$

*Solution viscosity*

$\eta_{rel.} = \eta/\eta_o \approx t/t_o$
= solution relative viscosity
subscript or denotes solvent
without subscript denotes solution (usually c = 0.5 or. 1%)
$\eta_{spec.} = \eta_{rel.} - 1$

$$[\eta] = IV = \lim_{c \to o} \frac{\eta - \eta_o}{c\eta_o} = \text{Intrinsic or limiting viscosity}$$

$$= \frac{1}{2K_c}[\sqrt{1 + 4K(\eta_{rel.} - 1)} - 1]$$

K = Huggins constant (see table)
$\eta_{rel.} = 1 + c[\eta] \cdot (1 + cK[\eta])$
Example using PET (K = 0.35)

$$[\eta] = \frac{1}{0.7}(\sqrt{1 + 1.4(\eta_{rel.} - 1)} - 1]$$

$$\eta_{rel.} = 1 + [\eta](1 + 0.35[\eta])$$

*Table of Solvents, Test Conditions and Huggins Constants*

| Polymer | Index* | Test conditions | K = Huggins constants |
|---|---|---|---|
| PA 6, PA 66 | 1 | Sulfuric acid (96%), 1 g/dl, 25 °C | 0.25 |
| | 2 | Formic acid (90%), 1 g/dl, 25 °C | 0.25 |
| | 3 | m-Cresol, 1 g/dl, 25 °C | 0.22 |
| | 4 | Formic acid(90%), ASTM D 789 | – |
| PET | 1 | Phenol/tetrachloroethane (1 : 1), 0.5 g/dl, 20 °C | 0.35 |
| | 2 | Phenol/tetrachloroethane (1 : 1), 0.5 g/dl, 25 °C | 0.35 |
| | 3 | Phenol/tetrachloroethane (6 : 4), 0.5 g/dl, 25 °C | 0.37 |
| | 4 | m-Cresol, 1.0 g/dl, 20 °C | 0.27 |
| | 5 | Phenol/1,2-dichlorobenzene (1 : 1), 0.5 g/dl, 25 °C | 0.35 |
| PP | 1 | Decalin, 0.1 g/dl, 135 °C | 0.29 |
| | 2 | 2.15 daN (kg), 230 °C (MFI test) | – |

*see Figs. 10.1 and 10.2 [2]

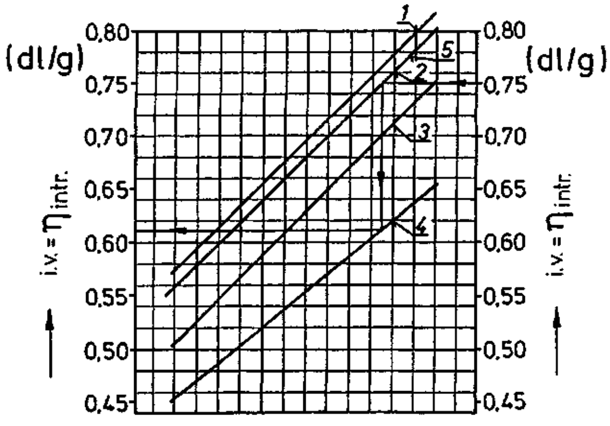



**Fig. 10. 1** Conversion nomogram for PET intrinsic viscosity IV (For IV indices, see Table 10.2 (solution viscosity))
Examples:
$IV_2$ (Ph/TCE, 1 : 1, 25 °C) = 0.750 → $IV_4$(m-cresol) = 0.610

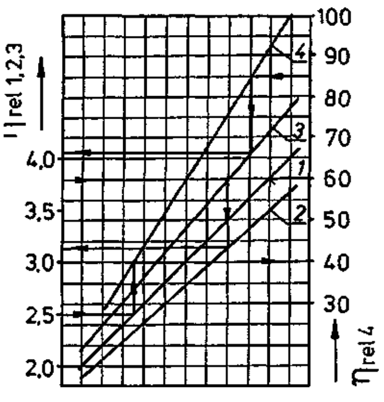



**Fig. 10. 2** Conversion nomogram for PA 6 and PA 66 relative viscosity $\eta_{rel}$ (for $\eta_{rel}$ indices, see Table 10.2 (solution viscosity))
Examples:
$\eta_{rel1}$ (sulfuric acid) = 2.50 → $\eta_{rel4}$(ASTM 789) = 40
$\eta_{rel3}$ (m-cresol) = 3.80 → $\eta_{rel2}$(formic acid) = 3.14
$\eta_{rel4}$ (ASTM 789) = 85 → $\eta_{rel3}$(m-cresol) = 4.05

*Table of Stoichiometric Formulas, etc.*

Gas density = Σ individual gas densities
e.g., ($H_2$ = 0.09 g/dm$^3$) + ($Cl_2$ = 3.17 g/dm$^3$) = (0.045 + 1.585) = 1.63 g/dm$^3$ HCl

Molar volume = $\frac{\text{molecular weight}}{\text{weight per liter}}$ = 22.4 dm$^3$ for gases (in above example: 36.5/1.63 = 22.4)

Molecular weight = sum of individual atomic weights, e.g., HCl = 1. ... + 35.5 ... = 36.5 ...
1 mole = molecular weight in g; e.g., 1 mol. HCl = 36.5 g HCl
1 mol./m$^3$ solvent = kg/m$^3$ = g/dm$^3$
1 g–equivalent = 1 mol./valency. E.g., 1 g – equiv. sulfate ion = 96 : 2 = 48 g $SO_4^{2-}$
1 g – equiv. Al ion = 26.98 : 3 = 8.99 $Al^{3+}$
pH value ≙ hydrogen ion concentration

| Equivalent acids and alkalis | pH | Merck indicator |
|---|---|---|
| 1 n hydrochloric acid | O | |
| n/1000 hydrochloric acid | 3 | dark red |
| Pure water | 7 | yellow green |
| Sea water | 8.3 | |
| | 10 | violet |
| 1 n sodium hydroxide | 14 | |

| | | | | | |
|---|---|---|---|---|---|
| Water chalk content | 5 | 10 | 15 | 20 | 25 g/100 l |
| German hardness scale ≙ | 1 ... 7 | 8 ... 12 | 13 ... 17 | 18 ... 22 | 25° GH |

1° GH ≙ 10 mg CaO/l $H_2O$ ≙ 1.25° English H ≙ 1.79° French H
(here the total salt content is calculated as CaO equivalent)
Atomic weight × spec. heat = atomic heat = 25.978 J = 6.2 cal.

**Table 10.3** Molecular Weights of Raw Materials [2]

| Substance | Formula | M |
|---|---|---|
| Acetaldehyde | $CH_3 \cdot CHO$ | 44.05 |
| Acetylene | CHCH | 26.04 |
| Acrylonitrile | $CH_2 : CHCN$ | 53.06 |
| Adipic acid | $HO_2C \cdot (CH_2)_4 \cdot CO_2H$ | 146.14 |
| AH salt | $H_2N \cdot (CH_2)_6 \cdot NH_2 \cdot HO_2C \cdot (CH_2)_4 \cdot CO_2H$ | 262.35 |
| Benzene | $C_6H_6$ | 78.11 |
| Caprolactam | $HN \cdot (CH_2)_5 \cdot CO$ | 113.16 |
| Diglycol terephthalate | $(HO \cdot [CH_2]_2 \cdot O \cdot CO)_2 \cdot C_6H_4$ | 254.23 |
| Dimethyl terephthalate | $(CH_3 \cdot O \cdot CO)_2 \cdot C_6H_4$ | 194.19 |
| Ethylene | $CH_2 : CH_2$ | 28.05 |
| Ethyleneglycol | $HO \cdot (CH_2)_2 \cdot OH$ | 62.07 |
| Formaldehyde | $CH_2O$ | 30.03 |
| Urea | $(NH_2)_2CO$ | 60.06 |
| Hexamethylenediamine | $H_2N \cdot (CH_2)_6 \cdot NH_2$ | 116.21 |
| Hexamethylenetetramine | $(CH_2)_6N_4$ | 140.19 |
| Carbon dioxide | $CO_2$ | 44.01 |
| Carbon monoxide | CO | 28.01 |
| Melamine | $C_3N_3 \cdot (NH_2)_3$ | 126.12 |
| Methane | $CH_4$ | 16.04 |
| Methanol | $CH_3 \cdot OH$ | 32.04 |
| Oxalic acid | $HO_2C \cdot CO_2H$ | 90.04 |
| Phenol | $C_6H_5 \cdot OH$ | 94.11 |
| Propylene | $CH_2 : CH \cdot CH_3$ | 42.08 |
| Oxygen | $O_2$ | 32.00 |
| Terephthalic acid | $HO_2C \cdot C_6H_4 \cdot CO_2H$ | 166.13 |
| Toluene | $C_6H_5 \cdot CH_3$ | 92.14 |
| Vinyl chloride | $CH_2 : CHCL$ | 62.50 |
| Water | $H_2O$ | 18.02 |
| Xylene | $C_6H_4 \cdot (CH_3)_2$ | 106.17 |

**Table 10.4** Definition of Yarn Types According to Spinning and Drawing Speed

| Spinning speed (m/min) | Drawing/winding speed (m/min) | Symbol | Description | Examples |
|---|---|---|---|---|
| 10...100 | 30...300 | LLOY | Slowly spun yarn | Wet spinning, compact spinning |
| 300...2000 | a) as per spinning speed | LOY | Low orientation yarn | Classical melt spinning |
| | b) drawn at 1000...3500 | RDY | Mechanically fully drawn yarn | BCF, tire yarn |
| 1700...2800 | | MOY | Middle orientation yarn | |
| 3000...4000 | | POY | Partially oriented yarn | PET POY |
| ...6000 | | POY | | PA POY |
| 4500 | | HOY | Highly oriented yarn | |
| 5000...8000 | | FOY | (Almost) completely (spun) drawn yarn | PET FOY |
| Each | × draw ratio | ROY | (Mechanically) fully drawn yarn* | PA ROY, etc. e.g., with godets |

*either continuously drawn at spinning or processed in 2 stages, e.g., LOY spun yarn drawn on a draw twister

*Abbreviations:* L = low, M = middle, P = partially, H = high, F = fully; R = ready,
BCF = bulked continuous filament, O = oriented, Y = yarn
For single filament titer dependence, see Fig. 10.3

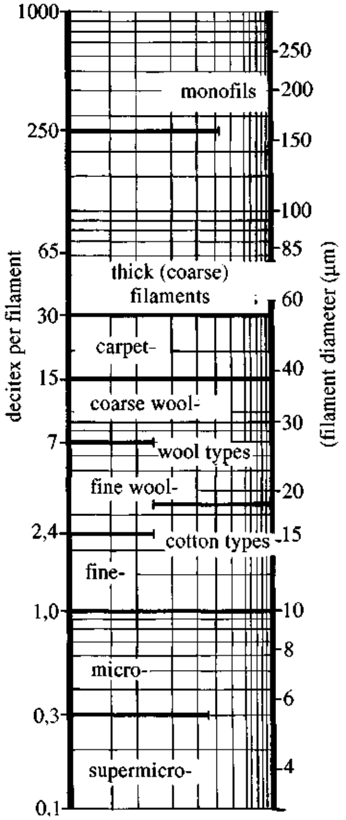



**Fig. 10. 3**
Filament and fiber types according to filament fineness (decitex per filament)

**Table 10.5** Abbreviations for Fibers, Polymers, Pre- and Intermediate Products [20, 21, 22]

| Fibers and polymers | Abbreviation acc. to BISFA* | DIN 7728 (plastics) |
|---|---|---|
| *Natural fibers* | | |
| Cotton | CO | |
| Flax (linen) | LI | |
| Wool (also W) | WO | |
| Mulberry silk | Ms | |
| Silk | SE | |
| *Chemical Fibers* | | |
| Acetate | CA | AC |
| Alginate | ALG | |
| Cupro | CUP | |
| Elastodiene (rubber) | ED | |
| Lyocell | CLY | |
| Modal | CMD | |
| Nitrocellulose | | CN |
| Protein | PROT | |
| Triacetate | CTA | CTA |
| Viscose | CV | |
| *Synthetic fibers* | | |
| Acrylonitrile | AN | |
| Aramid | AR | |
| Chlorofiber | CLF | |
| Elastane (Spandex) | EL | |
| Fluorofiber | PTFE | |
| Modacrylic | MAC | |
| Polyacrylonitrile | PAN | |
| Polyamide (with additional numbering of PC atoms in amine and acid) | PA | PA |
| *Synthetic fibers continued* | | |
| Polyarylether ketone | | PEEK |
| Polybutylene terephthalate | | PBT |
| Polyester | PES | SP (saturated) |
| Polyethylene | PE | PE |
| Polyethylene terephthalate | | PET |
| Polyether sulphone | | PES |
| Polyimide | PI | PI |
| Polyoxyamide | POA | |
| Polypropylene | PP | PP |
| Polypropylene, chlorinated | | PP-C |
| Polyurethane | | PUR |
| Polytetrafluorethylene | PTFE | PTFE |
| Polyvinylalcohol | PVA | PVAL |
| Polyvinylchloride | CLF | PVC |
| Polyvinylchloride, chlorinated | | PVC-C |
| Polyvinylidene chloride | CLF | PVDC |
| Polyvinyl fluoride | | PVF |
| Polyvinylate | PVAL | |
| *Inorganic* | | |
| Carbon fiber | CF | |
| Glass fiber | GF | |
| Metal fiber | MTF | |
| Silica fiber | SF | |
| Asbestos | AS | |

*BISFA = Bureau International pour Standardisation des Fibres Artificielles (Section 9.1.2)

*Abbreviations for Pre-products, Intermediate Products and Auxiliary Agents*

| | |
|---|---|
| ACN | Acrylonitrile (also AN) |
| ...-Ac | ...acetate |
| AH salt | Hexamethylene diamine adipic acid (nylon 6.6 salt) |
| AIBN | Azoiso butyronitrile |
| BG | Butylene glycol |
| BT | Butylene terephthalate |
| CHDM | 1,4-cyclohexane dimethylol |
| −COOH | Carboxyl end group |
| CL | ε-Amino caprolactam |
| DAB | 1,4 diamino butane |
| DGT | Diglycol terephthalate |
| DMAC | Dimethyl acetamide |
| DMF | Dimethyl formamide |
| DMSO | Dimethyl sulfoxide |
| DMT | Dimethyl terephthalate |
| HP-TPA | High purity TPA |
| MDI | Diphenyl methane-4,4′diisocyanate |
| MP-TPA | Middle purity TPA |
| NMP | N-methyl pyrrolidone |
| PTMEG | Polyether glycol |
| TDI | Toluene diisocyanate |
| TEG | Triethylene glycol |
| THF | Tetrahydrofuran |
| TPA | Terephthalic acid |
| VAC | Vinyl acetate |

**Table 10.6** Formulas for Spinning, etc.

*Spinning throughput*

| | |
|---|---|
| $(g/min) = 10^{-4}\ (dtex) \cdot i \cdot (m/min)$<br>$(kg/h) = 6 \cdot 10^{-6} \cdot (dtex) \cdot i \cdot (m/min)$<br>$(dtex) = 10^4\ (g/min) \cdot i^{-1} \cdot (m/min)^{-1}$<br>$(dtex) = 10^6\ (kg/h) \cdot i^{-1} \cdot (m/min)^{-1}/6$ | $(m/min) = 10^4 (g/min \cdots i^{-1} \cdot (dtex)^{-1}$<br>$(m/min) = 10^7\ (kg/h \cdot i^{-1} \cdot (dtex)^{-1}/6$<br>i = draw ratio<br>1 t/a ≙ 0.123 kg/h<br>$10^6$ lbs./y ≙ 55.5 kg/h ≙ 1330 kg/d |

*Extrusion velocity (in the spinneret capillary)*

| | |
|---|---|
| $v_B\ (m/min) = 4\ (g/min)_B/\pi\ d_B^2\ (mm)\rho\ (g/cm^3)$ | with $\rho$ = melt density ($g/cm^3$) |

*Spin draft (spin stretch ratio)*

| | |
|---|---|
| $i_{sp} = v_F/v_B$ | Indices: B = spinneret<br>F = filament |

*Spin finish application*

| | |
|---|---|
| With spin finish applicator and dosing pump:<br>$(g/min)_L = (g/min)_F \cdot a(\%)/c_L(\%)$<br>L = solution or emulsion<br>$a$ (%) = oil pick-up of the fiber<br>$c_L$ = solution or dispersion concentration | With kiss roll: correction of oil pick-up:<br>$n_2/n_1 = (a_2/a1)^{2/3}$<br>1 = actual, 2 = target<br>*Comment:* correction does not take into account the water pick-up. When using 2 rolls, each roll is corrected individually according to the formula |

*Winding*

| | |
|---|---|
| – Package circumferencial velocity u (m/min):<br>$u\ (m/min) = \sqrt{v_F^2 - v_t^2}$<br>– Helix angle<br>$\tan \alpha = 4\ DH\ b/v_F$ | $v_t$ (m/min) = traverse speed<br>= 2 DH ($min^{-1}$) $b$ (m)<br>$DH$ ($min^{-1}$) = no of double strokes<br>$b$ (m) = traverse stroke |

*Twisting*

| |
|---|
| $T$ (twists/m yarn) = $n$ (spindle, r/min)/$v_F$ (m/min)<br>Note whether S- or Z twist is required (see Fig. 3.32) |

*False twist texturizing*

| | |
|---|---|
| $T = \dfrac{250\,000\ f}{\text{Titer (dtex)} + 40}$ (twists/m)<br>For formulas by other authors, see Table 9.14, p. 744 | f = 1.0 for conventional texturizing<br>= 1.1 ... 1.2 for simultaneous draw texturizing |

*Textile testing*

| | |
|---|---|
| Conversions: dtex = den/0.9<br>tex = 9.1 den<br>Nm = 10 000/dtex | Tenacity (based on linear density, max. force):<br>$\sigma$ (cN/dtex) = 0.98$\sigma$ (g/dtex) = 0.88$\sigma$ (g/den)<br>= 0.098$\sigma$($kg/mm^2$)/$\rho$ ($g/cm^3$)<br>= 0.01$\sigma$ ($N/mm^2$)/$\rho$ ($g/cm^3$)<br>$\rho$ = density ($g/cm^3$) |

**Table 10.7** Statistics [2]

*Without class intervals*

$$\bar{x} = \frac{1}{n} \cdot \sum_{i=1}^{n} x_i \qquad s^2 = \frac{1}{n \cdot 1} \cdot \sum_{i=1}^{n} (x_1 \cdot \bar{x})^2 \qquad CV = \frac{s}{\bar{x}} \cdot 100 \qquad U = \frac{\sum_{i=1}^{n} (x_1 \cdot \bar{x})}{n} \frac{100}{\bar{x}}$$

$\bar{x}$ = average value
$x_i$ = individual value
$n$ = number of individual values
$s^2$ = variance
$s$ = standard deviation
$CV$ = coefficient of variation [%]
$U$ = linear non-uniformity [%]

*With class intervals*

$$\bar{x} = \bar{x}_a + \frac{d}{n} \cdot \sum_{m=1}^{m} m \cdot f_m \qquad s^2 = \frac{d^2}{n \cdot 1} \cdot \left[ \sum_{m=1}^{m} m^2 \cdot f_m \cdot \frac{1}{n} \cdot \left( \sum_{m=1}^{m} m \cdot f_m \right)^2 \right]$$

$\bar{x}$ = average value
$m$ = interval number
$f_m$ = class frequency
$d$ = interval width
$\bar{x}_a$ = average of class $m = 0$ as assumed average
$n = \sum f_m$ total number of individual values

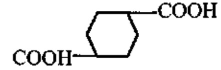
*Confidence interval of average*

$$\bar{x} - q \le \mu \le \bar{x} + q \quad \text{with} \quad q = t \cdot \frac{s}{\sqrt{n}}$$

$\mu$ = true average
$\bar{x}$ = calculated average
$q$ = distance of the confidence limit from $\bar{x}$
$s$ = standard deviation
$n$ = number of individual values
$t$ = factor (depends on statistical confidence $S$ and $n$)

| $n =$ | 4 | 5 | 7 | 10 | 15 | 25 | 100 | $\infty$ |
|---|---|---|---|---|---|---|---|---|
| $S = 95\%$, $t =$ | 3.18 | 2.78 | 2.45 | 2.26 | 2.15 | 2.06 | 1.98 | 1.96 |
| $S = 99\%$, $t =$ | 5.84 | 4.60 | 3.71 | 3.25 | 2.98 | 2.80 | 2.63 | 2.58 |

**Table 10.8** Pre-Products, Solids: Properties

| | Units | AH salt, nylon 66, salt [3], hexamethylene diamine adipic acid | ε-caprolactam [4, 5] | Dimethylterephthalate DMT [6, 12] | Terephthalic acid TPA [7, 8] |
|---|---|---|---|---|---|
| Formula | | $HOOC(CH_2)COOH$ +<br>$H_2N(CH_2)_6NH_2$ | $C_6H_{11}ON$ or<br>$CH_2-CH_2-CO$<br>NH<br>$CH_2-CH_2-CH_2$ |  | $HOOC-C_6H_4-COOH$<br> |
| Molecular weight | g/mol | 262.34 | 113.16 | 194.18 | 166.13 |
| Density | g/cm$^3$ | 62% aqueous solution:<br>90 °C 1.082<br>crystalline: 1.2014 | At 80 °C: 1.0135<br>100 °C: 1.0083<br>120 °C: 0.9829 | At 20 °C: 1.35<br>150 °C: 1.08<br>180 °C: | Bulk density: 1.066 |
| Melting (solidification) point | °C | 202 ... 205 on evolution of water | (69.2) | (140.63 ... 140.64) | 425 (in sealed tube) |
| Boiling point | °C | – | 268.5 | 282 | – |
| Delivery | | As salt: $H_2O$ content < 0.5%<br>As 40% aqueous solution | Water content < 0.05%<br>Molten: in heated tank wagons | In 40- or 100-kg<br>Molten: in heated tank wagons | Water content < 0.2%<br>40 kg sacks or<br>1 t or 23 t containers |
| Appearance, particle size | | White salt | White, crystalline flakes (hygroscopic).<br>Molten; clear, colorless; characteristic smell | | white powder<br>100 ... 200 ... 600 μm particle size |
| pH value | | (10% solution in $H_2O$, 25 °C) | | | |
| Specific heat | kJ/kg K | 62% solution: 3.02<br>crystalline: 1.67 | at 20 ... 60 °C: 1.34<br>80 °C: 2.14<br>150 °C: 2.34 | at 140 °C: 1.47<br>141 °C: 1.74 | |
| Thermal conductivity | W/m K | 62% solution: 0.420<br>crystalline: 0.275 | at 35 °C: 0.104<br>at 76 ... 183 °C: 0.14 | | |
| Heat of fusion (melting) | kJ/kg | | 124 | 159.1 | – |
| Heat of polymerization | kJ/kg | | 140 | | |
| Heat of vaporization | kJ/kg | | At 105 °C: 628<br>168 °C: 574<br>268 °C: 481 | At 170 °C: 342.5 | |
| Heat of combustion | kJ/kg | | 31 900 | | |

(*Continued on next page*)

**Table 10.8** (*Continued*): Pre-products, Auxiliary Agents, Fluids: Properties

| | Units | Acrylonitrile [9] AN | Dimethylformamide [10, 13] DMF | Dimethylacetamide [24] DMAC | Ethylene glycol [23] EG |
|---|---|---|---|---|---|
| Formula | | $C_3H_3N$<br>$CH_2{=}CH{-}CH$ | $HCON(CH_2)_2$ | $(CH_3)_2{-}N{-}CO{-}CH_3$ | $HO(CH_2)_2OH$ |
| Molecular weight | g/mol | 53.06 | 73.1 | 87.12 | 62.07 |
| Density | g/cm$^3$ | 0.806 (20 °C) | 0.9445 (25/4 °C) | 0.945 (15.6 °C) | 1.1133 ... 1.1140 (20 °C) |
| Solidification (melting) point | °C | −83.1 | −61 | −20 | +11 ... 12 |
| Boiling point | °C | 77.3 | 153 | 166.1 | 196 ... 199 |
| Delivery | | Liquid, having 0.2 ... 0.5% $H_2O$ | With < 0.02% $H_2O$ | With < 0.02%$H_2O$ | With < 0.1% $H_2O$ in iron or PE barrels (220 kg) or in tankers (not galvanized) |
| Appearance | | Clear, colorless, slightly volatile, typical odor | | | |
| pH value | | 5% aqueous solution: 6.0 ... 7.5 | | | |
| Specific heat | kJ/kg K | | 2.315 (20 °C) | | 2.3 (20 °C) |
| Thermal conductivity | W/m K | | | 0.1742 (22.2 °C) | 0.29 |
| Heat of evaporation | kJ/kg | | | 498 | |
| Dynamic viscosity | Cp | 0.35 (20 °C) | | 0.92 (25 °C) | 0.19 (20 °C) |
| Vapor pressure | mbar | 0.1 (20 °C) | 197.3 (100 °C)<br>11.8 (40 °C)<br>4.87 (25 °C)<br>0.86 (0 °C) | 2.7 (25 °C) | < 0.1 (20 °C) |
| Explosion limits (in air, upper/lower) (in $N_2$) | Vol. %<br>At % $O_2$ | 3.0/17 | 2.2/15.2<br>3 | | 3.0/ |
| Flame point | °C | −1 (in a closed kettle) | | 63 ... 70 | 119 |
| Ignition temperature | °C | 480 | | 490 | 410 |
| Refractive index | $n_D^{25}$ | 1.3882 ... 1.3891 | | | |
| Impurities (excluding water) | ppm | < 380 | | | ≤ 100 |

*Comment:* For additional properties, see original sources (manufacturers' catalogs), chemical analyzes, etc.

(*Continued on next page*)

**Table 10.8** (*Continued*): Important Properties of Polymers, Yarns and Fibers [12]

| *Polyamide* | PA 6[1] | | | PA 66 |
|---|---|---|---|---|
| Repeat unit | | $-(C_6H_{11}ON)_x-$ | | $-(C_6H_{14}N_2 + C_6H_8O_2)_n-$ |
| Relative solution viscosity $\eta_{rel.}$ (in n-$H_2SO_4$) | 2.4 | 2.7 | 3.3 | 2.5 |
| $TiO_2$ pigment [%] | | 0.03 ... 0.3 ... 1.6 | | 0.03 |
| Density [g/cm³] | 1.13 ... 1.14 | | 1.14 | 1.14 |
| Melting point range [°C] | | 215 ... 220 | | 255 ... 260 |
| Molecular weight [g/mol.] | 12 000 | | 25 000 | |
| Heat of fusion [J/g] | | 95 ... 100 | | 70 ... 75 |
| Specific heat (20 °C) [J/g K] | | 1.5 ... 1.7 | | 1.6 ... 1.7 |
| Extractables [%] | ≈0.6 | ≲0.6 | ≈0.2 | ≈0.1 |
| Melt spinning range [°C] | 260 ... 280 | 270 ... 300 | | 280 ... 300 |
| Melt density [g/cm³] | | 0.95 ... 0.99 | | 0.98 |
| Melt viscosity (at 290 °C) [Pa · s] | 50 | 100 | 160 | 50 ... 60 |
| *Yarns and fibers* | | | | |
| Moisture content [%] | | ~0.5 or < 0.08 | | ≲0.08 |
| Delivered, ready for spinning | | ≤0.08 | | < 0.5[2] |
| at 20 °C/65% RH | | 3.5 ... 4.5 | | 3.5 ... 4.5 |
| /100% RH | | 9 ... 10 | | 9 ... 10 |
| Extractables [%] | ≲2 | ≲0.8 | ≲0.2 | ≲0.5 |

1) See also Fig. 10.4
2) Only for spinning with a steam-blanketed grid melter

(Continued on next page)

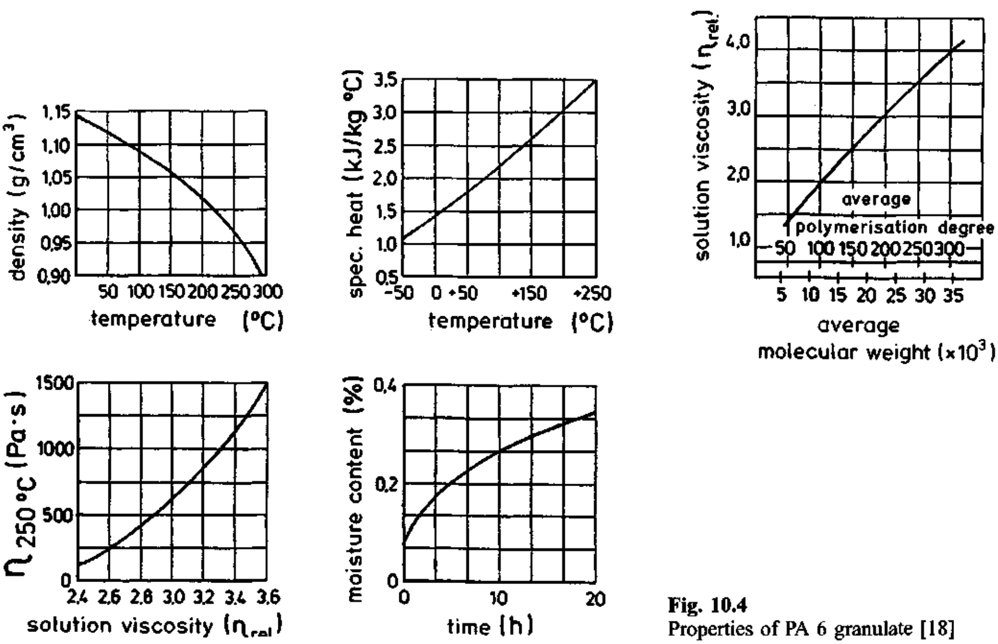



**Fig. 10.4**
Properties of PA 6 granulate [18]

**Table 10.8** (*Continued*): Polyester Granulate [15] Polyethylene terephthalate)

| Property | Unit | Value | Test method[1] |
|---|---|---|---|
| Specification<br>Relative viscosity | – | 1.36 ... 1.39 | 0.5% in phenol/o-dichloro-benzene in weight ratio 3 : 2; measurement temperature 25 °C BASF no.: 3101 |
| Limiting viscosity [$\eta$], (IV) | dl/g | 0.645 ... 0.690 | Calculated using Huggins constant K′ = 0.35 |
| Moisture content<br>– in bags, up to ca. 1000 kg<br>– delivered by large capacity trucks | % | <br>max. 0.5<br>max. 0.1 | BASF no.: 3201 |
| Titanium dioxide content | % | 0.05 ... 0.07 | BASF no.: 1403 |
| Product characteristics<br>COOH end groups | meq/kg | max. 30 | BASF no.: 3121 |
| Color number (APHA) | – | max. 25 | BASF No.: 3601 |
| DEG content | W/W % | max. 1.1 | BASF no.: 3702 |
| Reflectance[2)]<br>– lightness ($R_y$)<br>– yellowness index ($R_x - R_z$) | <br>%<br>% | <br>60 ... 67<br>0 ... 4 | BASF no.: 3602 |
| Granulate size | mm | ca. 2,5 × 3.5 × 2.5 (cylindrical) | |
| Specific chip number | chips/g | ca. 50 | |
| Oversized chips [3)] plus undersized [4)] chips | % | 0.2 | |
| General properties<br>Melting point | <br>°C | <br>≥ 259 | <br>BASF no.: 2301 |
| Density (chip, fiber) | g/cm$^3$ | 1.39 | |
| Bulk density | kg/m$^3$ | ca. 750 | |

[1)] Available to customers on request
[2)] $R_x$, $R_y$ and $R_z$ are the uncorrected % reflectances measured using a tristimulus measuring instrument from Zeiss. The color filters used are FMX/C, FMY/C and FMZ/C; the illumination is standard light source C.
[3)] At least three times one of the given dimensions
[4)] At most half of one of the given dimensions

**Table 10.8** (*Continued*): Polypropylene Granulate for Fiber Production [16]

*Mechanical and thermal properties of VESTOLEN® P polymers*

| Property | Test method ISO | Test method DIN | Units | Homopolymers 2000 (X2618) | 2000 CR (X4504) | 3000 D (X4144) | 4000 (1200) | 5000 (2200) | 6000 (3200) | 7000 (5200) |
|---|---|---|---|---|---|---|---|---|---|---|
| Melt flow index | ISO 1133 | DIN 53735 | | | | | | | | |
| MFI 190/5: | Proc. 18 | Code T | g/10 min | 70 | 60 | 45 | 33 | 20 | 10 | 4 |
| MFI 230/2: | Proc. 12 | Code M | g/10 min | 40 | 35 | 25 | 20 | 13 | 7 | 2.5 |
| MFI 230/5: | Proc. 20 | Code V | g/10 min | ca. 160 | ca. 140 | ca. 100 | 80 | 50 | 30 | 10 |
| Crystallite melting temperature | Polarization microscope | | °C | 164... 168 | 164... 168 | 164... 168 | 164... 168 | 164... 168 | 164... 168 | 164... 168 |
| Density at 20 °C | ISO/R 1183 | DIN 53479 | $g/cm^3$ | 0.908 | 0.908 | 0.907 | 0.907 | 0.906 | 0.906 | 0.905 |
| Impact strength acc. to *Charpy* | ISO 179/2 D | DIN 53453 | $kJ/m^2$ | 60 | 80 | 80 | 80 | 80 | 90 | unknown |
| Notched impact strength according to *Charpy* | ISO 170/2 C | DIN 53453 norm. rod | $kJ/m^2$ | 2 | 3 | 3 | 3 | 3 | 3.5 | 4.5 |
| Drawing tension | ISO/R 527 Elongation rate D Sample according to Fig. 1 | DIN 53455 Elongation rate VI Sample size 3 | $N/mm^2$ | 42 | 38 | 40 | 40 | 38 | 36 | 34 |
| Tenacity at break | | | $N/mm^2$ | 35 | 30 | 30 | 30 | 30 | 30 | 30 |
| Elongation at break | | | % | > 50 | > 50 | > 50 | > 50 | > 50 | > 50 | > 50 |
| Hardness (ball pressure) | ISO 2039 (H 358/30) | DIN 53456 (H 358/30) | $N/mm^2$ | 90 | 83 | 85 | 85 | 83 | 82 | 76 |
| Elastic modulus | ISO 178 | – | $N/mm^2$ | 1700 | 1500 | 1600 | 1600 | 1500 | 1400 | 1300 |
| Shear modulus | ISO 537 Method A | DIN 53445 | $N/mm^2$ | 850 | 750 | 800 | 800 | 750 | 700 | 650 |
| 3.5% bending stress | ISO 178 Standard sample 5.1 | DIN 53452 | $N/mm^2$ | 42 | 38 | 40 | 40 | 38 | 35 | 33 |
| Vicat softening point VST/B/50 | ISO 306 | DIN 53460 | °C | 105 | 100 | 100 | 100 | 100 | 100 | 100 |
| Shape retention under heating | ISO 75 Method A | DIN 53461 | °C | 60 | 55 | 55 | 55 | 55 | 60 | 55 |
| | Method B | | °C | 105 | 100 | 100 | 100 | 100 | 100 | 100 |
| Linear expansion coefficient | | DIN 53752 | $K^{-1}$ | $1.5 \cdot 10^{-4}$ | $1.5 \cdot 10^{-4}$ | $1.5 \cdot 10^{-4}$ | $1.5 \cdot 10^{-4}$ | $1.5 \cdot 10^{-4}$ | $1.5 \cdot 10^{-4}$ | $1.5 \cdot 10^{-4}$ |
| Specific heat capacity | Adiabatic calorimeter | | $kJ \cdot kg^{-1} \cdot K^{-1}$ | 1.68 | 1.68 | 1.68 | 1.68 | 1.68 | 1.68 | 1.68 |

**Table 10.8** (*Continued*): PAN Powder (Example) [13, 14]

| | | | |
|---|---|---|---|
| White powder | | | |
| Bulk density | 200 ... 250 g/l | Carbon content | 65.7 ... 67.4% |
| Particle size | 5 ... 40 μm (average 20 ... 30 μm) | Hydrogen content | 5.45 ... 5.90% |
| | | Comonomer content | 5 ... 14% |
| Molecular weight [M] | 80 000 ... 83 000 g/mol. | Typical comononers | Methacrylic acid or acrylic acid methyl ester, vinyl pyridene, itaconic acid or ester, vinyl acetate, etc. |
| K-value | 90 ± 1 | | |
| Intrinsic viscosity | 1.61 | | |
| Ash content | 0.1% (< 0.12%) | | |
| Iron content | ≤ 0.0005% | Acid number | below 0.25 mg alkali/g PAN |
| Peroxide content | ≤ 0.001% | | |
| Nitrogen content | 23.0 ... 24.1% | Water content | ≤ 0.7% |
| Sulfur content | 0.27 ... 0.54% | | |

**Table 10.8** (*Continued*): Densities of Fibers from Various Polymers and Other Materials

| Material | Density (g/cm$^3$) | Material | Density (g/cm$^3$) |
|---|---|---|---|
| Acetate 2½ | 1.32 | Polyamide 11 | 1.04 |
| Acetate, tri | 1.3 | Polyamide 12 | 1.08 |
| Alginate | 1.78 | Polyaramid: Kevlar, Twaron | 1.45 |
| Asbestos, amphibole | 3.1 | Polyaramid: Kermel 1 | 1.34 |
| Asbestos, chrysotile | 2.5 | Polyaramid: Nomex | 1.38 |
| Basalt | 2.6 | Polycarbonate | 1.2 |
| Cotton | 1.54 | Polyester: PET | 1.38...1.39 |
| Boron | 7.6 | Polyester: PBT | 1.35 |
| Cupro | 1.52 | Polyether ketone | 1.3 |
| Elastane (Spandex) | 1.14...1.30 | Polyethylene | 0.94...0.96 |
| Flax | 1.43...1.52 | Polyimide | 1.41 |
| Glass | 2.45...2.6 | Polypropylene | 0.9 |
| Jute | 1.45 | Polytetrafluorethylene | 2.1...2.3 |
| Ceramic | ca. 2.7 | Polyvinyl alcohol | 1.26...1.30 |
| Kodel | 1.22...1.23 | Polystyrol | 1.05 |
| Carbon fiber: PAN black | 1.40 | Polyvinylidene chloride | 1.68...1.75 |
| Carbon fiber: high modulus (HM) | 1.91 | Polyvinyl chloride | 1.38 |
| Carbon fiber: high tenacity (HT) | 1.77 | Polyvinyl chloride, post chlorinated | 1.44 |
| Steel (AISI 316 L) | 7.9 | Protein | 1.3 |
| Modacrylic | 1.30...1.42 | Qiana (polyamide 472) | 1.03 |
| Polyacrylonitrile: homopolymer | 1.17...1.19 | Silk, raw, boiled off | 1.37 |
| Polyacrylonitrile: mixed polymer, >85% PAN | 1.17...1.19 | Silicon dioxide | 1.8...2.0 |
| | | Titanium | 4.5 |
| Polyacrylonitrile: Dunova, water absorbent | 0.9 | Viscose | 1.52 |
| | | Whisker, C | 1.9 |
| Polyamide 6 and 66 | 1.14 | Whisker, Fe | 7.8 |
| Polyamide 46 | 1.18 | Wool | 1.32 |

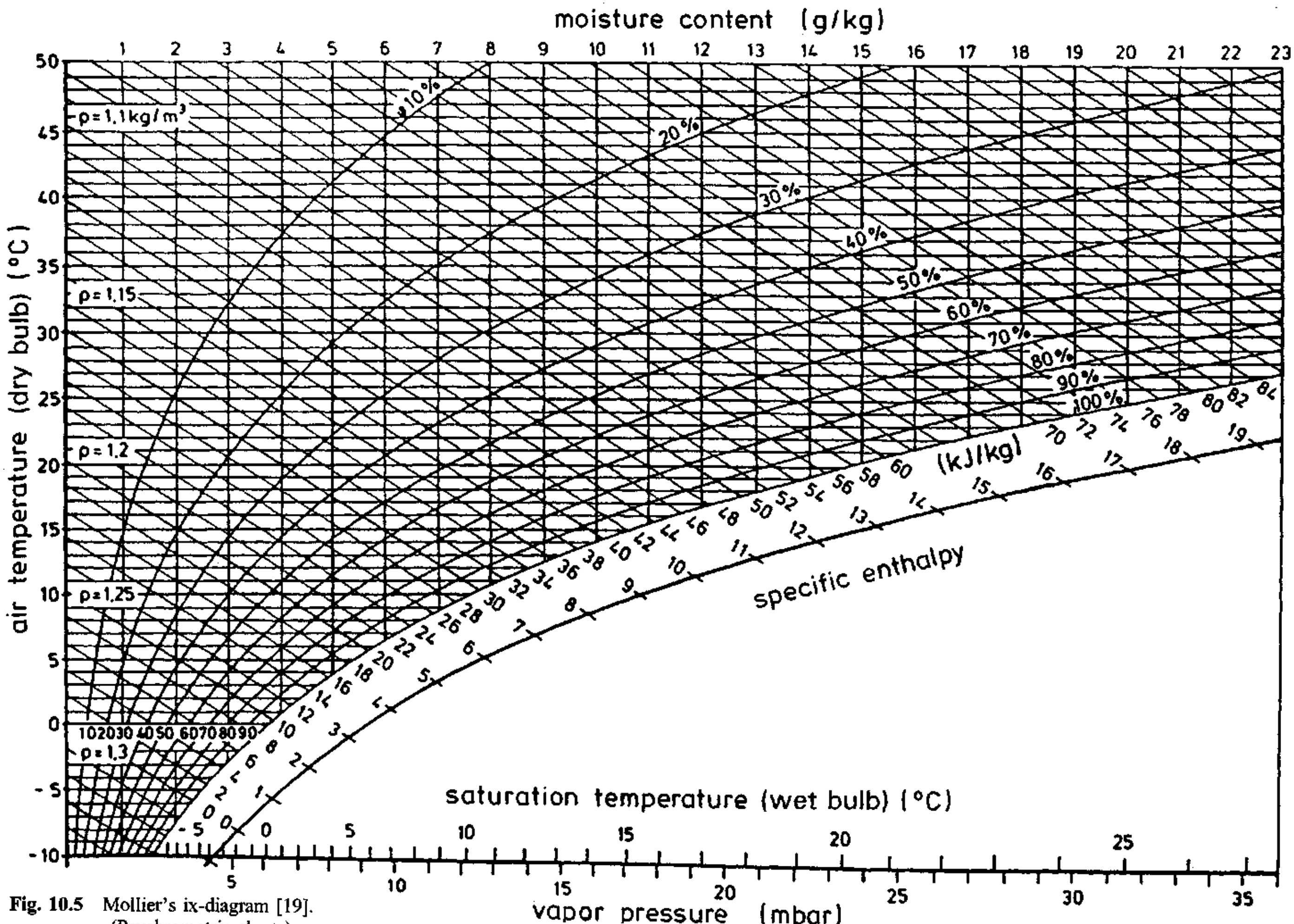
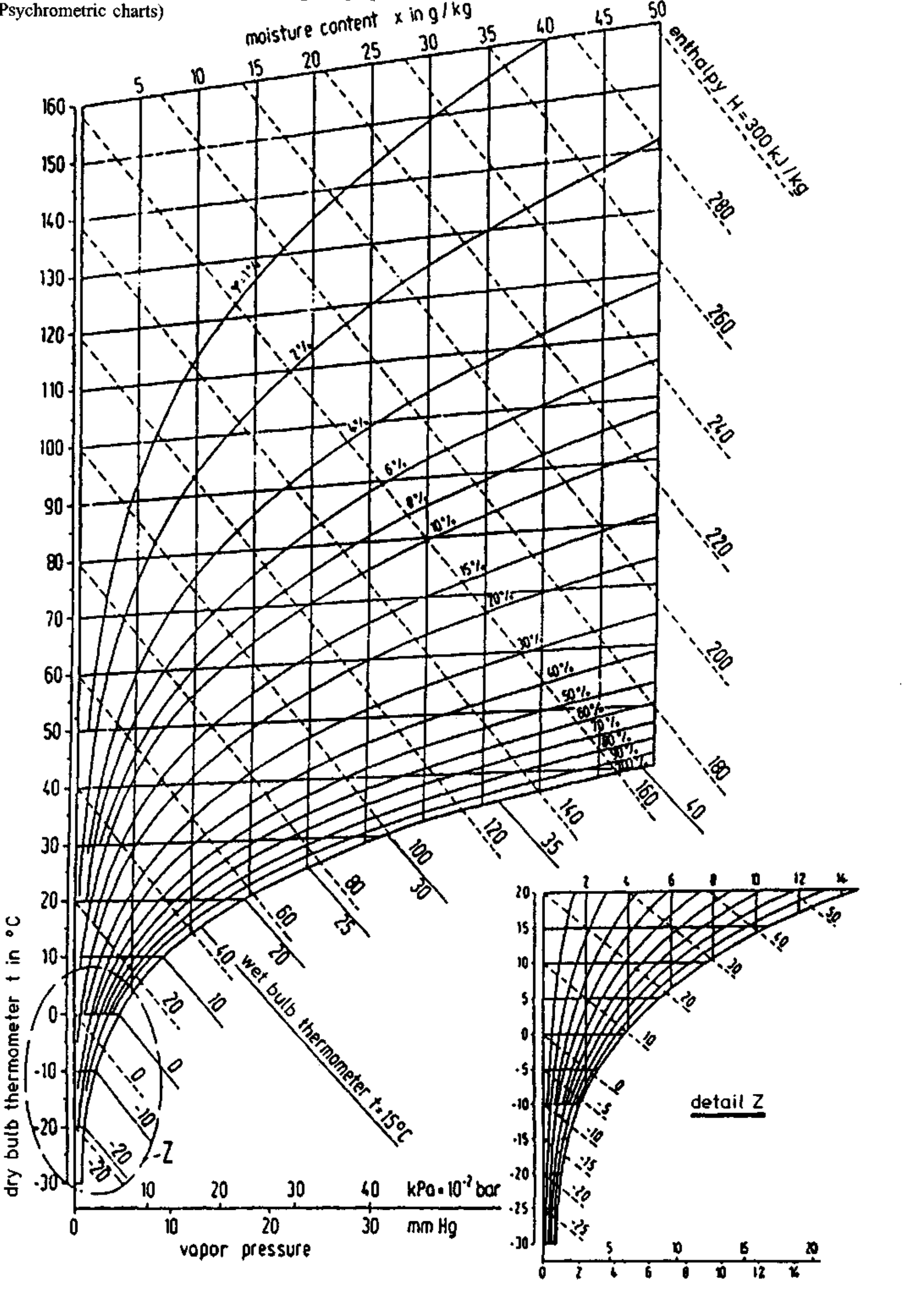



**Fig. 10.5** Mollier's ix-diagram [19].
(Psychrometric charts).
See Fig 6.10 for an explanation of how to use the diagram

**Fig. 10. 5** (*continued*) Mollier's ix-diagram [19].
(Psychrometric charts)



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