SI UNITS IN THE SUGAR FACTORY*

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Abstract

This paper lists the more common units used in the SI system and shows how the coherent units may be derived from a few basic conversion factors. Attention is drawn to metric sizes and strengths of materials and a factory calculation is illustrated.

General

When the introduction of the metric system in South Africa was approved in principle in 1966, it was decided that the SI system of units would be adopted. SI stands for Système International d'Unités. The units are a coherent system of metric units recommended by the International Standards Organization (I.S.O.) for adoption throughout the world.

Historically, the development of a rational system of units required two factors to ensure its adoption. One was a decimal fraction system and the other was a breakdown of the rigid social and political system in Europe before 1795.

The decimal fraction was developed in the 16th century and the Napoleonic wars swept aside the regional barriers. One of the lasting results of these campaigns was the adoption of the metric system throughout Europe and overseas dependencies such as South America. England, by a narrow margin, rejected the system at the time, and is only now converting to the SI system of units, the pressure coming from the engineering manufacturers with an eye to the European Common Market.

The cgs (centimetre, gramme, second) system was used for many years, mainly by scientists, until a proposal was put forward by Giorgi in 1902 for the use of the mks (metre, kilogramme, second) system as a more practical system for engineering and commercial use. It was eventually adopted in 1946 by the International Electrotechnical Commission and the more sophisticated coherent system as it stands today was accepted in 1954 and given the name SI.

The SI units are coherent. A coherent system is one in which a number of basic units is chosen and then any combination of these units will result in the correct unit for any new quantity without the use of conversion factors.

Basic Units

The basic units of the system are accurately defined in terms of modern technology and are given in Appendix 1. The units are:

Quantity	*Name of Unit*	*Symbol*
Length	metre	m
Mass	kilogramme	kg
Time	second	s
Electric current	ampere	A
Thermodynamic temperature	kelvin	K
Luminous intensity	candela	cd

Two other units must be mentioned, viz. the radian and the revolution. The steradian is a solid angle measure and is not often used.

Multiples and submultiples

A recommended system of multiples and submultiples of the basic units has also been established and is in powers of 10^3 or 10^{-3}. The numerous and varied factors of 3, 12, 2 240, etc. are now replaced by multiples of 10.

mega	M	1 000 000	10^6
kilo	k	1 000	10^3
		1.0	
milli	m	0.001	10^{-3}
micro	μ	0.000 001	10^{-6}

Others less frequently encountered are

tera	T	10^{12}	giga	G	10^9
nano	n	10^{-9}	pico	p	10^{-12}

The non-recommended multiples which are nevertheless still in very common use are:

hecto	h	10^2	deca	da	10
deci	d	10^{-1}	centi	c	10^{-2}

Prefixes

When a prefix is used the new unit is treated as a whole, e.g. $1 km^3 = (10^3 m)^3 = 10^9 m^3$

Only one prefix should be used in a unit, e.g. km/s not mm/μs

No plural must be used and no full stops after units e.g. 2 kg and not 2 kgs.

Use of symbols in texts

The decimal point is being retained in South Africa to separate whole numbers and decimals. In Europe a comma is used for this purpose and, to avoid confusion, numbers are to be grouped in threes to the left and right of the decimal point; no commas are to be used.

e.g. 4 760 221
0.304 621 72

A zero must precede all decimal quantities.

Units written out in full will all have small letters, but abbreviations of units named after people will have capital letters.

e.g. gramme	g
newton	N
kilogramme	kg
ampere	A

The correct abbreviation of kilowatt-hour is kWh. If symbols are wrongly used, say KWH, this means °kelvin watt henry, which is at best a little confusing.

Areas and volumes are expressed as m^2 or m^3 and the abbreviations sq and cu are not to be used.

The new units may appear using indices rather than the solidus / , kgm^{-3} in preference to kg/m^3 or

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* Written at the request of the S.A. Sugar Millers Factory Metrication Committee.

$kJ\ s^{-1}\ m^{-2}\ K^{-1}$ rather than the older form of Btu/(hr. sq. ft. °F). As $Js^{-1} = W$, by definition the SI unit of heat transfer rate is $Wm^{-2}\ K^{-1}$.

Basic SI units

Length **m**

The *metre* was originally proposed as $\frac{1}{4} \times 10^{-7}$ of the meridian through Paris and a metal bar was made to this length and accepted as the standard metre in 1875. The metre is now redefined in terms of atomic radiation corresponding to the length of this bar.

In small work and in engineering drawing practice the millimetre is to be used and for surface texture the micrometre would be appropriate.

The centimetre is not a recommended unit and the kilometre will be used for lengths where the mile is now commonly used.

1 m = 39.37 in   1 in = 25.4 mm
0.001 in = 25.4 μm   1 mile = 1.609 3 km

Mass **kg**

The *kilogramme* is the mass of a standard platinum cylinder, and is the unit of mass which should be used generally. For very large masses the metric ton which is equal to 1 000 kg will be used and for very small masses the gramme and milligramme are the appropriate units.

1 metric ton = 1 000 kg = 2 204.6 lb
1 oz = 28.35 g
1 lb = 0.453 592 kg

Time **s**

The *second* should be used wherever possible in calculations and occurs in units involving velocity, power, heat flow rates, etc. The use of the hour and minute will of course continue to be used, but the use of the second in mechanics and thermodynamics as mentioned above immediately simplifies calculations. Road speeds will be given in km/h. The use of the symbol h in hour is in itself confusing as h also stands for hecto = 10^2.

Temperature **K** *or* **°C**

The fundamental scale of temperature is the kelvin scale in which O K is taken as absolute zero and the triple point of water at 273.16 K.

The temperature intervals of this scale are equal to the Celsius scale which sets 0°C for the freezing point of water (273.15K) and 100°C for the boiling point (373.15K) under normal atmospheric conditions. This Celsius scale is well known even in non-metric countries and will be used in all general references to temperature.

The term centigrade is used in infrequent angular measurement of a 400° circle and must not be used in connection with temperatures.

$$K = \frac{5}{9}(°F + 459.67)$$

$$°R = (°F + 459.67) \text{ degrees Rankine}$$

$$K = (°C + 273.15)$$

$$°C = \frac{5}{9}(°F - 32)$$

Some sources distinguish between actual temperature and temperature difference by the terms °C and deg C, but this has not been recommended by ISO and therefore not be used.

Electric current **A**

The *ampere* is defined as a current which would produce in two infinitely long parallel conductors of neglible cross section placed 1 m apart in vacuo, a force of 2×10^{-7} newton.

Giorgi recognised the need of a fundamental electrical quantity with his system of mechanical units in 1902 and suggested the ohm as it was then the most accurate unit available, being measured in terms of a mercury column. The present unit (adopted in 1946) avoids dependence on physical properties.

Luminous Intensity **cd**

Luminous intensity has the unit *candela* and is the luminous flux per unit solid angle. Luminous flux is a measure of radiant energy which is capable of producing visual stimulus, and is in part a physiological quantity. The value of the candela is such that the brilliance of total radiation at the temperature of solidification of platinum is 60 candela per square centimetre.

Named units of the SI

Refer to fig. 1

Force **N**

Force = mass x acceleration and its unit, the *newton* is that force which when applied to a mass of 1 kilogramme will produce an acceleration of 1 metre per second per second.

$$1\ N = 1\ kg \times 1\ ms^{-2}$$
$$= 1\ kgms^{-2}$$

This is of course an absolute unit and no gravitational factor is involved.

1 dyne = 1g x 1 cms^{-2}
10^9 dyne = 1 J m = 1 Nm^2
1 erg = 1 dyne x 1 cm
10^7 ergs = 10^7 dyne x 10^{-2}m
1 joule = 10^7 dyne x 10^{-2}m
1 Nm = 10^7 dyne x 10^{-2}m
1 N = 10^5 dyne
1 N = 7.223 poundal.

Now that the newton has been defined let us clearly differentiate between mass and weight. Weight is a force with which a mass is attracted to a centre of gravity. A one kilogramme mass (a quantity of matter) remains the same even if measured on the moon. The weight of this mass on a lunar expedition could vary from the gravitational attraction of earth, to weightlessness, to the gravitational attraction of the moon. The weight (or force of attraction) of 1 kilogramme mass on earth is 9.806 newton, on the moon its weight would be about 1.6 newton.

$$F = \text{mass x acceleration}$$
$$= 1\ kg \times 9.806\ ms^{-2}$$
$$= 9.806\ kgms^{-2}$$
$$= 9.806\ N$$

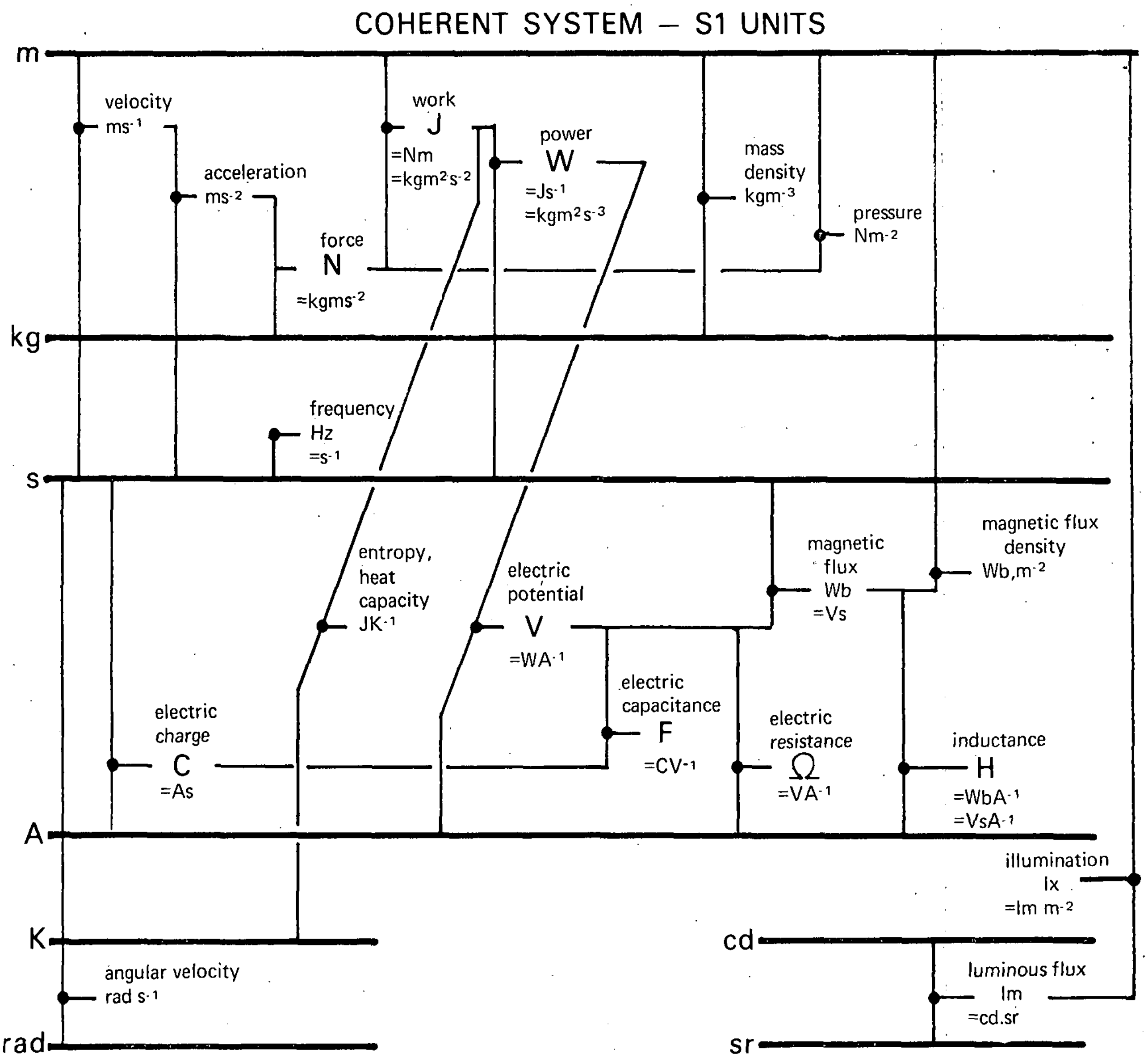


FIGURE I

In the Government Gazette No. 2595 of 31st December 1969 in the Weights and Measures Act, an amendment occurs:

"1. The deletion of the word "WEIGHT" in the heading of item 1 and the substitution therefor of the word "MASS".

Energy
Work } J
Heat

By definition, work = force × distance.
The *joule* is that amount of work done when a force of 1 newton is moved through a distance of 1 metre.

$$1\ \mathrm{J} = 1\ \mathrm{N} \times 1\ \mathrm{m}$$
$$= 1\ \mathrm{Nm}$$
$$= 1\ \mathrm{kgm^2s^{-2}}$$

As a unit of heat it is the direct thermal equivalent of the defined amount of mechanical energy and is thus independent of conversion factors for the mechanical equivalent of heat

1 kWh = 3.6 MJ
1 Btu = 1.055 kJ
1 erg = 10^{-7} J
1 cal = 4.186 8J

Power **W**

$$\text{Power} = \frac{\text{work}}{\text{time}}$$

The *watt* is equal to 1 joule per second.

$$1\ \mathrm{W} = 1\ \frac{\mathrm{J}}{\mathrm{s}}$$
$$= 1\ \frac{\mathrm{Nm}}{\mathrm{s}}$$
$$= 1\ \mathrm{kgm^2s^{-3}}$$

The watt will be used to express all quantities of power whether mechanical, electrical or thermal

1 hp = 745.7 W
1 kW = 1.341 hp
1 W = 3.414 Btu/h

Electric Potential **V**

The *volt* is specified as WA^{-1}

$WA^{-1} = JA^{-1}s^{-1}$
$= kg\ m^2A^{-1}s^{-3}$

For practical use the volt remains identical to what it was, only the definition has changed.

Units not named

Pressure **Nm^{-2}** *(pascal)*

Pressure, which is defined as force per unit area, is measured in newtons per square metre (Nm^{-2}). The value of 1 Nm^{-2} is too small for practical purposes (1 $Nm^{-2} = 0.145\,038 \times 10^{-3}$ lbf/sq in) and the kN/m^{-2} and MNm^{-2} are more acceptable (0.145 and 145 lbf/sq in respectively). There is, however, merit in a unit which is at roughly atmospheric pressure and for this reason the unit **bar** has been selected (1 bar $= 10^5$ Nm^{-2} = 14.503 8 lbf/sq in) even though this is not a recognised multiple in the SI system. The submultiple is the millibar.

An "atmosphere" in physics is defined as an air pressure which is in equilibrium with a mercury column of 760 mm. Mercury with a specific gravity of 13.6 will then exert a pressure of

$13.6 \times 76 = 1\,033.6\ gfcm^{-2}$
$= 1.033\,6\ kgfcm^{-2}$

In the past the technical atmosphere was taken as 1 $kgfcm^{-2}$

The bar is defined as $10^5\ Nm^{-2}$

$$= \frac{10^5}{10^4}\ N\ cm^{-2}$$
$$= 10\ Ncm^{-2}$$

On earth one newton is $\frac{1}{9.806}$ part of a kg weight and hence 10 Ncm^{-2} = 1.019 8 $kgfcm^{-2}$, likewise it can now easily be shown that

$$1\ bar = 1\,000\ millibar = \frac{1.019\,8}{1.033\,6}$$
$$= 0.986\,6\ \text{"atmosphere"}$$
$$\text{and 1 atmosphere} = \frac{1\,000}{0.986\,6} = 1\,013.6\ mbar\ approx.$$

Heat Units

There seems to be more mystery than necessary around the heat unit of the new SI metric system.

Here follow a number of ways to convert the Btu into kilojoules (kJ).

1Btu = 1 lb × 1°F
= 0.453 6 kg × 0.555 6°C
= 0.252 kcal (not used any longer)
1 kcal = 426.9 kgf.m (Joule's heat equivalent).
∴ 1 Btu = 426.9 × 0.252 = 107.58 kgf.m

To check:

1 kgf.m = 1 kgf × 1 m
= 2.205 lbf × 3.280 84 ft
= 7.233 ft. lbf
∴ 1 Btu = 7.233 × 107.58
= 778.2 ft lbf (Joule's heat equivalent).

Obviously, whether we go from the kcal or the Btu, we find that:

1 Btu = 107.58 kf.m

The kg force is not used any more and the kg mass takes its place. Now as the average acceleration of the gravity force = 9.81 ms^{-2}

1 kgf = 9.81 Newton
∴ 1 Btu = 9.81 × 107.58 = 1 055.1 Nm

By definition we know that 1 Nm = 1 joule (J) or

1 Btu = 1 055 J
= 1.055 kJ

Identically:

$$1\ kcal = \frac{1}{0.251} = 3.968\ Btu$$
$$1\ kcal = 3.968 \times 1.055 = 4.187\ kJ$$

The factor Btu/lb can now easily be converted in kJ/kg

$$Btu/lb = \frac{1.055\ kJ}{0.453\ kg}$$
$$= \underline{2.33\ kJ\ kg^{-1}}$$

Another approach would be:

1kWh = 3 412 Btu
= 3 600 kWs
= 3 600 kJ
3 412 Btu = 3 600 kJ
1 Btu = 1.055 kJ

Specific entropy in kJ kg^{-1} K^{-1} can be calculated as follows:

$$\frac{Btu}{lb \times {}^\circ R} = \frac{1.055\ kJ}{0.453\ kg \times 0.555\ K}$$
$$= \underline{4.187\ kJ\ kg^{-1}\ K^{-1}}$$

Also the conversion for the heat transfer coefficient is easy:

$$1\ Btu/(sq\ ft{}^\circ Fhr) = \frac{1.055\ kJ}{0.304\,8^2 m^2 \times 0.555\ {}^\circ C \times hr}$$
$$= 20.44\ kJm^{-2}{}^\circ C^{-1}h^{-1}$$
$$= 0.005\,67\ kJ\ m^{-2}{}^\circ C^{-1}s^{-1}$$
$$= \underline{5.678\ Wm^{-2}\ {}^\circ C^{-1}}$$
$$= \underline{5.678\ Wm^{-2}\ K^{-1}}$$

Summary of units commonly used in thermodynamics are given below:

	Imperial Units			*SI Units*
Quantity of heat	Btu	×1.055	=	kJ
Heat flow rate	Btu/hr	×0.293	=	W
Specific enthalpy	Btu/lb	×2.326	=	$kJkg^{-1}$
Specific heat	Btu/(lb°F)	×4.187	=	$kJ\ kg^{-1}{}^\circ C^{-1}$
Specific entropy	Btu/(lb°R)	×4.187	=	$kJ\ kg^{-1}K^{-1}$
Coefficient of heat transfer	Btu/(ft^2°Fhr)	×5.678	=	$Wm^{-2}{}^\circ C^{-1}$

TABLE I
Saturated Water and Steam
Pressure from the triple point up to $100 kN/m^2$ (1 bar)
($100 kN/m^2$ = 1 bar = 14.5 lbf/in^2)

Pressure kN/m^2	*Celsius* temp. °C	*Specific volume* m^3/kg		*Specific internal energy* kJ/kg		*Specific enthalpy* kJ/kg			*Specific entropy* kJ/kg K		*Pressure* kN/m^2	
		Water	Steam	Water	Steam	Water	Evapora'n	Steam	Water	Steam		
p	t	v_f	v_g	u_f	u_g	h_f	h_{fg}	h_g	s_f	s_g	p	
0.611	0.01	0.001 000	206.2	zero	2 375.6	+0.0	2 501.6	2 501.6	zero	9.157	0.611	Triple point
80	93.5	0.001 039	2.087	391.6	2 498.8	391.7	2 274.1	2 665.8	1.233	7.435	80	
85	95.2	0.001 040	1.972	398.5	2 500.8	398.6	2 269.8	2 668.4	1.252	7.415	85	
90	96.7	0.001 041	1.869	405.1	2 502.6	405.2	2 265.6	2 670.9	1.270	7.395	90	
95	98.2	0.001 042	1.777	411.4	2 504.4	411.5	2 261.7	2 673.2	1.287	7.377	95	
100	99.6	0.001 043	1.694	417.4	2 506.1	417.5	2 257.9	2 675.4	1.303	7.360	100	1 bar
101.325	100.0	0.001 044	1.673	419.0	2 506.5	419.1	2 256.9	2 676.0	1.307	7.355	101.325	1 atm

Steam Tables

The various columns are set out (in Table 1) and values around standard atmospheric pressure are given as well as the triple point mentioned in the temperature definitions.

The suffixes used in all the columns indicate:

f Saturated liquid state
g Saturated vapour state
fg Difference between saturated vapour and liquid state

Two or three Total Heat/Entropy diagrams are available differing only in size and clarity of printing. A good one is available in the Haywood Tables which have been issued to all mills. The Keenan and Keyes Steam Tables will be used as the Standard reference tables and this book also includes a very large H/Ø diagram.

Area $\mathbf{m^2}$

The square metre will be the basic unit of area except for very small areas like the cross-sectional areas of wires, etc.

The square metre is now used in survey area measurements and its multiple, the hectare, is used for larger area measurements.

$1 m^2$ = 10.764 sq ft $1 mm^2$ = 0.001 55 sq in
1 hectare = $10^4 m^2$ = 2.47 acres

Volume $\mathbf{m^3}$

The cubic metre is the basic volumetric unit but is rather on the large side and for smaller measurements the litre or dm^3 will be used. The term litre should not be used for precision measurements.

$1 m^3$ = 35.315 cu ft 1 litre = 1.76 pints
1 Imp gal = 4.546 litres

Stress $\mathbf{Nm^{-2}}$

The basic unit of stress is the same as for pressure, i.e. newtons per square metre. Again this unit is too small for calculating stresses in materials and the kNm^{-2} and MNm^{-2} are used.

Usage of the hectobar may also be found, but the MNm^{-2} (or $N mm^{-2}$) seems to be published more frequently.

$1 MNm^{-2}$ = 145.038 lbf/sq in
1 hectobar = 1 450.38 lbf/sq in

The units used for Moduli, e.g. Youngs Modulus will again be Nm^{-2}, but of a higher order, i.e. $GN m^{-2}$ particularly for metals.

$1 GNm^{-2}$ = 145 000 lbf/sq in

Hardness

Hardness is usually obtained by certain physical tests involving indentation of metal surface and these numbers will remain, as no direct conversion is possible between them. The four hardness numbers in common use are Brinell, Vickers, Rockwell and Shore.

Density

The simplicity of the metric system is best illustrated in calculation of density. In fact, for water at 4°C and under normal atmospheric pressure the units of mass and volume are identical. For any other material the ratio between units of mass and volume are identical at the specific weight of the material.

1 litre is the volume occupied by 1 000 g of water at prescribed conditions. The litre is the equivalent of 1 cubic decimetre.

The mass of 1 cm^3 of water = 1 g
The mass of 1 dm^3 of water = 1 kg
The mass of 1 m^3 of water = 1 000 kg
= 1 metric ton
The mass of 1 cm^3 of mercury = 13.6 g etc.

$$1 \text{ lb/cu ft} = \frac{454}{30.48 \times 30.48 \times 30.48} \text{ g cm}^{-3}$$
$$= 0.016 \text{ g cm}^{-3}$$

1 lb/cu ft = 0.016 kg dm^{-3} or kg per litre
1 lb/cu ft = 0.016 metric ton per m^3

Viscosity

The units of viscosity are given below and as yet have not been given names in the SI units. The cgs definition of dynamic viscosity is given as a basis for consideration. Absolute or dynamic viscosity, measured in poise, is the resistance (in dynes per square centimetre of its surface) offered by a layer of the fluid to the motion, parallel to that layer, of another layer of the fluid at a distance of 1 cm from it with a relative velocity of 1 cm/s. The dimensions of the Poise in the old system are dyne sec/cm^2. In the new SI system these units have been replaced and the unit of dynamic viscosity is measured in Nsm^{-2}.

The name poiseuille (Pl) has been suggested for this new unit.

Poise = dyne s cm^{-2} can be multiplied by 10^{-1} to give the SI units of Nsm^{-2}.

$$\text{Poise} = \frac{\text{dyne s}}{\text{cm}^2} = \frac{10^{-5}\text{ N s}}{10^{-4}\text{ m}^2} = 10^{-1}\text{ Ns m}^{-2}$$

$$\text{centipoise} = 10^{-3}\text{Nsm}^{-2}$$

The centipoise (cP) = 10^{-3} Nsm^{-2} is listed by S.A.B.S. as a unit which may be used.

Kinematic viscosity, which is dynamic viscosity divided by mass density is given in m^2s^{-1} but again the centistoke (cSt) which equals 10^{-6} m^2s^{-1} may be used.

$$\text{Stoke} = \frac{\text{Poise}}{\text{mass density}} = \frac{\text{dyne s}}{\text{cm}^2} \times \frac{\text{cm}^3}{\text{g}} = \frac{\text{g} \times \text{cm}}{\text{s}^2} \times \frac{\text{s}}{\text{cm}^2} \times \frac{\text{cm}^3}{\text{g}} = \frac{\text{cm}^2}{\text{s}} = 10^{-4}\text{m}^2\text{ s}^{-1}$$

$$\text{centistoke} = 10^{-6}\text{m}^2\text{s}^{-1}$$

Volume flow $\mathbf{m^3s^{-1}}$

The cubic metre per second is the basic volumetric flow measurement (cumec) but small units will be more commonly used and these are the litre per second and the cm^3 s^{-1}.

1 m^3s^{-1} = 35.315 ft^3/sec (cusec)
1 litre s^{-1} = 13.2 gal/min
1 ft^3s^{-1} = 0.028 m^3s^{-1}

Mass flow **kg s^{-1}**

For calculations involving the flow of liquids in pipes, etc. kgs^{-1} should be used

1 kgs^{-1} = 7 936.6 lb/hr

Electric Units

These are derived from the basic units as shown in fig. 1 taking the volt as a derived unit from the basic watt and ampere. These units have been in use for many years and the system as a whole will not require much rethinking by electrical engineers.

Properties of some metals

The properties of some commonly used engineering materials are given in Table 2 in SI units so that the order of magnitude of the units can be established for conversions which may have to be carried out. The second set of values in Imperial units are from another source and are *NOT* arithmetical conversions of the SI table.

Mild steel as used in normal boiler plate, RSJ's, austenitic stainless steels 18/8 and higher grades of cast iron will fall under the following ranges:

Yield Stress	*Tensile Strength*
200 - 300 MNm^{-2}	300 - 450 MNm^{-2}
20 - 30 hbar	
15 - 20 tons/sq in	20 - 30 tons /sq in

A reasonable working stress in a steel structure would be between 100 and 200 MN/m^{-2}.

Preferred Numbers

In the production of engineering materials it is not sufficient merely to convert the Imperial sizes to the

TABLE 2
Properties of Some Metals and Alloys

	Melting Point	Density	Specific Heat Capacity	Youngs Modulus	Poisson's Ratio	Ultimate Strength				
	K	kgm^{-3}	$Jkg^{-1}K^{-1}$	GNm^{-2}		MNm^{-2}				
Aluminium	933	2 710	875	70	0.34	90–150				
Copper	1 356	8 960	386	107–130	0.36	200–350				
Brass	1 200	8 370	365	100	0.34–0 40	350–510	65%Cu35%Zn (Yellow)			
Phosphorbronze	1 270	8 850		120	0.38	450–700	90%Cu10%Sn			
IRON:								%C	%Mn	%Si
Wrought		7 850		210	0.28	330		0.7	0.05	0.15
Cast	1 500	7 600		100–130	0.23–0.30	210&730*		3.5		2 0
Mild Steel	1 600	7 800	444	210	0 28	490		0.15	0 45	0 2
High C Steel		7 700		210	0.29	1 600		1.0	0 26	0 16
	°F	lbs/cuft	Btu/(lb°F)	psi × 10^6		psi × 10^3				
Aluminium	1 210	160	0.219	10.0		19	1 060 Strain Hardened			
Copper										
Brass	1 850	545	0.092	17.0		40	85%Cu15%Zn (Red)			
Phosphorbronze				16.0		66	10%Sn Annealed.			
IRON:										
Wrought		480		29.5		48				
Cast	2 200	450	0.114	14.7		32				
Mild Steel	2 500	493	0.116	30.0		57				

*Tensile & Compressive

nearest convenient metric size, but that a logical sequence of an increase in strength should go with increase in size. This size increase should be a geometric series, each size should be larger than the previous one by the same percentage. (B.S. 2045).

The SI system first expected that every size in the series should have one ten times as great. It then required the number of intermediate steps to be decided. This number was fixed at five, ten, twenty, forty or eighty. If the first series from 1 mm to 10mm must be divided into five steps, then the common ratio is $\sqrt[5]{10}$ or 1.585, and every size would be 1.585 larger than the lower one. The series would then be

1 1.585 2.51 3.98 6.31 10

Rounded off values are

1 1.6 2.5 4 6.3 10

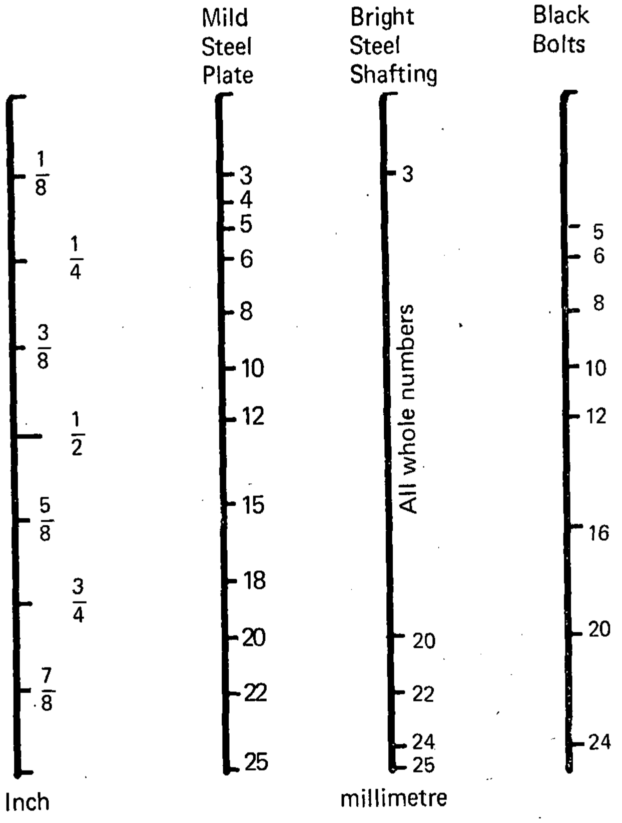
This is called the R5 series because the fifth root of ten is used. R stands for Renard. As the 58½% rise is often found too great the R10 series is used, each size increasing 1.259 times, or by 25.9%

The rounded off series is

1 1.25 1.6 2.0 2.5 3.15 4.0 5.0 6.30 8.0 10

Similarly there are R20, R40 and R80 series. These numbers are known as Preferred Numbers, the R5 series being first choice and so on. Plate, round bar and bolt sizes have been adopted using this basis and the nearest sizes to inch sizes are tabulated below:

METRIC SIZES FOR BASIC MATERIALS



It can be seen that the Renard series has not been rigidly adhered to and where costly alterations to steel rolling mills have to be made, Imperial sizes are being continued. This is the case with all structural sections. Pipe and pipe threads will be manufactured to British Specifications but with metric dimensions.

Screw Thread

The ISO metric screw thread is to be adopted as the standard for the new system. The thread angle is 60° with the top flattened and the bottom rounded. Specifications will give exact details of the three classes of fits to be made. (B.S. 3643.) The pitch will be expressed in mm and not as so many threads per unit length. It is expected that stocks of black bolts will be readily available during 1971. (B.S. 4190).

Drawing Office Practice

The S.A.B.S. have issued a Standard No. 0111 on drawing office practice. All drawings will be dimensioned in mm, the number only appearing on the dimension line and not the unit mm. Scales will be of the order of 1:2, 1:5, 1:10, etc. 1:100 will replace the building plan scale of 1/8" = 1 ft. Drawing paper will be ISO 'A' series, which is based on a rectangle of 1 m^2 with sides in the ratio of 1 to $\sqrt{2}$.

Tolerances

The ISO standard for Limits and Fits has been published as BS 4 500 : 1969. This is a formidable journal and the S.A.B.S. are preparing an abridged version which will be available for practical use in the workshop.

Example of SI units in a calculation

300 metric tons of mixed juice per hour at 14° Bx and 30°C are to be pumped through a juice heater using vapour at 1.3 bar abs. The required temperature is 44°C and the heater has 14 passes of 26 tubes each. The tubes are 2" O.D. and 16 ga × 4 m long. The static pumping head is 6 m. What size motor must be used on the pump, how much vapour will be condensed and what is the coefficient of heat transfer of the heater?

$$\text{Juice flow rate} = \frac{\text{mass}}{\text{mass density}}$$

$$14^\circ\ \text{Bx} = 1.056\,54\ \text{S.G.}$$

$$\text{Flow rate} = \frac{300 \times 1\,000}{1\,000 \times 1.056\,54} \times \frac{1}{3\,600}\ m^3s^{-1}$$

$$= 0.078\,87\ m^3s^{-1}$$

$$\text{Tube area per pass} = \frac{\pi d^2}{4} \times 26$$

$$= 0.046\,312\ m^2$$

$$\text{Juice velocity} = \frac{0.078\,87}{0.046\,312}\ m^3s^{-1}$$

$$= 1.703\ ms^{-1}$$

$$\text{Pressure drop across heater} = P = 0.002\ \frac{V^2}{D}\ C\,(L+1)$$

V = flow velocity ms^{-1}
D = tube diameter m
C = number of passes
L = tube length m

$$P = 0.002 \times \frac{1.703^2}{0.047\,6} \times 14\,(4 + 1)$$

$$= 8.529\,4 \text{ m}$$

Assuming a 50% pump and transmission efficiency:

$$\text{Power required} = \frac{300 \times 1\,000 \times 9.81 \times (8.529 + 6)}{3\,600 \times 0.5}$$

$$\left(\frac{\text{kg}}{\text{s}} \times \frac{\text{m}}{\text{s}^2} \times \text{m}\right)$$

$$= 23\,754 \text{ watts}$$

$$= 23.754 \text{ kW}$$

Heat required for juice per hour $= 300 \times 1\,000 \times (44 - 30) \times (0.9 \times 4.186)$

$\text{kg h}^{-1} \times {}^\circ\text{C} \times \text{kJkg}^{-1}\,{}^\circ\text{C}^{-1}$

Heat available in steam $= M \times (2\,687 - 449)$

$\text{kg} \times \text{kJ kg}^{-1}$

Mass steam required

$$M = \frac{300 \times 1\,000 \times 14 \times (0.9 \times 4.186)}{2\,242}$$

$$= 7\,070 \text{ kg h}^{-1}$$

Heating Surface × Coeff. Heat Transfer × log mean temp. diff.

= Flow rate × Temp. rise × Spec. Heat

$$\text{H.S.} = 0.047\,6 \times 3.141\,6 \times 26 \times 14 \times 4$$

$$= 217 \text{ m}^2$$

$$\text{Log mean temp. diff.} = \frac{44 - 30}{2.3 \log \frac{77}{63}} = 69.6^\circ\text{C}$$

$$\text{Coeff. H.T.} = \frac{300 \times 1\,000}{3\,600} \times 14 \times \frac{(0.9 \times 4.186)}{217 \times 69.6}$$

$$= 0.291 \text{ kW m}^{-2}\,{}^\circ\text{C}^{-1}$$

$$= 291 \text{ Wm}^{-2}\,{}^\circ\text{C}^{-1}$$

To check order of magnitude of results:

$$23.754 \text{ kW} \times \frac{1}{0.746} = 31.8 \text{ hp}$$

$$7\,070 \text{ kgh}^{-1} \times 2.204 = 15\,582 \text{ lbs/hr}$$

$$291 \text{ Wm}^{-2}\,{}^\circ\text{C}^{-1} \times \frac{1}{5.678} = 51.25 \text{ Btu/(ft}^2\text{hr}^\circ\text{F)}$$

Simple derivation of units

By remembering a few important conversion factors it is very easy to build up the correct form of any of the SI units.

Area

We must know 1 in = 25.4 mm
1 acre = 4 840 sq yds
1 hectare = 10 000 m^2

Then: 12 inches = 304.8 mm
1 ft = 0.304 8 m
3 ft = 0.914 4 m

$$1 \text{ metre} = 36 \times \frac{1\,000}{914.4} = 39.37 \text{ inches}$$

How many miles in a kilometre?

$$1 \text{ km} = 1\,000 \text{ m} = \frac{1\,000}{12} \times \frac{39.37}{5\,280}$$

$$= 0.621\,36 \text{ miles}$$

How many acres per hectare?

1 ha = 10 000 m^2
1 acre = 4 840 sq yds
1 acre = 4 840 × 0.914 4 × 0.914 4

$$= \frac{10\,000}{4\,046.8}$$

$$= 2.471 \text{ acres.}$$

Volumes

1 cu ft = 0.304 8 × 0.304 8 × 0.304 8 m^3
= 0.028 316 8 m^3

1 m^3 = 39.37 × 39.37 × 39.37
= 61 023 cu ins

$$= \frac{61\,023}{1\,728} \text{ cu ft}$$

$$= 35.314 \text{ cu ft}$$

$$= \frac{35.314}{27} \text{ cu yds}$$

$$= 1.307\,9 \text{ cu yds}$$

Note: 1 Imperial gallon = 0.16 cu ft
Then 1 gallon = 0.16 × 0.028 316
= 0.004 5 m^3
= 4.5 dm^3 (or litres)

Temperature

If we remember that both Fahrenheit and Celsius scales start at different points and that the Fahrenheit scale covers 180° from freezing to boiling and the Celsius scale covers 100° from freezing to boiling, it is not difficult to remember that

$${}^\circ\text{F} = \frac{({}^\circ\text{C} \times 180)}{100} + 32$$

$${}^\circ\text{C} = ({}^\circ\text{F} - 32) \times \frac{100}{180}$$

	°C	°F
Freezing point (ice)	0	32
Room temperature	20	68
	30	86

Body temperature	36.9	98.4
	60	140
	80	176
Boiling point (water) ...	100	212

Heat Units

Remember:
1°F = 0.555 5 °C
1 in = 25.4 mm
1 lb = 453.6 g
1 Btu = 1.055 kJ

$$\text{Then: } 1\ \text{lbf/sq in} = \frac{1\ \text{lbf}}{1\ \text{sq in}} = \frac{453.6\ \text{gf}}{25.4\times 25.4\ \text{mm}^2}$$

$$= \frac{453.6\times 10^{-3}\ \text{kgf}}{25.4\times 25.4\times 10^{-2}\ \text{cm}^2}$$

$$= 0.070\,3\ \text{kgf cm}^{-2}$$

$$\text{or } 1\ \text{lbf/(sq ft °F hr)} = \frac{\text{lbf}}{\text{sq ft}\times \text{°F}\times \text{hr}}$$

$$= \frac{453.6\ \text{gf}}{144\times 25.4\times 25.4\times 0.555\,5\times 3\,600}$$

$$= \frac{453.6\times 10^{-3}}{144\times 25.4^2\times 10^{-6}\times 0.555\,5\times 3\,600}\ \text{kgfm}^{-2}\text{°C}^{-1}\text{s}^{-1}$$

$$= 0.002\,44\ \text{kgfm}^{-2}\text{°C}^{-1}\text{s}^{-1}$$

$$\text{or } 1\ \text{Btu/(sq ft hr)} = \frac{\text{Btu}}{\text{sq ft}\times \text{hr}}$$

$$= \frac{1.055\ \text{kJ}}{12^2\times 25.4^2\times 10^{-6}\ \text{m}^2\times 3\,600\ \text{s}}$$

$$= 3.15\times 10^{-3}\ \text{kJ m}^{-2}\ \text{s}^{-1}$$

$$= 3.15\ \text{Wm}^{-2}$$

It will be sufficient to remember the four basic conversions given above.

Factory Conversion

The main factors in factory conversion have been

(1) Conversion of scales and weighbridges to read kilogrammes
(2) Alterations to laboratory control sheets
(3) Recalibration of process vessels for stocktaking
(4) Education of factory personnel at different levels and of different interests
(5) Conversion of gauges, charts, etc.

Pressure Units

It has been decided that for low pressure and vacuum measurements the bar absolute will be used. For vacuum measurements the sub-multiple millibar absolute will replace inches of mercury.

Boiler pressure gauges and other process lines will be measured in bars (gauge).

$1\ \text{bar} \doteq 10^5\ \text{Nm}^{-2} = 100\ \text{kNm}^{-2}$
$1\ \text{bar} = 14.503\,8\ \text{lbf/sq in}$
$= 750.062\ \text{mm Hg}$
$= 29.530\ \text{in Hg}$
$1\ \text{atm} = 760\ \text{mm Hg}$
$= 1.013\,25\ \text{bar}$

Millibars abs	Vac. gauge in Hg.	Sat Temp °C
300	21.061	69.1
280	21.651	67.5
260	22.242	65.9
240	22.832	64.1
220	23.423	62.2
200	24.014	60.1
180	24.604	57.8
160	25.195	55.3
140	25.785	52.6
120	26.376	49.4
100	26.967	45.8

APPENDIX I

Basic SI units and Definitions

METRE: Length equal to 1 650 763.73 wavelengths in vacuo of the radiation corresponding to the transition between the energy levels $2p_{10}$ and $5\ d_5$ of the krypton 86 atom.
KILOGRAMME: The mass of the international prototype kilogramme in the custody of the Bureau International des Poids et Mesures in Sevres, France.
SECOND: The duration of 9 192 631 770 oscillations of a radiation corresponding to a transition between the two hyperfine levels F = 4, M = O and F = 3, M = O of the fundamental stage $2\ S\ \frac{1}{2}$ of an atom of caesium 133.
AMPERE: The constant current which, if maintained in two parallel rectilinear conductors of infinite length, of negligible cross section and placed at a distance of one metre apart in vacuo, would produce between these conductors a force equal to 2×10^{-7} newton per metre length.
KELVIN: A unit of temperature equal to the fraction 1/273.16 of the temperature of the triple point of water.
CANDELA: The luminous intensity in a direction perpendicular to the surface of 1/600 000 square metre of a black body at the temperature of the freezing point of platinum at a pressure of 101 325 newton per square metre.

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