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Units of measurement in petroleum geoscience: towards the elimination of ambiguity

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Abstract: The petroleum industry, for historical reasons, has been landed with a mixture of US, British, and SI (metric based) units. The resulting confusion has been compounded by incorrect use of symbols, and use of several different non-standard symbols for the same units. Errors and ambiguity arising are at best vexatious to the reader, at worst can result in serious, expensive, and conceivably dangerous consequences. Petroleum scientists, to be worthy of the name, should aim to eliminate ambiguity by using standard symbols and abbreviations, where possible in the SI system. The extraction of large amounts of data from various sources for use in computer modelling, makes precision, clarity, and elimination of errors that result from lack of adherence to internationally understood abbreviations and symbols increasingly important.

Clarity is important in all reports, but particularly so in publications. A geoscience paper should be intelligible not only to the in-group of the writer's company or speciality, but to as broad a spectrum of scientists as possible, including others such as economists and administrators, who may be interested in aspects of the data presented.

INTRODUCTION

Petroleum geology has made and is making an enormous contribution to the general body of geological knowledge. Petroleum exploration is responsible for most of the subsurface data that have been gathered from sedimentary basins, for advances in surveying techniques, and many new concepts. Obvious examples are reflection seismic techniques and interpretation leading to new insights through seismic stratigraphy; detailed studies of diagenesis in sandstones; revolutionary advances in organic geochemistry, leading to new techniques and concepts in reconstructing thermal and structural history of basins. Integration of these different lines of evidence and large amounts of data into "basin modelling" is in part essentially what geologists have always done in reconstructing geological history; a new element is the increasing use of computers to deal with the enormous amount of quantifiable data available. Computer modelling and simulation, until recently confined to research institutes, is now becoming available through fairly easy to use off-the-shelf programs, that can be run on standard PCs, themselves becoming cheaper and more powerful by the month. Because of this increasing quantification, I think it is timely to re-examine the way we express our measurements, to avoid errors, retain precision, and communicate our exact meaning to a wide readership, using the international language of science.

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A MEASUREMENT OF CHAOS

"Some thirty countries have already decided to adopt the International System of Units — System International d'Unites (or SI for short) — as the only legally acceptable classification of measurement of physical quantities. The system adopted by the General Conference of Weights and Measures (CGPM) and endorsed by the International Organisation for Standardization (ISO) is clearly destined to become the only one in use throughout the world in the near future."

This quotation, from Socrates and Sapper (1969) was somewhat optimistic; it underrated the basic conservatism of many of us. If we have learnt to think in °F, we find it difficult to imagine how hot the weather is if it is expressed in °C, some of us never manage it. Someone who has been used to drinking his or her beer in pints, may refuse to drink in litres (unless he is really thirsty). If our training has been to measure sections in feet and inches, metres seem inconvenient; in fact a case can be made (and often is) that the old measures of length — the foot, inch, and fathom — based as they are on the average length of a human foot, thumb joint, and span of outstretched arms, are more natural and useful units. If we have spent a good deal of effort to learn to think about pressures in psi (pounds/square inch), kilopascals (kPa) do not come trippingly off the tongue or easily into our minds. (In fact, one does not need to go down hole to meet complications as far as pressure is concerned: my local garage has a pressure gauge in kilopascals, with a conversion table into pounds/square inch and bars, but the car manual quotes the recommended tyre pressures in kg cm^{-2}! See figure 1).

Even so, most sciences now use SI units exclusively where possible, and the majority of scientific publications specify that SI should be used unless there is an exceptional need to use some other units, in which case they may be permitted, with SI equivalents stated. The advantages in consistency, clarity, and international understanding among scientists are such that unless there is a compelling reason otherwise, SI units are best.

Because of the way in which the petroleum industry has evolved from its pioneering origin in the USA, the dominance, until recently, of US standards in drilling, and the partial change piecemeal into SI units, we have inherited a mishmash of US, Imperial (British), metric ('cgs'), and now SI units, that can lead to confusion, sometimes serious ambiguity, and mistakes that could conceivably be expensive or even dangerous. Moreover, individual companies have introduced into their in-house reports and on logs literally thousands of different abbreviations, some of which become generally used within companies, groups of companies, or in certain countries, but which are not understood internationally, in scientific spheres outside the speciality used, or even universally within the petroleum industry of one country.

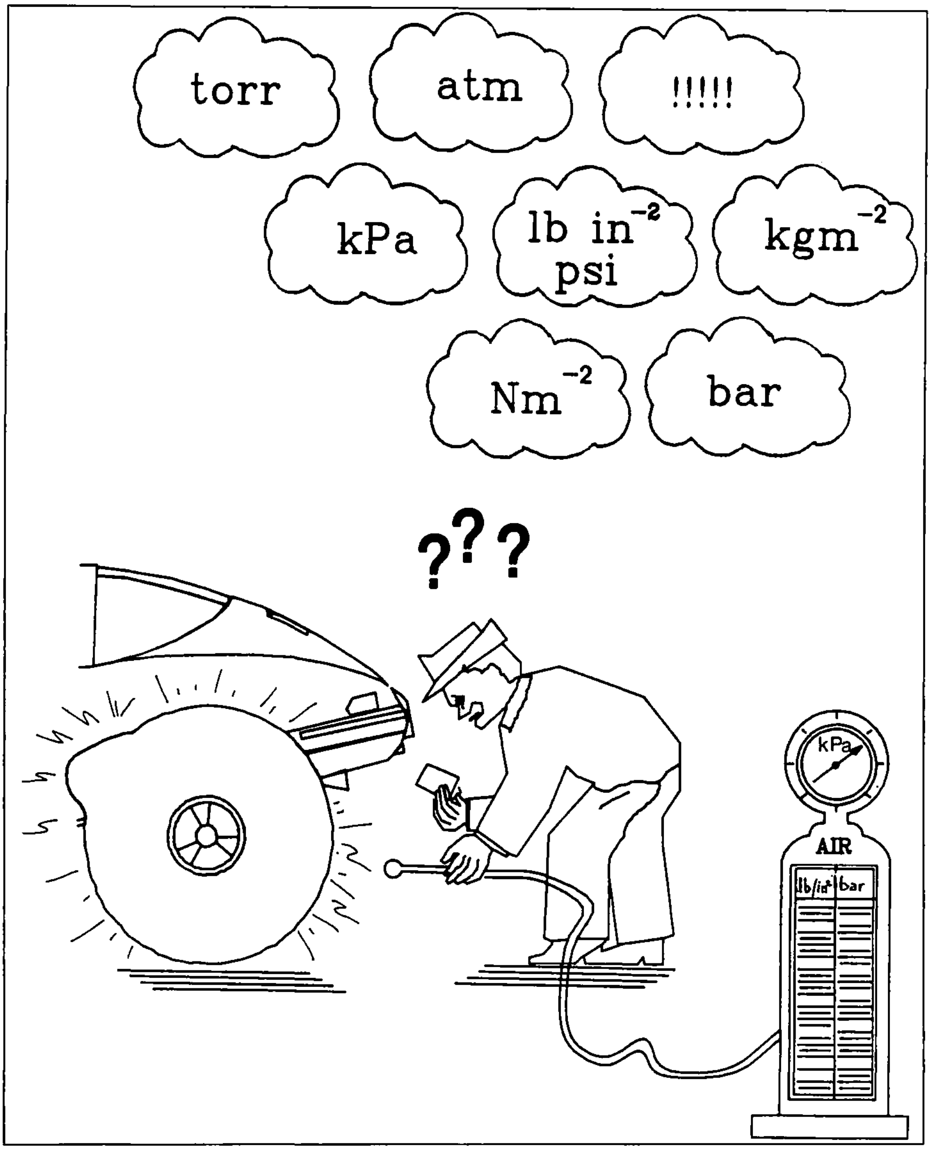

Figure 1: Confusion of a motorist confronted by different pressure units

Difficulties that occur arise from the following:

a) Confusion between SI and Imperial/US units;

b) Incorrect use of SI symbols and abbreviations;

c) A plethora of non-standard abbreviations, commonly using the same letter for many different meanings.

CONFUSION BETWEEN SI AND IMPERIAL/US UNITS

A simple example is units of temperature. Bottom hole temperatures and reservoir temperatures are still stated in °F on some logs. Geothermal gradients may be given in °F/100 feet, °C/100 m, or °C/km. It is not all that unusual to come across a temperature incorrectly recorded on a log or well report, e.g. stated as 275 °C when it is clear from the context that °F is meant. In the case of lower temperatures, such an error may not be detectable. Would it not be an improvement if temperatures were all recorded in Celsius (°C) and gradients stated in °C/km?

INCORRECT SYMBOLS FOR SI UNITS

The second kind of ambiguity can arise through use of the incorrect symbols for SI units (see Table 1). In a recent (1990) major publication on petroleum geology by a prestigious British geological society, the following abbreviations appear: For metre (m): M, Mt, MT; for cubic metre (m^3): M3, cm, CM. In many places it is clear from the context what is meant, but elsewhere ambiguity results. In SI, M stands for mega, and Mt means megatonne; MT would mean megatesslar (if such a unit were ever needed).

In SI, symbols are given in singular only, and without a full stop, e.g. 100 km, not 100 kms, km., kms, or Km; 's' in SI stands for second, so ambiguity can result. One might assume that authors from the continental part of Europe would have no difficulty with SI units, but this is surprisingly not always the case. I recently spent half an hour with a colleague, trying to puzzle out what

Table 1. Correct and incorrect symbols for common SI units

UNIT	SYMBOL	
	Correct	Incorrect
metres	m	ms, Ms, M, m., Mt.
kilometres	km	km., kms, Km, Km.
grams	g	gm, g., gms, gs
kilograms	kg	kg, kg., kgs, etc
seconds	s, sec	Sec., s., secs
cubic metres	m^3	cu.m, cm, CM etc
cubic centimetres	cm^3	cc,c.c., ccm, cu. cm.
tonne	t	T, t., tn

an author meant by a sedimentation rate of 1 μmm/year, which appeared in three tables. The unit as given, if it means anything, must mean a millionth of a millimetre a year (1 nm/a), although it is not allowable in SI to combine prefixes in this way. From the context it became clear that the author meant 1 μm/a (i.e. 1 m x 10^{-6}). Since the mistakes occur in a basic text from an international scientific publisher, and the author is a Professor of Mathematical Geology of continental origin, it is not surprising that we ordinary mortals are sometimes confused.

Another potential source of ambiguity is to use commas or full stops to space long numbers; commas are the SI approved indication of the decimal point, although a dot on the line is approved for use in English, and commas and dots are properly used in numbers only to indicate the decimal point. Thus 56 736.547 90 (or 56 736,547 90) should be written, not 56,736.547,90 (or, in the old continental fashion, 56.736,547.90). Ambiguity does not usually result if this rule is broken, but may do in some cases, particularly where less familiar units are used; for example, 2,500 kPa could mean either 2½ kPa (if the author is following the rules) or 2 500 kPa (if the author is breaking them). Thus one would need to know the author's country of origin to guess the meaning. The possibility of major error is clear.

NON-STANDARD ABBREVIATIONS AND SYMBOLS

The third type of ambiguity arises from use of non-standard abbreviations, which abound in the petroleum industry (see Table 2). Many of these are quite acceptable in in-house reports, although even there they can cause mistakes, and it would be better to aim to use standard international abbreviations and units where at all possible. One system which causes difficulty is the convention, largely obsolete elsewhere, of M = thousand, MM = million, MMM = thousand million. Since M in SI means mega, or million, the possibility of large errors is apparent, and it would seem to be highly desirable to abandon this system. In figures giving volumes of petroleum in reserves and production tests, the traditional measurement of barrels (US barrel = 44 US gallons) will probably still be used for a time, although long abandoned by the Norwegian Petroleum Directorate and other continental institutions, and recently by the Department of Energy, UK, in its annual review (known popularly as "the Brown Book"). Just to make the situation interesting, the NPD quotes its oil reserves in cubic metres, whereas the DofE uses tonnes! Similarly the cubic foot still is seen in many estimates of gas reserves, although it is, one hopes, destined to be replaced by cubic metres sooner rather than later. A way of quoting recovery factors and source rock productivity which seems to be antediluvian to a present day scientist still lingers on; in the geological society publication referred to above recovery is given in one paper as "1000 MCF per acre-foot". This is reminiscent of the old unit for assessing tin reserves in Malaysia, in

Table 2. Some ambiguous or non-standard units/abbreviations and recommended usage.

Unit	Recommended symbol/ abbreviation	Not recommended	Recommended SI unit or term
Barrels	bbl	B, Bbl, BBL, BBLS	m^3
Cubic feet	ft^3	CF, cu.ft.	m^3
Thousand	k	M, K	k
Million	M (but see note 2)	MM	M (mega) or x 10^6
"Billion"	(see note 3)	B	G (giga) or x 10^9
"Trillion"	(see note 3)		T (tera) or x 10^{12}
Million cubic metres per day	$10^6 m^3$/day	MCMD, MMCMD mmcmd, mcmd	see note 1
"Billion" cubic feet gas/day	10^9 ft^3/day gas	BCFPD, BCFD bscfd etc.	
Barrels of oil per day	bbl/day oil	BOPD, bopd bbls/d	
Million years	Ma	m.y. M.yr	Ma
Million years ago	Ma or Ma ago	MYBP, mybp	Ma

Note 1: When a unit is raised to a power, the power affects the whole unit, including the prefix. For example, Mm^3 is not a million cubic metres but a million metres cubed (i.e. $10^{18}m^3$), in the same way that 1 km^2 is a square kilometer (a million, not a thousand, square metres). For this reason, the SI prefixes M, G, and T are not used for reserve figures when these are quoted in SI units.

Note 2: Because the symbol M is still sometimes used in the generally obsolete meaning of thousand, it is better to write million in full or use exponential notation (10^6) in contexts where there is any possibility of ambiguity.

Note 3. "Billion" and "Trillion" are not recognised terms in SI, and most authorities recommend that their use should be avoided in a scientific context.

catties per acre-foot, and should, one hopes, be just as obsolete in scientific use, though for legal reasons it may be needed in parts of the United States.

A CAUTIONARY TALE

The use of standard units of measurement is becoming increasingly more important as large amounts of data are extracted and fed into computer modelling programs. Commonly these data are extracted from paper records of various origins by technical staff, who cannot be expected to spot anomalies resulting from non-standard abbreviations. Errors made by failure to convert or wrongly converting to the units used in the program (which almost always will operate in SI) may never be detected (Table 3). A colleague of mine, extracting test data from logs, once came across a record of a flow rate of 32 Mm^3/h, which he interpreted and tabulated as 32 million cubic metres per hour. I queried this as an impossibly high rate; we then thought that perhaps the logger was using M = x1000 and (impermissibly) using it with an SI unit? Still, a flow of 32 000 m^3 an hour still seemed too high. Closer inspection led us to the conclusion that what was actually meant was 32 thousand cubic metres per day – the log was an Indonesian one and 'h' stood for '*hari*' (day) not 'hour'. Such an error (of 2 399 900%!) was detectable by inspection (see figure 2), as the interpreted rate is impossibly high; however, there will be other cases where this is not so (or where no-one is alert enough to spot the error), and if the figures are entered into a computer with many other values, decisions which could have serious and expensive consequences may be made based on resulting wrong models. How much better to eliminate this probable error source by using SI units (correctly) in the first place! (In point of fact, in SI, Mm does not mean a mere million cubic metres but a megametre cubed, i.e. 10^{18} m^3 and so the potential error was much greater, namely 2.4 x 10^{16} %!).

GEOLOGICAL TIME

The basic SI unit of time is the second, which is not of much use to geologists, since we deal in millions of years. The abbreviation "a" (annum) for year, is permitted in SI, and seems to be generally understood in combinations such as ka, Ma, and Ga for thousand, million, and thousand million years respectively. Ma can also mean "million years ago" according to context; it is not usually necessary to add "before present". Elsewhere, year, with day and hour, are best written in full. It may be noted that "billion" and "trillion" are not recognized in SI nomenclature, and most authorities (such as the Society of Petroleum Engineers) recommend that their use is best avoided in a scientific context. The reason is that the meaning has differed: in US "billion" means a thousand million or 10^9, "trillion" a million million or 10^{12}; in Europe, officially, a billion means a million million, and a trillion, a million million million (10^{18}).

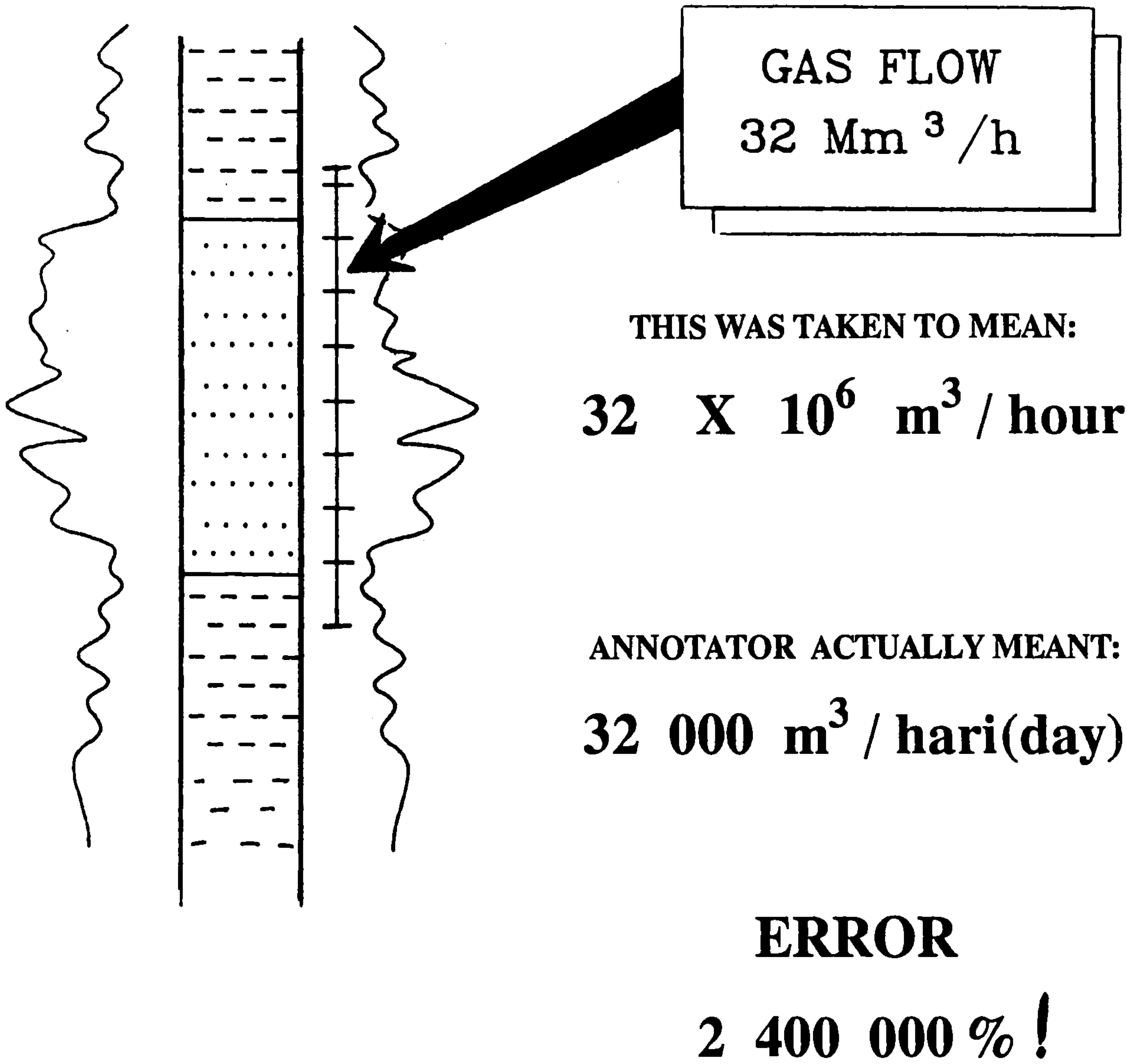

Figure 2: Confusion and error produced by non-standard symbols on a well log

Table 3. Conversion factors

To convert:	To:	Multiply by:
	Linear units	
inches (in)	centimetres (cm)	**2.54**
feet (ft)	metres (m)	**0.3048**
miles (mi)	kilometres (km)	1.609
nautical miles (nm)	kilometres (km)	1.852
metres (m)	feet (ft)	3.2808
kilometres (km)	miles (mi)	0.621
kilometres (km)	nautical miles (nm)	0.540
	Square units	
square feet (ft^2)	square metres (m^2)	0.0929
square miles (mi^2)	square kilometres (km^2)	2.590
acres (ac)	hectares (ha)	0.405
square metres (m^2)	square feet (ft^2)	10.764
square kilometres (km^2)	square miles (mi^2)	0.386
hectares (ha)	acres (ac)	2.471
	Volume units	
cubic feet (ft^3)	cubic metres (m^3)	0.283
barrels (bbl)	cubic metres (m^3)	0.159
barrels (bbl)	cubic feet (ft^3)	5.61
cubic metres (m^3)	cubic feet (ft^3)	35.31
cubic metres (m^3)	barrels (bbl)	6.290
tonnes (t)	barrels (bbl)	7.34 appr.
barrels (bbl)	tonnes (t)	0.14 appr.
litres (l)	US gallons (US gal)	0.264
barrels (bbl)	litres (l)	158.987
litres (l)	barrels (bbl)	0.0063
barrels (bbl)	US gallons (US gal)	42
acre-foot	cubic metres (m^3)	1 233.489
	Mass units	
pounds (lb)	kilograms (kg)	0.454
kilograms (kg)	pounds (lb)	2.205
short tons (tons)	tonnes (t)	0.07
tonnes (t)	short tons (tons)	1.102
	Pressure units	
pounds/in^2 (psi)	kilopascals (kPa)	6.895
kilopascals (kPa)	pounds/in^2 (psi)	0.1450

Table 3 cont'd.

To convert:	To:	Use formula:
	Temperature	
deg. Fahrenheit (°F)	deg. Celsius (°C)	0.556 (°F – 32)
deg. Celsius (°C)	deg. Fahrenheit (°F)	1.8°C + 32
deg. Celsius (°C)	deg. Kelvin (K)	°C + 273.15
deg. Kelvin (K)	deg. Celsius (°C)	K – 273.15

	Miscellaneous	
1°F/100ft	=	18.227°C/km
1°C/km	=	0.05486°F/100ft
1 darcy	=	0.9869 um^2
1 barrel per acre-foot	=	1.289×10^{-3}:1
	=	0.1289%
SG of oil	=	$\frac{141.5}{131.5 + °API}$
Gas/oil ratio 1 ft^3/bbl	=	0.178:1

Note: Conversion factors except those shown in bold, which are exact equivalents, are rounded; more precise factors are given, for example, in the Petroleum Engineering Handbook of the Society of Petroleum Engineers (Bradley, ed., 1987, chapter 57).

CONCLUSION

Petroleum geoscientists need to be familiar with several systems of measurement, and a plethora of abbreviations, to find their way around the reports, publications, and drilling records that are their stock-in-trade. However, in our own writing we should try to avoid making our potential readers run such an obstacle course, but communicate in clear universally understood terms — which means, as far as possible, using SI units, and using them in the internationally agreed way.

When writing for publication, we should bear in mind that our potential readership will include non-industry geologists, scientists from other disciplines, and possibly economists, some of whose mother tongues will differ from the language of our paper.

Useful general accounts on units are given in the Royal Society booklet (Anonymous, 1975). Units specific to the petroleum industry are discussed in the Society of Petroleum Engineers book (Anonymous, 1984) and by Campbell and Campbell (1985a and b). A comprehensive list is contained in the monumental SPE Petroleum Engineering handbook (Bradley, 1987).

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