Nuclear Engineering Data and Formulae

Forms of the Laplacian operator

Cartesian	$\nabla^2 = \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} + \frac{\partial^2}{\partial z^2}$
Cylindrical	$\nabla^2 = \frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial}{\partial r}\right) + \frac{1}{r^2}\frac{\partial^2}{\partial \theta^2} + \frac{\partial^2}{\partial z^2}$ or $\nabla^2 = \frac{\partial^2}{\partial r^2} + \frac{1}{r}\frac{\partial}{\partial r} + \frac{1}{r^2}\frac{\partial^2}{\partial \theta^2} + \frac{\partial^2}{\partial z^2}$
Spherical	$\nabla^2 = \frac{1}{r^2}\frac{\partial}{\partial r}\left(r^2\frac{\partial}{\partial r}\right) + \frac{1}{r^2 \sin\theta}\frac{\partial}{\partial \theta}\left(\sin\theta\frac{\partial}{\partial \theta}\right) + \frac{1}{r^2 \sin^2\theta}\frac{\partial^2}{\partial \varphi^2}$ Or, and radial only: $\nabla^2 = \frac{\partial^2}{\partial r^2} + \frac{2}{r}\frac{\partial}{\partial r}$

General solutions of differential equations (where $D=d/dx$)

$(D^2 - n^2)\psi = 0$	$\psi = A\,e^{-nx} + C\,e^{nx}$
$(D^2 + n^2)\psi = 0$	$\psi = A \sin nx + C \cos nx$
$\left(D^2 + \frac{2}{x}D + n^2\right)\psi = 0$	$\psi = A\,\frac{\sin nx}{x} + C\,\frac{\cos nx}{x}$
$\left(D^2 + \frac{2}{x}D - n^2\right)\psi = 0$	$\psi = A\,\frac{e^{-nx}}{x} + C\,\frac{e^{+nx}}{x}$
$\left(D^2 + \frac{1}{x}D + n^2\right)\psi = 0$	$\psi = A\,J_0(nx) + C\,Y_0(nx)$

Bessel functions of zero order: assorted useful values

$Y_0(x) \to -\infty$ as $x \to 0$
$J_0(x) = 1$ at $x = 0$
$J_0(x) = 0$ at $x = 2.405$ (first root)

Geometric bucklings for unreflected geometries:

Cuboid, sides a, b, c	$\left(\frac{\pi}{a}\right)^2 + \left(\frac{\pi}{b}\right)^2 + \left(\frac{\pi}{c}\right)^2$
Cylinder, radius R, height H	$B^2 = \left(\frac{2.405}{R}\right)^2 + \left(\frac{\pi}{H}\right)^2$
Sphere, radius R	$B^2 = \left(\frac{\pi}{R}\right)^2$

Thermal Neutron Cross Sections (barns, 10^{-28} m^2)

-natural elemental composition unless indicated

- 'capture cross section + fission cross section = absorption cross section '

Species	Fission	Absorption	Neutrons per fission
Al		0.24100	
B-10		3410.00000	
Be		0.01000	
Boron (natural)		759.00000	
C		0.00400	
D		0.00046	
Fe		2.62000	
Gd		49000.00000	
H		0.33000	
Mg		0.06900	
O		0.00020	
Pu-239	749	1029.00000	2.90
S		0.52000	
Na		0.52500	
U-233	529	581.00000	2.50
U-235	587	683.00000	2.43
U-238		2.71000	
Zr		0.18500	

Take natural uranium as 0.7% 235-U, 99.3% 238-U

Assorted physical data:-

Typical energy release on fission (eV) 200×10^{6}

Speed of light (ms^{-1}) 2.9979×10^{8}

Electron volt (J) 1.602×10^{-19}

Avogadro's number ($kmol^{-1}$) $6.02214199 \times 10^{26}$

Avogadro's number is the number of atoms in 12kg of pure isotope 12C. It is also the number of molecules in one kmol of any substance.

Atomic mass unit:

The atomic mass unit is defined as one twelfth of the mass of the most abundant isotope of carbon: C12.

1 AMU is $1.66053873 \times 10^{-27}$ kg

Masses in kg x 10^{-27}

proton	1.67261
neutron	1.67492
^{1}H	1.67238
^{2}H	3.34401
^{3}H	5.00846
^{4}He	6.64461

Selected thermophysical properties

(Many of these vary considerably over the wide range of temperatures of interest. Values quoted are suitable averages.)

		UO2	U-metal	Liquid sodium (400 C)	Saturated water (300 C)	Stainless steel	Zircalloy
Density	kg m^{-3}	10.97×10^3	19.3×10^3	856	713	7.81×10^3	6.55×10^3
Conductivity	W m^{-1} K^{-1}	3	30	72.2	0.541	16	21.5
Specific heat	J kg^{-1} K^{-1}	250	120	1.27×10^3	5.794×10^3	460	285
Melting point	K	3100					
Heat of fusion	J kg^{-1}	277×10^3					
Viscosity	kg m^{-1} s^{-1}			2.85×10^{-4}	0.907×10^{-4}		
Prandtl No				0.00501	0.971		

Carbon dioxide at 4 MPa

		300 K	600 K	900 K
Density	kg m^{-3}	use $\rho = Mp/RT$ (M=44.01)		
Conductivity	W m^{-1} K^{-1}	0.022	0.042	0.064
Specific heat	J kg^{-1} K^{-1}	1047	1110	1215
Viscosity	kg m^{-1} s^{-1}	16.6×10^{-6}	28.7×10^{-6}	38.6×10^{-6}
Prandtl No		1.05	0.762	0.737

Definitions

Equivalent diameter $d_e = \dfrac{4\,x\,\text{flow area}}{\text{wetted perimeter}}$

Prandtl number $\mathrm{Pr} = \dfrac{\mu C_p}{k}$

Stanton number $\mathrm{St} = \dfrac{h}{\rho u C_p}$

Nusselt number $\mathrm{Nu} = \dfrac{h d_e}{k}$

Peclet number $\mathrm{Pe} = \mathrm{Re}\,\mathrm{Pr}$

Fanning friction factor $f = \dfrac{\tau_w}{\frac{1}{2}\rho u^2}$

(The Darcy-Weisbach friction factor, as generally used in Moody charts, is four times bigger).

Correlations

Fanning friction factor

$$f = 0.046\,\mathrm{Re}^{-0.2}$$

Darcy-Weisbach friction factor (as generally used in Moody charts) (four times bigger)

$$f = 0.184\,\mathrm{Re}^{-0.2}$$

Dittus-Boelter, water & gas; smooth channels

$$Nu = 0.023\,\mathrm{Re}^{0.8}\,\mathrm{Pr}^{0.4}$$

$$St = 0.023\,\mathrm{Re}^{-0.2}\,\mathrm{Pr}^{-0.6}$$

Dittus-Boelter, ribbed AGR pins

$$Nu = 0.054\,\mathrm{Re}^{0.8}\,\mathrm{Pr}^{0.4}$$

$$St = 0.054\,\mathrm{Re}^{-0.2}\,\mathrm{Pr}^{-0.6}$$

Liquid metals, where θ is the pin pitch to diameter ratio

$$Nu = 4.0 + 0.16(\theta)^{5.0} + 0.33(\theta)^{3.8}\left(\frac{Pe}{100}\right)^{0.86}$$