

241 Quantities, units and their symbols in production and consumption

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Abstract

The International System of Quantities (ISQ) shall be used in education and textbooks, in scientific and engineering journals, in conference papers and proceedings, in industry, etc. The names of quantities together with their symbols and units are being published by the International Organization for Standardization – the standard ISO 80000 Quantities and units, composed of 14 parts. Mathematics and natural sciences (physics, light and radiation, acoustics, physical chemistry, atomic and nuclear physics, condensed matter physics) compose most of the parts. Also, some engineering disciplines (mechanics, thermodynamics, electromagnetism), and characteristic numbers are covered. The units are based on the International System of Units (SI). Unfortunately, chemical and process engineering as well as environmental engineering and engineering economics are not dealt with in the standard. In this paper they will be proposed as an additional part of the ISO standard with a tentative name Chemical and environmental engineering.

The additional part of the standard is proposed to include a) reaction and separation engineering together with mass transfer and reaction kinetics, b) process design, control and optimization, c) process economics, mathematical modelling, operational research, and d) environmental engineering with climate change, pollution abatement, increase of resource efficiency, zero waste and circular economy. The number of quantities is planned but not limited to about 70 – the average of ISO 80000 parts. Each quantity item contains a quantity name and definition (including an equation if suitable), SI unit and remarks (running number will be added later). The rules are defined in ISO 80000-1 General rules, and practice of the other ISO 80000 parts is respected; the quantities already included in the other parts are not repeated. Also, the IUPAC (International Union of Pure and Applied Chemistry) Green Book rules are respected. The literature used included Ullmann's Encyclopedia, Perry's Chemical Engineers' Handbook, and some traditional textbooks from the chemical engineering and environmental fields. Some common mistakes in printing symbols of quantities and units are mentioned.

Keywords: chemical engineering, quantities, standard, symbols, units

Introduction

After the letters, numbers and units, the system of quantities was the last one developed and standardized globally. Quantity is a property of a phenomenon, body, or substance, where the property has a magnitude that can be expressed by means of a number and a reference (unit). The first international organizations trying to standardize chemical and physical quantities have been the International Union of Pure and Applied Physics, IUPAP (established in 1922) and the International Union of Pure and Applied Chemistry, IUPAC (formed in 1919). IUPAP prepared its first edition of Symbols, Units and Nomenclature in Physics in 1961 (IUPAP), for official use only; its 1987 revision is available online (Cohen). IUPAC published the first edition of the Manual of Symbols and Terminology for Physicochemical Quantities and Units in 1969 (McGlashan). After the 3rd edition they changed the title of the manual and published it as a Green Book, again with three editions (IUPAC, 2007). The Green Book is available on Internet, too.

In 1988, the International Organization for Standardization, ISO, in cooperation with International Electrotechnical Commission, IEC, published the first edition of international standard ISO 31 Quantities and units in 13 parts (ISO, 1978), and ISO 1000 SI units and recommendations for use (ISO, 1981). In 1992 a new version of both standards was published. In 2009 the two standards have been substituted by ISO 80000 Quantities and units containing 14 somewhat reorganized parts; the last edition was published in 2019, the exception being the parts mentioned in parentheses (the parts 1 and 6 are planned to be updated in the year 2021):

- | | |
|----------------------------|---|
| 1) General (2009) | 9) Physical chemistry and molecular physics |
| 2) Mathematics | 10) Atomic and nuclear physics |
| 3) Space and time | 11) Characteristic numbers |
| 4) Mechanics | 12) Condensed matter physics |
| 5) Thermodynamics | 13) Information science and technology (2008) |
| 6) Electromagnetism (2008) | 14) Telebiometrics related to human physiology (2008) |
| 7) Light and radiation | |
| 8) Acoustics (2020) | |

The general part contains information about quantities and units, printing rules, rules for terms in names for physical quantities, rounding of numbers, and logarithmic quantities. In parts 3–14, the quantities of each subset are listed, including item number, quantity name, symbol and definition, unit symbol, and eventual remarks. Since 2019, each part has an alphabetical index of quantities at the end to enable searching for the items. Three further parts, 15–17 (Logarithmic and related quantities, Printing and writing rules, Time dependency) are under development (ISO/IEC, 2021).

As can be seen from the above cited list of ISO 80000 parts, chemical and process industries (CPI) are not included although they are very important in many respects (turnover, profit, investments, employment, research, etc.). Besides the chemical industry, CPI is involving pharmaceuticals, cellulose and paper, metals, ceramics,

textiles, food and beverages industries, etc. The area is including process, plant and equipment modelling, design, construction, analysis, optimization, operation, control, process economics, safety, hazard assessment, transport phenomena, etc.

There is also no standard on environmental science and engineering although we are in the climate change/crisis, facing species extinction, pollution, and raw-materials scarcity. Paris agreement, European Green Deal, Net Zero by 2050, Sustainable Development Goals are some of the most frequent buzzwords which we are facing every day. They are dealing with greenhouse gas emissions, renewable sources, critical raw materials, biodiversity, resource efficiency, zero waste, circular economy, etc. Therefore, it is necessary to define internationally agreed names, symbols and units for the quantities used in the area.

Methods

Literature search included chemical and environmental engineering textbooks, handbooks, encyclopaedias, lexicons, manuals, standards, and Google searches. As the number of items is limited, the most important quantities have been selected according to the importance and frequency of their usage.

The proposal starts with chemical engineering quantities, continues with process economic ones in design, and finishes with the environmental ones. Some common mistakes in symbols of quantities and units are mentioned, they can also be found in literature (Glavič, 2021).

The proposed terms will be discussed at the ERSCP 2021 meeting – after an improvement they will be sent to the EFCE (European Federation of Chemical Engineering), the AIChE (American Institute of Chemical Engineers), the IChemE (British Institution of Chemical Engineers), and the DECHEMA (Deutsche Gesellschaft für chemisches Apparatewesen). After their approval they will be asked to send the proposal to the Technical Committee ISO/TC 12 Quantities and units.

Results and Discussion

Chemical and process engineering quantities are very exhaustive as they cover many topics based on chemistry, physics, mathematics, economics that deal with a very broad range of materials, methods, and equipment, e.g. (Ullmann, 2000; Perry, 2007):

- principles of fluid and particle dynamics, heat and mass transfer, chemical thermodynamics and kinetics, statistics, and optimization methods
- very diverse reactions – homogeneous liquid or gas ones, gas-liquid, or gas-liquid solid ones, using blast, or rotary furnaces, fixed or fluidized beds, heterogeneous gas catalysis, electrolysis, photo-, or plasma-chemistry, etc.
- unit operations like size reduction and classification, transportation and storage, mechanical, magnetic, electric separations, mixing and conveying, heating,

cooling, adsorption, absorption, extraction, ion exchange, distillation, evaporation, sublimation, refrigeration, crystallization and drying

- process design, construction, operation, control, and development with modelling, costing, simulation, optimization, process safety, pollution, energy integration, waste management and reuse, circular economy, renewable energy.

Therefore, an ISO standard about quantities and units is truly needed. Besides it, a similar edition as a Green Book in chemistry (IUPAC et al., 2007) would also be welcome.

Basic chemical engineering principles and unit operations

Some basic quantities that are not included in other parts of ISO 80000 are presented in Table 1. Values of constants are taken from BIPM (2019) and CODATA (2018).

Table 1. Basic chemical engineering quantities

Name	Symbol	Definition	Unit	Remarks
Avogadro constant	N_A	$N_A = N/n$	mol^{-1}	$6.022\ 141\ 76 \times 10^{23}$
Boltzmann constant	k, k_B		J K^{-1}	$1.380\ 649 \times 10^{-23}$
Faraday constant	F	$F = eL$	C mol^{-1}	$9.648\ 533\ 212 \times 10^4$
Henry's law constant	k_H	$k_{H,B} = (\delta f_B / \delta x_B)_{x_B=0}$	Pa	
fugacity coefficient	ϕ	$\phi = f_B/p_B$	1	
2 nd virial coefficient 3 rd virial coefficient	B C	$pV_m = RT(1 + B/V_m + C/V_m^2 + \dots)$	$\text{m}^3 \text{mol}^{-1}$ $\text{m}^6 \text{mol}^{-2}$	$pV_m = RT(1 + B_p p + C_p p^2 + \dots)$
Stefan-Boltzmann constant	σ	$M = \sigma T^4$	$\text{W m}^{-2} \text{K}^{-4}$	$5.670\ 374\ 419 \times 10^{-8}$
Planck constant	h	$H = E/f$	J s	$6.626\ 070\ 15 \times 10^{-34}$
coefficient of mass transfer	k_c	$k_c = q_n/A\Delta C_A$	m s^{-1}	
specific surface area	s	$S = A/m$	m^2/kg	
logarithmic-mean temperature	ΔT_{lm}	$\Delta T_{lm} = (\Delta T_2 - \Delta T_1) / \ln(\Delta T_2/\Delta T_1)$	1	

Chemical Reaction Engineering

Chemical reaction is the heart of chemical engineering activity – reactants are flowing into a reactor where they react, and products are flowing out of the reactor. Therefore, amount flow rates must be discussed first. The symbol F is used in English literature (Levenspiel, 1999), \dot{n} in German one (Fitzer and Fritz, 1989). Mass flow rate, q_m (kg/s), and volume flow rate, q_V (m^3/s), are defined in ISO 80000-4-30.2 and 4-31 but amount (of substance) flow rate is not; it is not defined in the Green Book (IUPAC, 2007), either. By analogy, q_n (mol/s), could be used (Table 2). ISO 80000-4 defined mass flow, j_m , too; therefore, amount flow, j_n , is also included in the list.

Table 2. Chemical reaction engineering quantities.

Name	Symbol	Definition	Unit	Remarks
amount flow	j_n	$j_n = cv$	$\text{mol m}^{-2} \text{s}^{-1}$	c – concentration
amount flow rate	q_n	$q_n = \iint j_n \cdot e_n dA$	mol s^{-1}	e_n – normal vector
(fractional) conversion	X_B	$X_B = (n_B - n_{B0}) / n_{B0}$ $= 1 - c_B / c_{B0}$	1	n – amount (of sub.) $dX_B = dc_B / c_{B0}$
selectivity	σ_P	$\sigma_P = dc_P / (dc_P + dc_S)$	1	
(fractional) yield	φ Φ	$\varphi = dc_P / (-dc_A)$ $\Phi = c_{Pf} / (c_{A0} - c_{Af})$	1 1	instantaneous over-all, f – final
rate of conversion	ω	$\omega = d\xi / dt$	mol s^{-1}	
specific rate of conv.	r_m	$r_m = (1/m) (dn_i / dt)$	$\text{mol kg}^{-1} \text{s}^{-1}$	
areic rate of conv.	r_A	$r_A = (1/A) (dn_i / dt)$	$\text{mol m}^{-2} \text{s}^{-1}$	
volumic rate of conv.	r_V	$r_V = (1/V) (dn_i / dt)$	$\text{mol m}^{-3} \text{s}^{-1}$	V – reactor volume
rate of reaction	r_c r_p	$r_c = (1/\nu_P) (dc_i / dt)$ $r_p = (1/RT) (dp_i / dt)$	$\text{mol m}^{-3} \text{s}^{-1}$ $\text{mol m}^{-3} \text{s}^{-1}$	for liquids for ideal gases
rate constant	k	$r = k \prod c_B^{m_B}$	$(\text{m}^3/\text{mol})^{m-1} / \text{s}$	m – order of reaction
residence time distribution, RTD	E	$\int_0^\infty E dt = 1$	1	age distribution at reactor exit
space-time	τ	$\tau = V_r / q_{V,F}$	s	
space-velocity	s	$S = 1/\tau$	s^{-1}	
recycle ratio	R	$R = q_{V,r} / q_{V,f}$	1	r – recycled, f – final

Conversion is the next quantity to be defined. It is often called fractional conversion (Umsatzgrad). The ISO 80000-9 and the Green Book cite extent of reaction, ξ (mol), and the Green Book also rate of (absolute) conversion, $\dot{\xi} = d\xi/dt$ (mol/s). In American textbooks X_A , or x_A , or f_A are used for conversion of a reactant A, while U_A (Umsatz) is used in German ones. X_A is adopted here. Subscripts A, B, C, etc., are used for reactants, and P, R, S, etc. for reaction products. Selectivity, σ_P is the amount ratio of desired product P to all products S formed. The definition in Table 2 is appropriate for reactors with constant volume. For selectivity calculation of a batch reactor, amounts of product P and reactant A are used, $\sigma_P = n_P / (n_{A0} - n_A)$. For continuous reactors amount flows are needed, $\sigma_P = q_{n,P} / (q_{n,A0} - q_{n,A})$. Yield (Ausbeute) is the amount ratio of desired product P to reactant A fed. It can be instantaneous, φ , or overall, Φ . Yield is always the selectivity times the conversion, $\varphi_P = \sigma_P X_A$.

The name 'rate of reaction' is used with constant volume fluids or with ideal gases, only. In other cases, the rate of conversion for any species i is proposed to be used; the specific rate of conversion is applied in cases of solid in fluid-solid systems. The areic rate of conversion is suitable for interfacial surface in two-fluid systems and in surface of solid catalyst in gas-solid systems. The volumic rate of conversion is based

on volume of a reactor, not the volume of a fluid; it could also be named rate of production, but this name is used in the case of selectivity, $q_{n,B} = \Phi q_{n,A0} = \sigma_B X_A q_{n,A0}$.

Equilibrium constants are described in ISO 80000-9, space time, space velocity and yield are not. Space-time, τ (s), is the time required to process one reactor volume of feed at specified conditions. Space-velocity, s (s^{-1}), is the space-time reciprocal. Recycle ratio, R (1), is the quotient of the volume flow rate returned to the reactor entrance and the one leaving the system.

Only a few quantities from reaction engineering are presented in Table 1. Single and multiple (series or parallel) reactions, elementary and nonelementary are known, number of molecules (molecularity with different orders of reaction) can differ and influence the rate equation. Temperature and pressure effects can vary, reaction can be exothermal or endothermal. Also, we know different type of reactors – batch, plug flow, mixed flow, recycle ones. Flow patterns and contacting can be ideal or non-ideal; in the last case dispersion, convection, or earliness of mixing must be accounted for. Finally, fluid-fluid (liquid or gas), fluid-solid, catalytic, and various biochemical (enzyme or microbial) reactors exist – heat and mass transfer become important in these cases, too. It will be difficult to standardize all of the quantities used in one standard. Especially so because process control, economics, and optimization influence the design of reactors.

Regarding axial dispersion, the dispersion coefficient, D (m^2/s), mean time of a passage, \bar{t} (s), and variance, σ^2 , are important quantities; probability distribution, statistics and uncertainties are described in the Green Book (pp. 151, 152). In the case of catalytic systems, the rate of conversion equations from Table 1 can be used; they can be based on volume of voids in reactor, mass or volume of catalyst pellets, catalyst surface area, or total reactor volume; activity of catalyst, a (1), may also be important. For heterogeneous reactions with two or more phases, the standard could contain some other quantities like interfacial area density, a (m^2/m^3), effectiveness factor (\mathcal{E} or η , 1), mass transfer coefficient of the gas film, β , or k_g , liquid film, k_l (m/s), H ($Pa\ m^3\ mol^{-1}$), Thiele modulus, M_T (also h_T , ϕ in German literature), Wagner or Weisz modulus, M_W , and Hatta modulus, M_H (the unit 1 for all).

Other unit operations

Unit operations are numerous and differ very one from another. Let us take distillation as an example. It is normal to write amount flow rates (mol/s) with a symbol of a flow rate name – F for feed flow rate, D for distillate flow rate, S for side stream flow rate, V for vapour flow rate, etc. F could be used as a quantity symbol with a subscript denoting different flow rates, $q_{n,F}$, $q_{n,D}$, $q_{n,S}$ and $q_{n,V}$ in this case. The second disrespect of ISO 80000 rules is the name “duty” for the heat flow rate (W), e.g., condenser duty, reboiler duty while their symbol, \dot{Q} is in accordance with the ISO one. Also, void fraction, ε is

not well defined – volume fraction of voids is the right name, and φ the right symbol. Some other proposals for quantities of unit operations and their symbols are presented in Table 3.

Table 3 Quantity names, symbols, and units in separation units

Name	Symbol	Definition	Unit	Remarks
amount flow	j_n	$j_n = q_n/A$	$\text{mol m}^{-2} \text{s}^{-1}$	
external reflux ratio	R	$R = q_{n, N+1}/q_D$	1	$q_{N+1}/V_N = R/(1 + R)$
vapor-liquid equilibrium ratio	K_i	$K_i = x_i/y_i$	1	
relative volatility	α_{ij}	$\alpha_{ij} = K_i/K_j$	1	
fugacity coefficient	ϕ_i	$\phi_i = f_i/p$	1	$\phi_i = 1$ for ideal gas
volume fraction of voids	φ_v	$\varphi_v = V_v/V_{\text{tot}}$	1	
efficiency of batch experiment	η_b	$\eta_b = 1 - e^{-k t_b}$	1	t_b batch mixing time
efficiency of a continuous process	η_c	$\eta_c = k\theta/(1 + k\theta)$	1	θ total liquid residence time

Process development and design

Process development data which can be internal or external, process evaluation which is including capacity determination, and economics, process optimization and decision making are important. Table 4 is presenting the most frequent quantities in process engineering optimization using mathematics and economics. Statistics is well covered in ISO standards; therefore, it will not be regarded here. Economics on the other side is not standardized, and often acronyms are used instead of symbols; it also lacks international coordination (Couper, 2003).

Table 4. Chemical and process engineering design economics

Name	Symbol	Definition	Unit	Remarks
cost	C		EUR, USD, ...	cost index
investment	I		€, \$, ...	fixed capital
interest rate	i		%	V_p – present value
future value	V_f	$V_f = V_p (1 + i)^N$	1 (% = 10^{-2})	N – number of years
net sales, revenue	S_n	$S_n = S_g - O_c$	€, \$, ...	S_g - gross sales
turnover ratio	r_{to}	$r_{to} = S_g/I$	1	reciprocals
capital ratio	r_c	$r_c = I/S_g$	1	
production rate	q_m	$q_m = m/t$	kg/s, t/a	capacity dependent
operating expenses	O	$O = O_d + O_i$	€, \$, ...	
depreciation	D	$D = I/N$	€/a, \$/a, ...	with no salvage value
gross income	P_g	$P_g = R - O - D$	€/a, \$/a, ...	gross profit
net income	P_n	$P_n = P_g (1 - t)$	€/a, \$/a, ...	net profit, t – tax rate

Name	Symbol	Definition	Unit	Remarks
income tax	T	$T = \tau(R - O - D)$	%	τ – tax rate
net profit after tax	P_n	$P_n = P_g(1 - \tau)$	€/a, \$/a, ...	net income
cash flow rate	q_c	$q_c = P_n + D$	€/a, \$/a, ...	
return on investment	R_{oi}	$R_{oi} = P/I \times 100$	%	internal rate of return
payout time	t_{po}	$t_{po} = I/P_n$	a	payout period, years

The most used cost indices are Marshall and Swift (M&S, since 1926), Chemical Engineering (CE, since 1958), and Nelson-Farrar (since 1946) ones. Capital investment is including equipment cost, instrumentation, piping, insulation, electrical and engineering costs without any contingency; contingency is about 15–20 % of capital investment – when added to capital investment, the battery-limits capital investment is obtained. Working capital is including the fund for wages and salaries, purchase raw-materials, supplies, etc.

Operating expense is the sum of expenses for the processing of a product plus general, administrative, and selling expenses. They can be grouped into direct, indirect and product expenses; direct expenses are raw-materials, utilities, labour, maintenance, supervision, payroll charges, operating supplies, clothing and laundry, technical service, royalties, and environmental control ones. Indirect expenses include depreciation and plant indirect costs. Total manufacturing expense is adding packaging, loading, and shipping expenses to the operating expense. Revenues are the net sales received from selling a product to a customer. The value added to the product is the difference between the raw material expenses and the selling price of that product.

Time value of money, the expected interest rate that capital should or would earn, is diminishing because of the inflation. The present value of money, V_p , is lower than the future value, V_f . When a company loans money, a charge is made for the use of borrowed funds – the interest rate includes inflation expectation, the borrower's cost and his desired profit. The cost of capital is what it costs the company to borrow money from all sources (loans, bonds, stocks); it is expressed as an interest rate.

Besides the term depreciation, the quantity amortization is often used – there is a slight difference between them. If the period of life is known exactly, the annual expense is called amortization. If this time is estimated, it is called depreciation.

Rate of return and its variations are known by various names, e.g., internal rate of return, interest rate of return, discounted cash flow rate of return.

Environmental quantities, units, and symbols

Sustainable development with its three pillars (environmental, social, economic ones) is gaining importance and so is the Paris agreement with the 17 sustainable 20th European Round Table on Sustainable Consumption and Production
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development goals (SDGs). The most problematic is the climate crisis caused by greenhouse gas (GHG) emissions with global warming. Table 5 presents some of the most important quantities in this area, starting with GHG emissions and climate change.

Table 5 Environmental quantities with symbols and units

Name	Symbol	Definition	Unit	Remarks
amount fraction of CO ₂ equivalent	$x(\text{CO}_{2,\text{eq}})$	$x_B = n_B / \sum_i n_i$	μmol/mol	in atmosphere
electricity, emissions coefficient	$E_e(\text{CO}_{2,\text{eq}})$	$E_e = m/W$	kg/(kW h)	not factor
travel, emission coefficient	E_l	$E_l = m/l$	g/km	various forms
carbon footprint per user	F_c	$F_c = m/t$	t/a	per person, ...
ecological footprint	F_e	$F_e = A_{\text{eq}}$	ha	not gha
water footprint	F_w	$F_w = V/t$	m ³ /a	
amount fraction of air pollution	$x(\text{SO}_2)$	$x = n_{\text{SO}_2} / \sum n$	nmol/mol	not ppm
mass concentration of particulate matter pollution, $d \leq (2.5, 10) \mu\text{m}$	$\gamma_{\text{PM}_{2.5}}$ $\gamma_{\text{PM}_{10}}$	$\gamma = m_{\text{PM}}/V$	μg/m ³	in air
number concentration, microplastics	C	$C = N/V$	m ⁻³	in lake, ocean
mass concentration, heavy metal	$\gamma(\text{Hg})$	$\gamma = m_{\text{Hg}}/V$	μg/L	in water
mass fraction, heavy metal	$w(\text{Pb})$	$w = m_{\text{Pb}} / \sum m$	mg/kg	in soil
waste generation per capita	q_m	$q_m = m/t$	kg/a	mass flow rate
mass fraction of waste recycled	w_r	$w_r = m_r/m_w$	1, %	not recycl. rate

GHGs contain the most dangerous gases: water vapour, H₂O, carbon dioxide, CO₂ and methane, CH₄, and also nitrous oxide, N₂O, ozone, O₃, chlorofluorocarbons, CFCs, and hydrofluorocarbons, HFCs; they are recalculated into CO₂ equivalents. The literature is usually writing about their concentrations in ppm (parts per million) as a unit. The quantity is not concentration (mol/m³) but rather amount fraction (μmol/mol). The units, ppm, ppb (part per billion), etc. are not recommended by IUPAC, therefore, amount (of substance) fraction with the symbol x and unit μmol/mol is used.

GHGs originate from burning of fossil fuels in transportation, energy production, industry, residential areas, from fermentation of waste and in agriculture. The CO_{2,eq} emissions can be expressed in different ways, e.g., as mass per energy produced (kg/kW h, or mg/J), mass per volume of fuel (mg/l), mass per distance travelled (g/km), mass of CH₄ per agricultural area released or absorbed(kg/ha). They can be calculated per person, per company, per city, per country, or per world. No special names and symbols are available now. Many mistakes can be observed in statistical collections and in literature, e.g., by including CO₂ formula, or the words “per person” or “per capita”, into the units.

In Table 5 some tentative symbols for quantities and units regarding emissions are proposed by analogy with the ISO 80000 rules. According to these rules “emission factor” is switched to “emission coefficient”. Using the proposed names, symbols and units, different forms of travelling (car, train, plane, etc.) or different users of carbon footprint can be addressed and compared. Ecological footprint uses a special name for land and water area unit name – global hectare with a symbol gha (GFN, 2009). According to the ISO rules, the name ‘global’ is a part of the quantity name (global area) and its symbol (A_g), and not of the unit one (hectare, ha). Many other footprints have been developed (water, land, nitrogen, phosphorus, material, biodiversity, chemical, plastic, energy, etc.); the environmental footprint family, relating to the nine planetary boundaries and their connection with SDGs is being developed (Vanham et al., 2019).

Pollution of air, water, soil with chemical substances, heavy metals, particulate matter, noise, electromagnetic radiations, etc., is the second major problem of the modern society. Accepted terminology and symbols can be used for them but are usually not applied. An international standard could improve their usage. Waste minimization, recycling and circular economy are becoming more and more important. “Waste generation” (per capita) actually means an abbreviated name for “mass flow rate of waste generated”. “Recycling rate” means mass flow rate of recycled material (q_m , kg/a) what is a different quantity; therefore, the name is substituted by the “recycling fraction” in %.

Conclusions

Chemical and process engineering as well as environmental science and engineering are not represented in the 14 parts of ISO 80000 standard on quantities and units. The chemical industry sales alone (3.66 TEUR – trillion euros, 10^{12} EUR) reach 5.4 % of the world’s GDP (gross domestic product, 68.10 TEUR). It is very interdisciplinary and specialized, and different from the manufacturing industry. It is also very important in the area of sustainable engineering, especially in environmental sustainability. Therefore, it deserves a special part in the standardization of quantities and units. The literature review has shown that there are many names of quantities and units that are not in accordance with the ISO 80000 rules. Even worse is the situation with quantity symbols and units – many symbols of quantities are not coherent with the international system ISQ, and many units do not respect the SI rules. Acronyms cannot be used as quantity symbols, and SI units may not be intermixed with quantity specifications.

This paper tried to discuss and propose some of the most important quantities in the areas of chemical and environmental engineering, and process economics. Regarding the names and symbols selected, the rules accepted in the systems ISQ and SI were tried to be obeyed. The choice of quantities is of course just an illustration of names and symbols to be included in the proposal. Health and safety, management and

quality were not discussed as standards for them exist, but this does not mean that a review of quantity names, units and symbols in those standards is not needed. Also, basic concepts of statistics, process modelling, simulation, synthesis, design, integration, and optimisation were not included, yet.

The area is too broad and complex for the definite selection of quantities, their names, and symbols, but every journey starts with a single step. The proposal with proposed quantities, their names, symbols, and units must be discussed in national and international associations as well as the International Organisation for Standardization. Environmental and economic quantities could also be discussed as separate standards because their importance is broader than the chemical and process industries area.

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