Letter to the Editor

To the Editor:

In the editorial on "Metrology" in the March 1971 issue of the *Journal*, its former editor, Dr. Robert C. Reid stated, "Recognizing the inevitable, the *AIChE Journal* will require that all papers submitted after July 1, 1971, conform in notation to the SI System." Subsequently, its "Instructions for Contributors" has been recommending the use of the SI system of units. Looking back on this editorial, we would like to recognize that the *Journal* has given impetus and encouragement to the use of the SI system among chemical engineering researchers. In light of the resistance to the changeover to SI that still existed at the time, it was not easy for Professor Reid to publish the above-mentioned editorial when very few chemical engineering textbooks even referred to the SI system. The courage of this decision was recognized in a Letter to the Editor written by Professor Octave Levenspiel in the July 1971 issue. "I was electrified by your editorial on Metrology, I applaud and congratulate you. In one fell swoop you hurried this aspect of American chemical engineering square into the twentieth century."

This editorial not only had repercussions at the other American chemical engineering journals, but also influenced the introduction of the SI system in the chemical engineering textbooks. Before 1971, textbooks did not include the SI system in the list of recommended systems and, after the editorial, new textbooks (and new editions of older books) included the SI system. An example is the book *Basic Principles and Calculations in Chemical Engineering* by D. M. Himmelblau. The first (1962) and second (1967) editions of this book do not even mention the SI system, while the third edition (1974) and subsequent edition included the SI system. This book also shows the trend toward the use of the SI system, without forgetting the necessary ability of a chemical engineer to handle English units.

Presently, three separate systems of units coexist, American Engineering frequently used by practicing engineers, and the SI and cgs or metric systems largely used by researchers. Usually, this coexistence does not raise any problem, but sometimes, when units from two different systems are mixed in an application, it can lead to confusion or even to serious error. One dramatic example of the risk of mixing different unit systems was the loss of NASA's Mars Climate Orbiter spacecraft in which engineers failed to make a simple conversion from English to metric units (*Washington Post*, October 1, 1999).

In spite of the explicit statement "SI units must be used for **all** dimensional quantities" in the *Journal's* Instructions for Contributors," exceptions to the strict SI system can be found in many recent articles published in the *Journal*. Some of those non-SI uses may be considered acceptable and, in our opinion, the use of cgs system should be sometimes allowed because, for example, most of the physical properties determined in the laboratory or in handbooks have been expressed in the cgs system. For example, diffusivities in most handbooks are in units of cm^2/s, and the viscosities are in poises or centipoises.

We have carried out an analysis of the June 2000 issue of *Journal* and found, among many others, the following exceptions to and comments on the strict use of the SI system:

- The use of submultiples of the meter, such as μm, for the measurement of objects of small dimensions as the pore radius of membranes (p. 1150) or particles of small size (pp. 1161, 1246 and 1255) is a common practice in the scientific publications and should be allowed. But the simultaneous use of mm (for wire diameter) and μm (for fiber diameter) on the same page (Tables 1 and 2 of p. 1133) is not desirable.
- The basic unit for time in the SI system is the second. However, other units of time appear repeatedly: minutes (Figures 4 and 9 on pp. 1162 and 1165, respectively), hours (in Figures 6 to 10 and 12 on pp. 1185 to 1189, not only hours are used but they are incorrectly designed by "hr" instead of the correct "h" for this unit; Table 2 on page 1203; Figures 3 to 9 on pp. 1212 to 1214) and simultaneously minutes and hours in the same figure (Figure 6 on page 1175). Other examples of non-SI use with derived units include cases in which time appears: flow rate in mL/min (Figures 3 to 6 on pp. 1195 and 1196), flow rate in $L \cdot h^{-1}$ (p. 1141), flow rate in m^3/day (Figure 16 on p. 1129) and controller gain in mL/min·K (p. 1215) and mL/min·°C (p. 1217).
- Although the unit of energy in the SI is the Joule, on p. 1276 derived units in $kcal \cdot mol^{-1}$ $kcal \cdot mol^{-1} \cdot rad^{-2}$, and $kcal \cdot mol^{-1} \cdot \text{Å}$ were used.

The possibility of using different units for each parameter in tables of results can be allowed. However, the use of different unit systems when presenting dimensionally homogeneous equations may lead to confusion and can cause errors when readers use these equations. In fact, a discussion that presents dimensionally homogeneous equations need not include any reference to a specific unit. It should be understood, without an express need to indicate it, that a consistent unit system has to be used. In any case, when there is a wish to specify the units to be used in a **homogenous** equation, all units should belong to a coherent unit system, such as SI or cgs. Examples of not doing this can also be found in the June 2000 issue of the *Journal*:

Equation 1 on p. 1149 is an example of inconsistency of units, where two units systems, cgs and SI, have been used simultaneously in the Stokes-Einstein equation:

$$D_\infty = \frac{k_B T}{f_\infty} = \frac{k_B T}{6\pi\mu r_s}$$

There the following units were mentioned for each variable: D_∞ is the bulk solution diffusion coefficient (cm^2/s), k_B is Boltzmann's constant (1.38×10^{-16} J/K), T is the absolute temperature (K), f_∞ is the molecular friction coefficient in bulk solution (kg/s), μ is the solvent viscosity ($N \cdot s/m^2$), and r_s is the radius of the solute (cm). A similar situation occurs in Eq. 7 on p. 1151, where the Hagen-Poiseuille equation is presented as

$$Q = \frac{n\pi\langle r_p^4\rangle}{8\mu\,\ell}\Delta P$$

where Q is the flow rate (m^3/s), ΔP is the pressure drop across the membrane (Pa), n is the number of pores, $\langle r_p^4\rangle^{1/4}$ is the average pore radius (cm), and ℓ is the pore length (cm). In both cases, two different unit systems were mixed, and the direct application of the equation with the reported units lead to equations that are dimensionally homogeneous, but nonhomogeneous in units.

Thanks to the pioneering effort of the *AIChE Journal*, teachers and practitioners of chemical engineering are increasingly using the SI system. We are sure that the *Journal* will continue making progress in this direction. Therefore, given the numerous exceptions to the use of SI units found in the *Journal*, it is suggested that an explanation to the "Instructions to Contributors" be added indicating where the exceptions to the strict use of the SI system may be allowed. In this regard, we mention E. B. Nauman's request in the Letter to the Editor in the July 1971 issue that a number of reasonable exceptions to the strict use of the SI System be tolerated and the Editor's response to this comment, "Dr. Nauman's suggestions are eminently reasonable and the *Journal* will follow his recommendations."

Francisco Ruiz Beviá*
and Amparo Gómez Siurana
Dpto. Ingeniería Química
Universidad de Alicante
03080 Alicante, Spain

Editor's Response:

Professors Beviá and Siurana have raised two valid points in their Letter to the Editor. First, while the stated policy of the *Journal* for 30 years has been the use of SI units, their analysis shows that not enough attention has been devoted to this policy. An article in the August 1977 issue of *Chemical Engineering Progress* and in the January 1981 issue of the *Journal* confirmed this policy, by providing a detailed list of acceptable SI units, conversion factors, derived units with specific names, and other information. In the future we will be more diligent in enforcing this long-stated policy. If other than SI units are used, SI units in parentheses should follow. Second, the authors of this Letter to the Editor point out the special problems of using a mixed set of units for different terms in an equation. Those of us who teach are familiar with the confusion this causes our students and similar problems arise in engineering practice. Using SI units throughout will eliminate this problem.

The January 1981 issue (pp. 1 to 4) should be referred to for guidance on the use of SI units. For convenience, an abbreviated list appears below.

Abbreviated List of SI Units and Formatting to be Used in the *AIChE Journal*

The first unit listed is the base unit; others are commonly used multiples thereof. Accepted alternate units are listed in brackets.

Quantity	Accepted SI	Not Permitted in SI
Amount of substance	mol, kmol, mmol	g-mole, kg-mole
Angle	rad [degree(°), minute (′), second (″)]	
Angular velocity	rad/s	
Area	m^2, cm^2, mm^2	
Density	kg/m^3 [g/L]	
Energy, work, heat, enthalpy	J, kJ, MJ	caloire, erg, eV
Force	N, kN, mN	dyne, kilogram force (kgf)
Heat capacity	J/K, kJ/K	
Heat transfer coefficient	$W/m^2 \cdot K$	
Length	m, cm, mm, μm	Angstrom (Å), micron (μ)
Mass	kg, g, mg, μg	
Molality	mol/kg, mmol/kg	
Molar concentration	mol/m^3, $kmol/m^3$, mol/L	normality (N), molarity (M)
Molar mass, molecular weight	g/mol, kg/kmol, [Da = Dalton]	
Power	W, mW, kW, MW	
Pressure, stress	Pa, kPa, MPa	atm, bar, torr
Specific heat capacity, entropy	$J/g \cdot K$, $kJ/kg \cdot K$	
Temperature	K [°C]	
Thermal conductivity	$W/m \cdot K$	
Time	s [minute (min), hour (h), day (d), year (a)]	
Velocity	m/s, cm/s, mm/s	
Viscosity, dynamic	$Pa \cdot s$, $(kg/m \cdot s)$, $mPa \cdot s$	poise, stokes
Viscosity, kinematic	m^2/s, mm^2/s	
Volume	m^3, dm^3 (= L), cm^3, [L]	

Formatting notes:
Lower case letters are used for units, except for
(a) the first letter of a unit named after a person (K for Kelvin, Pa for Pascals)
(b) prefixes larger than kilo, i.e., M, G, etc.
(c) abbreviation for liter, L
There are no periods in units, except if the unit is at the end of a sentence.
A space is left between a numerical value and the unit (298.15 K; however 25°C).
If different usages of an SI unit are possible, the exact meaning should be given in the text or in parentheses, i.e., 100 kPa (gauge) not 100 kPag.
Numbers with many significant figures should be written in groups of three separated by a space and decimal points in a column should be aligned. Generally, numbers should be between 0.1 and 1000 with an appropriate power of 10. That is, $1.234\ 567 \times 10^4$ rather than 12345.67. An exception to this is that all numbers of the same unit in a single table or figure should contain the same multiple of ten to make comparisons easier.
To avoid confusion, do not use powers of 10 in units in symbols and tables. For example, in a table of thermal conductivity values, $W/m \cdot K \times 10^2$ probably is meant to indicate $W/cm \cdot K$.
Only one solidus or division sign should be used in units, that is $W/m \cdot K$ not W/m/K.
Use a dot to indicate a product of units ($J/kg \cdot K$), and a multiplication sign for the product of numbers (2×3).

Stanley I. Sandler
Editor