Chapter II

UNITS OF MEASUREMENTS

1.1 Values, Units and Dimensions

The ability to solve problems by using engineering calculations represents the very essence of engineering. While certainly not all engineering problems can be solved by using numerical calculations, such calculations are absolutely necessary for the development of technical solutions. Engineering calculations make it possible to describe the physical world in terms of units and dimensions that are understood by all those with whom communication takes place.

Study of the units are very important in the engineering. A quantity is described by values and units. Units simply describe what the quantity is about. While measuring and reporting an environmental quantity, both of these items need to be mentioned. For example, a river discharge of 500 m^3/s, a sand particle of 2 mm, snow mass of 500 km^3 in Himalayas. In the study of environmental engineering it is quite common to encounter both extremely large quantities and extremely small ones. The concentration of some toxic substance may be measured in parts per billion while the discharge of a large river may be measured with a larger unit. To describe quantities that may take on such extreme values, it is useful to have a system of prefixes that accompany the units. Some of the most important prefixes are presented in Table 2.1. The size of a colloidal particle to the area covered by urban settlement serve the good example of the quantities to be handled. Thus it is essential to use a practical and less scientific figure to represent the quantity under consideration. Specific symbols are also used to describe these quantities.

Dimension is a unique quantity that describes a basic characteristics of the measurement. Mass (M), length (L) and time (T) are three fundamental dimensions. Dimensions are descriptive but not numerical. They can not describe how much; they simply describe what. For example, the length (L) dimension may be described in units as meters, inches or Angstrom. A Summary of some of the commonly used key parameters, their symbols and their dimension is given in Box 1.

Table 2.1 Common Prefixes

Quantity	Prefix	Symbol
10^{-12}	pico	p
10^{-9}	nano	n
10^{-6}	micro	μ
10^{-3}	milli	m
10^{-2}	centi	c
10^{-1}	deci	d
10	deca	da
10^{2}	hector	h
10^{3}	kilo	k
10^{6}	mega	M
10^{9}	giga	G
10^{12}	tera	T
10^{15}	peta	P
10^{18}	exa	E

Box 1 : Commonly used parameters, their notation and dimension

(Dimensions are denoted as: length – L; Mass-M; time-T; temperature - θ; mole = mol.)

Symbol	Quantity	Dimension
I. Geometric dimensions, amounts, concentrations		
H	Height or depth	L
L	Length	L
δ	Thickness	L
A	Area	L^2
V	Volume	L^3
ε	Intergranual porosity or void fraction	-
X	Particulate material concentration	ML^{-3}
S	Soluble material concentration	ML^{-3}
C	Total material concentration (particulate plus soluble)	ML^{-3}
II. Thermodynamic parameters		
T	Temperature	θ
p	Total pressure	$ML^{-1}T^{-2}$
R	Ideal gas constant	$ML^{-1}T^{-2}\theta^{-1}mol^{-1}$
P	Power	ML^2T^{-3}
III. Physical properties of matter		
D	Diffusion coefficient, dispersion coefficient or material diffusivity	L^2T^{-1}
η	Dynamic viscosity	$ML^{-1}T^{-2}$
ν	Kinematic viscosity	L^2T^{-1}
ρ	Density	ML^{-3}
IV. Time, velocities, and flow rates		
t	Chronological or running time	T
θ	Space time (volume of reaction phase divided by volumetric flow rate of phase entering the reactor)	T
T	Mean hydraulic residence time	T
θ_x	Mean solids residence time	T
u	Velocity	LT^{-1}
g	Gravitational acceleration	LT^{-2}
Q	Liquid volumetric flow rate	L^3T^{-1}
Q_G	Gas volumetric flow rate	L^3T^{-1}
R	Recycle ratio	-
V. Parameters of mass flow rate and reaction rates		
F	Mass flow rate	MT^{-1}
B_A	Mass flow rate per unit area	$ML^{-2}T^{-1}$
B_V	Mass flow rate per unit volume or volumetric loading rate	$ML^{-3}T^{-1}$
r_A	Reaction rate per unit area	$ML^{-2}T^{-1}$
μ	Specific biomass growth rate	T^{-1}
μ_{max}	Maximum specific biomass growth rate	T^{-1}
Y	Biomass yield coefficient	MM^{-1}
k	Reaction rate coefficient or constant	Dimension depends on kinetic model
K_s	Saturation constant, half velocity coefficient, or Michaelis-Menton constant	ML^{-3}

1.2 Size

Substances causing pollution can exist in water in one of three classifications: suspended, colloidal or dissolved. Having knowledge of the size of these substances is important in understanding the different aspects of the pollution. Table 2.2 provides a list of selected particles and their sizes.

Table 2.2: Average size of the substances

Substances	Size		
	cm	**mm**	**μm**
Gravel	1	10	10,000
Sand		1	1000
Fine sand (diameter of body hair)			100
Algae			50
Fungi			50
Clay			10
Giardia			10
Cryptosporidium			5
Bacteria			1
Protozoa			1-300
Colloidal particle			0.1
Humic acid			0.05
Dissolved particle			0.001

Note : 1 meter(m) = 100 centimeter (cm) = 1000 millimeter (mm) = 10^6 micrometer (μm) = 10^9 nanometer (nm)

1.3 Concentration and density

The mass density or density of a material or a solution is defined as its mass per unit volume, or

$$\rho = \frac{M}{V}$$

Where ρ = density
M = mass
V = volume

In SI system, the base unit for density is kg/m^3.

Water in the SI system has a density of 1×10^3 kg/m^3, which is equal to 1 g/cm^3.

Where as the concentration of a substance in a solution is defined as mass of solute per unit volume of the solution (including solute and liquid).

$$C_A = \frac{M_A}{V_A + V_B}$$

Where C_A = concentration of A
M_A = Mass of material A
V_A = Volume of material A

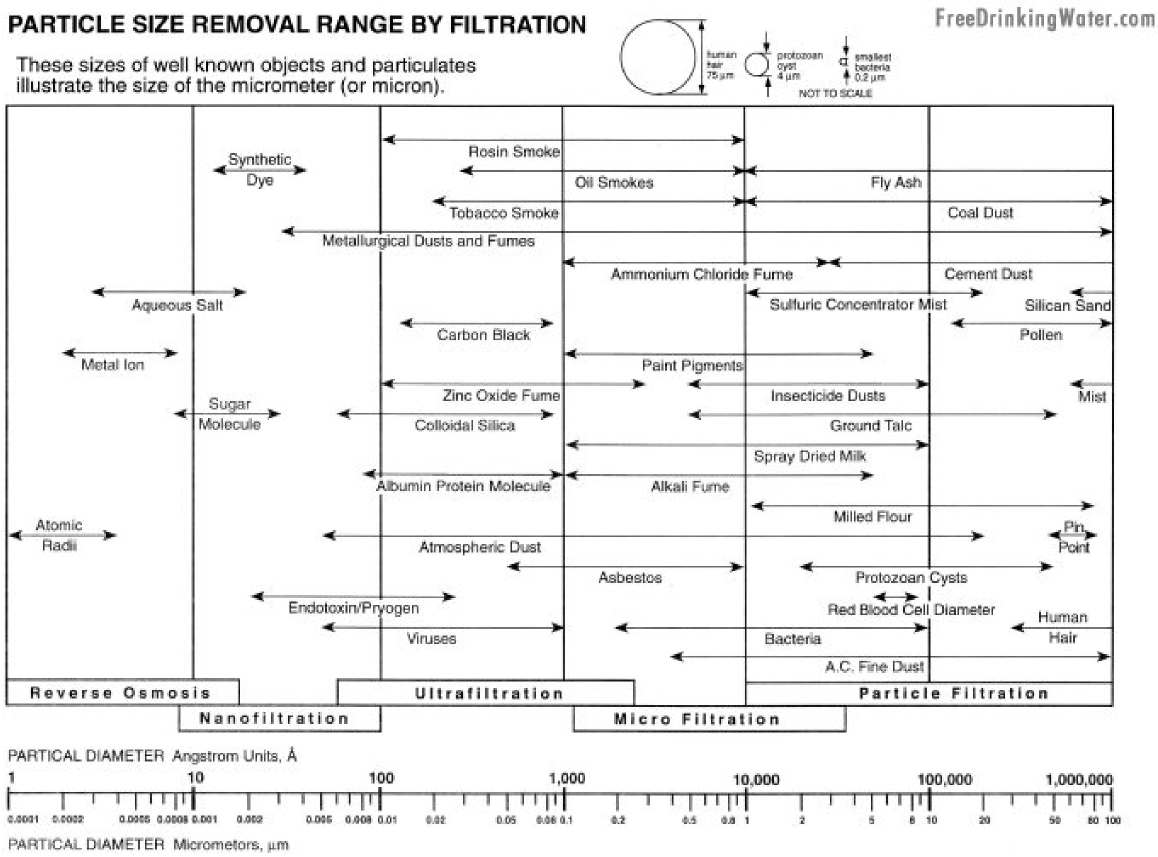

Fig. 1 : Particle size removal range by filtration process

In SI system, the basic unit for concentration is kg/m^3.

A typical example of the concentration of total dissolved solid in a polluted river like at Bagmati at Teku is 825 mg/L or 0.825 kg/m^3.

Since solutes in solution are often analyzed by weight the terms milligram per liter or microgram per liter is used. It is often assumed that the substance does not change the density of water. If such assumption is made and we recall that 1 mL water weighs 1 g, then

$$\frac{1mg}{L}=\frac{10^{-3}mL}{L}=\frac{10^{-3}mL}{10^{3}\,mL}=\frac{1mL}{10^{6}\,mL}=1\,ppm$$

$$\frac{1mg}{L}=\frac{1mg}{1000\,mL}=\frac{1mg}{1000\ g}=\frac{1\ mg}{10^{6}\,mg}=1\,ppm$$

Alternative proof

If the density of a solution = $\rho = \dfrac{mass\, of\ solution}{volume\, of\ solution}$

and concentration of a constituent in mg/L = $C_{A1} = \dfrac{mass\, of\ constituent}{volume\, of\ solution}(mg/L)$

and concentration of a constituent in ppm = $C_{A2} = \dfrac{mass\, of\ constituent}{mass\, of\ solution}(mg/kg)$

then rearranging,

$$\rho = \frac{C_{A1}}{C_{A2}}$$

If $\rho = 1$ kg/L, then $C_{A1} = C_{A2}$

i.e. the concentration of a constituent in ppm mg/kg = concentration of a constituent in mg/L

For most applications in water and wastewater environment, $\rho = 1$ kg/L. For applications in the air environment, the equation is not applicable. The use of mg/L is most common in water applications as the volume of the solution is usually determined as well as the mass of the solute. The unit ppm is typically used in sludges or sediments.

Some material concentrations are most conveniently expressed as percentages, usually in terms of mass:

$$\phi_A = \frac{M_A}{M_A + M_B}$$

where ϕ_A = percent of material A
M_A = mass of material A
M_B = mass of material B

ϕ_A can also be expressed as a ration of volumes.

1.3 Flow (discharge) rate

The flow rate can be expressed as volume of the liquid per unit time.

$Q_V = V/T$

where Q_V = Volumetric flow rate
V = Volume of the liquid
T= Time period

In SI system, the basic unit of volumetric flow rate is m^3/s.

The flow of water is measured in units of volume per unit time. Commonly used units for flow measurement are: liter per second (lps), liter per day (LD), millions liter per day (MLD), cubic meter per second (m^3/s).

1 m^3 = 1000 L

1 MLD = 10^6 Liters per day

एक करोड लिटर प्रति दिन = 10 MLD

In engineering processes the flow rate can be either volume flow rate or mass flow rate. Mass and volumetric flow rates are not independent quantities because the mass (M) of material passing a point in a flow line during unit time is related to the volume (V) of that material.

Q_M = M / T = (Concentration × Volume) / T = Concentration × Volumetric flow rate

$Q_M = C_A \times Q_V$

Mass flow rate of waste materials is also called as "waste load" which is often measured in kg/day. For example, the BOD or nutrient loads of a wastewater discharged from a community. Biochemcial Oxygen demand (BOD) is measured in mg/L, therefore, this concentration should be multiplied by the wastewater flow rate to get the BOD load.

Example 1 : A stream can have a sediment load of upto 2000 mg/L in the rainy season. The stream water has been diverted using a dam and is supplied to a treatment plant. The tapped flow is 25 lps (liters per second). Find the mass flow rate of the sediment in the influent pipe. If the treatment plant can remove 90 % of the suspended solids, find the concentration of sediments in the effluent of treatment plant ?
Solution:

Given data
Concentration of suspended solids in the transmission pipe (C) = 2000 mg/L
Flow tapped (Q) = 25 lps
Efficiency of treatment plant (η) = 90 %

Mass removal rate (Q_M) = C × Q

$$= 200 \ \frac{mg}{L} \times 25 \ \frac{L}{s}$$

$$= 200 \ \frac{mg}{L} \times 25 \ \frac{L}{s} \times \frac{1}{10^6} \frac{kg}{mg} \times 86400 \ \frac{s}{day}$$

= 432 kg/day

Concentration of sediments removed by the treatment plant = 90 % of 2000 mg/L
= 1800 mg/L

Concentration of sediments in the effluent = 10 % of 2000 mg/L

= 200 mg/L

1.5 Retention Time

One of the most important concepts in treatment processes is retention time, also called detention time or even residence time. is the time an average particle of the fluid spends in a container through which the fluid flows (which is the time it is exposed to treatment or a reaction). An alternate definition is the time it takes to fill the container.

Mathematically, if the volume of a container, such as large holding tank, is V (m^3), and the flow rate to the tank is Q (m^3/s), then the retention time is :

$$T = \frac{V}{Q}$$

The average retention time can be increased by reducing the flow rate Q or increasing the volume V, and decreased by doing the opposite.

In SI system, the basic unit of retention time is sec.

1.6 Approximations in engineering calculations

Engineers are often called on to provide information not in its exact form but as approximations. For example, a KU engineering graduate may be asked by a client, such as a mayor of Dhulikhel, what it might cost to construct a new wastewater treatment plant for the population of Dhulikhel. The mayor is not asking for an exact figure but a tentative estimate. Obviously, the engineer cannot in a few minutes conduct a thorough cost estimate. S/he would recognize the highly variable nature of land costs, construction costs, coverage of the municipality as it extends to rural areas as well, required treatment efficiency, etc. Yet, the mayor wants a preliminary estimate – a number – and quickly !

In the face of such problems the engineer has to draw on whatever information might be available. For example, s/he might know that the population of the community to be served is approximately 50, 000. Next, s/he estimates, based on experience, that the domestic wastewater flow might be about 100 Liter per person per day, thus requiring a plant of about 5 MLD capacity. With room for expansion, industrial effluents, storm inflow and infiltration of groundwater into the sewers, s/he may estimate that 7 MLD capacity may be adequate. Such domestic wastewater treatment plant, s/he is aware, cost about 25 crore (करोड) Nepali Rupees per MLD of influent wastewater treated. S/he calculates that the plant would cost about 105 crore Nepali Rupees. Giving him/herself a cushion, she could respond by saying, “about 1.1 billion Nepali Rupees”.

This is exactly the type of information the mayor seeks. S/he has no use for anything more accurate because s/he might be trying to decided whether to ask for a budget of 1 billion or 1.5 billion. There is time enough for more exact calculations later (Slightly modified from Vesilind and Morgan, 2004).

1.7 Procedures for calculations with approximations:

Problems not requiring exact solutions can be solved by

2. Carefully defining the problem
3. Introducing simplifying assumptions
4. Calculating an answer
5. Checking the answer, both systematically and realistically.

Defining the problem:

The engineer in the previous case is asked for an estimate, not an exact figure. The intended figures might have been required for preliminary planning purposes and thus, valid approximations are adequate. Similarly, s/he also recognizes that the mayor wants a cost figure answer, thus establishing the units.

Simplifying:

The engineer should use intuition and judgment in simplifying the problem. For example, the engineer has to first estimate the population served and then consider the average flow. What does s/he ignore? Obviously, a great deal, such as daily transient flows, variability in living standards and seasonal variations. A thorough estimate of potential wastewater flows requires a major study. S/he has to simplify her problem and choose to consider only an estimate of the population and an average per capita discharge.

Calculating:

The calculations are usually straight forward.

Checking:

The important procedure is the process of checking. The two types of checking are systematic and realistic.

In systematic checking, the units are checked to see whether they make sense or not.

For example,

$$\left[persons\right] \text{ x } \left[\frac{Liters}{persons}\right] = \text{liters which make sense}$$

While,

$$\frac{persons}{\left[\dfrac{Liters}{persons}\right]}$$

$$= \frac{\left[persons\right]^2}{Liters}$$

doesnot make any sense. If such is the case, the numbers should be recalculated to check for mistakes. It is wise always to write the units as the calculation proceeds and finally have a check of the units.

Reality checking is also necessary which when routinely performed will save considerable pain and embarrassment. Possibly no practicing engineer will explicitly recognize that they perform reality checks day in and day out, but such checks are central to good engineering. Consider, for example, if the engineer had made a mistake and thought (erroneously) that a wastewater treatment plant needed by Dhulikhel Municipality costs 25 billion per MLD of wastewater treated. With this figure, the cost of the treatment plant will turn out to be 105 billion Nepali

Rupees. On reporting this to the mayor, he might say "I would construct 100 wastewater treatment plants with 105 billion Nepali Rupees".

Example 2 : The wastewater treatment plant in Guheshwori receives 0.20 m^3/s of wastewater. The plant was established to directly serve a population of 2×10^5 in Gokarna and Chabahil area. The total project cost of the plant was half billion Nepali Rupees (NRs) in 1999. Estimate the per capita cost of the project in 1999 in (a) NRs / MLD of treated wastewater and (b) NRs/individual benifited.

Class activities

(1) What must be the volume of a drop of water dripped from a faucet? Estimate the loss of water in a day and a year?

(2) What must be the thickness of a sheet in a book? Estimate the thickness of sheets in a book.