Environmental Engineering CE456

1st Lecture Dr. Ahmed Bdour Spring 2022

Ecological Systems

A typical natural ecosystem is divided into:

- Biotic components: 1.
 - a) Producers: green plants, algae
 - b) Consumers: <u>herbivores</u> (an animal that gets its energy from eating plants), <u>carnivores</u> ('meat eater '), <u>omnivores</u> ('all-eater ')
 - c) Decomposers: microorganism
- Abiotic components: 2.
 - a) Soil
 - b) Water
 - c) Nutrients (A *nutrient* msinagro na taht lacimehc a si na ni desu ecnatsbus a ro worg dna evil ot sdeen sti morf ni nekat eb tsum hcihw msilobatem s'msinagro tnemnorivne).
 - d) Climate elements: heat, humidity, wind
 - e) Physical elements: gravity, radiation, light

Pollutants, in the form of substances &/or physical effects, are foreign components to the natural ecosystem.

Important Definitions

Ecology:

Branch of biology covering relations among living systems as well as between these and their surroundings – Provides knowledge on ability of natural systems for self-purification.

Environment:

- Global: Sphere in which the life-sustaining resources of the earth are contained.
- Local: region or area where a specific problem is being addressed.

What is our environment?

- Environment: the total of our surroundings
- •All the things around us with which we interact:
 - **<u>Biotic factors</u>** living things
 - Examples: Animals, plants, forests, fungi, etc.
 - <u>Abiotic factors</u> nonliving things
 - Examples: Continents, oceans, clouds, soil, rocks
 - Our built environment
 - Buildings, human-created living centers
 - Social relationships and institutions

Pollution:

 Undesirable change in the physical, chemical and / or biological characteristics of air, water or land that can harmfully affect the health, survival or activities of humans or other living organisms.

Environmental Science & Engineering (next)

Environmental Science

- Environmental Science the study of the air, water, and land surrounding an organism or a community, which ranges from a small area to Earth's entire biosphere.
- It includes the study of the impact of humans on the environment

What is Environmental Science?

- Science can be differentiated into the social sciences and natural sciences.
- <u>Natural sciences include</u>
 > core sciences: chemistry, biology, and physics
 - numerous applied sciences such as geology, meteorology, forestry, and zoology

environmental science is an integrative applied science that draws upon nearly all of the natural sciences to address environmental quality and health issues

What is Environmental Science?

- We are concerned with the quality and availability of environmental resources and with the waste streams that impact them
- Science...improve our understanding of natural processes
- Engineering...use this understanding to develop and apply technologies that will maintain or improve environmental quality

Environmental science

- Environmental science helps us understand our relationship with the environment and informs our attempts to solve and prevent problems.
- Identifying a problem is the first step in solving it
- Solving environmental problems can move us towards health, longevity, peace and prosperity
 - Environmental science can help us find balanced solutions to environmental problems

What is Environmental Engineering?

- Environmental engineering uses environmental science principles, along with engineering concepts and techniques, to assess
 - the impacts of societal activities on the environment,
 - The impact of the environment on people, and to protect both human and environmental health.

(Eng. Techniques involves design, operation and maintenance of engineering units (structures, equipment).

Environmental engineering requires a sound foundation in the environmental sciences

What is an engineer?



- Problem solver.
 - Specifically, one who uses science to solve real world problems.
- SO, what about an environmental engineer ?
 - Solves environmental problems using scientific tools

Interdisciplinary Nature of Environmental Science and Engineering: Examples

- Groundwater contamination by leaking gasoline storage tanks – material science, hydrogeology, geochemistry, microbiology, hydraulics AND environmental engineering
- Urban air pollution chemical/mechanical/ automotive engineering, meteorology, chemistry, AND environmental engineering

Key Elements of Modern Environmental Science and Engineering

- Based on chemistry environmental quality described by chemical composition of the system
- Quantitative magnitude of the problem and feasibility of the solution are described numerically
- Driven by government policy, which is increasingly set on the basis of risk

Environmental Systems Overview

 Water Resource Management Systems:

 a) Water Supply Sub-system
 b) Wastewater Disposal Sub-system
 2. Air Quality Management System
 3. Solid Waste Management System
 I Hazardous Waste Management System

Water Supply Sub-system

- System Components:
 - Planning
 - Design
 - Operation of processes: collection, treatment (purification), transmission, distribution.
- Water Sources:
 - Meteorological water: rain, snow
 - Ground water: springs, wells
 - Surface water: rivers, lakes, oceans







Wastewater Disposal Sub-system

- Wastewater Sources:
 - Domestic sewageIndustrial effluents

 - Agricultural runoff Storm runoff
- Collection: 3 types of sewers (sanitary, storm, combined) •
- Treatment: •

Stabilization of waste material or pollutant so that it will not be harmful to humans or the environment when disposed of.

Objectives of WW management:

- 1. Protect drinking water supply; surface & ground.
- 2. Protect public health hazard: w.w. should not be accessible to insects, rodents, birds or other carriers that may later come into contact with food or drinking water.
- 3. Protect coastal areas or streams used for recreational purposes.
- 4. Avoid nuisance due to odor or unsightly appearance.
- 5. Comply with laws or regulations governing water pollution or sewage disposal.

Wastewater Treatment Plant



Environmental Engineering

The application of science and engineering principles to minimize the adverse effects of human activity on the environment.

Related Sciences

- Philosophy
- Inorganic and Organic Chemistry
- Biological Sciences
- Mathematical and Physical Sciences
- Geophysical Sciences
 - Communication Skills

Social Sciences

Related Topics In C. E.

- Hydrology
- Highway Design
- Material Science
 - Construction Management
- Water and Wastewater Transport

Soil and Foundations Eng..

Causes of Environmental Problems

- Increasing Population
- Greater Consumption of Natural Resources *esp.* Fossil Fuels

Pollution: Personal Problem

- air 7.7 lbs/day/person
- water 0.2 lbs/day/person
- land 5 lbs/day/person (collected)
 10 lbs/day/person (total)

world population - > 6.9 x 10⁹ people

Pollution Sources

• Natural: rivers, precipitation create silt

- necessary: nothing is 100% efficient
- increased standard of living increases waste production

Alternatives

- Pollution can't be eliminated
- Control location and conditions
- Reduce the volume concentration
- Accelerate naturally occurring reactions
- Problematic when nature's balancing capacity is exceeded

Intro to Treatment Technologies

Role of Environmental Engineering

- As pollutants enter air, water and soil, natural processes convert them to more acceptable forms.
- Unfortunately, these natural systems have become overwhelmed.
- Environmental Engineering seeks to amplify, optimize and speed operations observed in nature to handle large volumes.

Natural Systems of Purification

- In nature self purification mechanisms include Physical; Chemical and Biological
- Physical Processes
- Dilution
- Sedimentation & Re-suspension
- Filtration
- Gas Transfer
- Heat Transfer

Chemical Processes

- Dissolution-precipitation Nitrogen, phosphorous as well as iron, manganese, copper, zinc etc are important to growth of microorganisms that degrade waste. These are changed to soluble forms that are usable by MO
- Oxidation-Reduction MO used the above chemicals for growth and reproduction. The reactions require external source of energy for activation, which is supplied by the microorganisms.

Biological Processes

 The total sum of the processes by which living organisms assimilate and use food for subsistence, growth and reproduction is called metabolism

2 types of processes occur

 Catabolism – provides energy for the synthesis of new cells and energy for maintenance of other cell functions
 Anabolism – provides material necessary for cell growth When external food sources are interrupted, organisms will use stored food for maintenance energy – <u>endogenous</u> <u>catabolism</u>

The continued presence of toxic substances will lead to development of a specific bacteria capable of decomposing and <u>utilizing toxic substances</u> – Many New Technologies are based on this



Catabolic Processes involve either oxidation or reduction of materials in the substrate (food supply)

If free molecular oxygen is available it will be added to the substrate and the waste products will be oxidized compounds – leads to stable non objectionable end products (H₂O and CO₂)

In the absence of free oxygen, bound oxygen may be removed from oxygen bearing compounds and is hydrogen added to elements of the substrate. The result is a waste product composed of reduced compounds objectionable to streams e.g. methane, H₂S

Principles of Waste Treatment

- 1. Convert objectionable material to less objectionable forms
- 2. To disperse pollutants so that their concentration is minimal
- 3. To concentrate them for isolation from the environment

Water-quality parameters
Topics

- Physical water-quality parameters
- Chemical water-quality parameters
- Biological water-quality parameters
- Water quality requirements



Impurities occur -at point of condensation -Human activities : Industrial Domestic and Agri chemicals

Form of Impurities –Suspended –Dissolved –Colloids

100% Precipitation; 50% Percolation; 30% Evaporation; 40% Evapotranspiration; 20% Surface Runoff ; 10% Groundwater Flow Suspended- Larger than molecular size supported by buoyant and viscous forces Dissolved-molecules or ions held by molecular structure of water Colloids- Technically suspended but exhibits characteristics of dissolved

Difference Between Dissolved, Suspensions and Colloidal Solutions

Property	Dissolved	Suspensions	Colloidal Solutions
Particle size	Less than 10 ⁻⁶ mm	Greater than 10 ⁻ ³ mm	Between 10 ⁻⁶ and 10 ⁻³ mm
Visibility of particles	Invisible to naked eye not visible under powerful microscope	Easily visible	Invisible to naked eye. Visible under powerful microscope.
Sedimentation of particles	Do not settle down	Settle down due to gravity	Settle down under high centrifugation
Filtration through filter power	No residue is formed	Residue is formed	No residue is formed

Water Pollution - The presence in water of impurities in such quantity and of such nature as to impair the use of the water for a stated purpose
Water quality is predicted on the intended use

Water Quality Requirements

- Water quality parameters qualitatively reflect the effect of various impurities on the intended use of water
- Standard Methods for the Examination of Water and Wastewater- Standard analytical test procedures which provide quantitative measurements of these parameters

Water Quality Requirements

Water quality requirements vary according to proposed use of the water. Water unsuitable for one use may be satisfactory for another. These are set by the user. It represents a known or assume need and are based on prior experience of the user.

Assignment: determine water quality criteria for agriculture; fish and wildlife; recreation uses; some typical industrial use; power generation
Water Quality Standards are set by a governmental agency and represent a statutory requirement

Water Quality Requirements

- In-Stream standards Streams have minimum quality standards based on its use. Wastewater discharged from human activities together with the geology and natural characteristics of the watershed.
- Potable-water Standards EPA ; WHO addresses turbidity, SS taste, odor, moderate dissolved inorganic; absence of organics, toxic substances and pathogens
- Wastewater effluent standards- e.g. EPA standards for the discharge of wastewater. - require secondary treatment. Industrial wastewater must be pretreated to become compatible with receiving domestic WW.

Physical Water-Quality Parameters

- Define those characteristics of water that respond to the senses of
- Sight
- Taste
- Touch
- Smell

Parameters:

- Suspended Solids
- Turbidity
- Colour
- Taste
- Odor
- Temperature

Sources of Suspended Solids



Seldom found in groundwaters due to the natural filtering capacity of soils

Impact of Suspended Solids

- Aesthetically Displeasing
- Provide adsorption sites for chemical and biological agents
- May be degraded organically resulting in objectionable by products – e.g. methane
- May include disease causing organisms

Measurement

- Total Solids Test quantifies dissolved and suspended including organic and inorganic
- Evaporate a sample to dryness and weigh the residue mg/L on a dry mass of solids basis
- Temp 104 degree Celsius
- Temp 180 degree Celsius (for occluded water)

- 2. Filtration -
- a. Suspended Solids
- Filter the water sample
- Dry the filter and sample to 104 Degree Celsius
- Determine mass of residue- mg/L

 b. Total Dissolved Solids = Total Solids - SS
Note 1 Colloids can be adsorbed unto the filter or pass through the filter. Thus the term filterable and nonfilterable solids is used in analytical work

 Organic Solids – Determine by firing the samples at 600 Deg Cel for 1 hr. Organics are converted to Carbon Dioxide, water and other gases

Work example

EXPERIMENT ON DETERMINATION OF TOTAL SOLIDS IN WATER

14.2 INTRODUCTION

The term "solids" is generally used when referring to any material suspended or dissolved in water or wastewater that can be physically isolated either through filtration or through evaporation.

Solids can be classified as either filterable or non filterable. Filterable solids may either be settleable or non settleable. Solids can also be classified as organic or inorganic.

Total Solids is the term applied to the material residue left in the vessel after evaporation of a sample and its subsequent drying in an oven at a defined temperature.

Measurement of Solids can be made in different water samples (industrial, domestic and drinking water) and it is defined as residue upon evaporation of free water.

Thus, Total solids are nothing but summation of total dissolved solids and total suspended solids.

14.2.1 ENVIRONMENTAL SIGNIFICANCE

Total solids measurements can be useful as an indicator of the effects of runoff from construction, agricultural practices, logging activities, sewage treatment plant discharges, and other sources.

Total solids also affect water clarity. Higher solids decrease the passage of light through water, thereby slowing more rapidly and hold more heat; this, in turn, might adversely photosynthesis by aquatic plants. Water will heat up affect aquatic life that has adapted to a lower temperature regime.

As with turbidity, concentrations often increase sharply during rainfall, especially in developed watersheds. They can also rise sharply during dry weather if earth-disturbing activities are occurring in or near the stream without erosion control practices in place.

Regular monitoring of total solids can help detect trends that might indicate increasing erosion in developing watersheds.

14.4 MATERIALS REQUIRED

14.4.1 APPARATUS REQUIRED

- 1. Crucible
- 2. Oven
- 3. Desiccators
- 4. Analytical Balance
- 5. Dish Tongs
- 6. Magnetic Stirrer
- 7. Wash Bottle



PROCEDURE CHART





14.6 PROCEDURE

 To measure total solids, take a clean porcelain dish which has been washed and dried in a hot air oven at 105°C for one hour.

Now weigh the empty evaporating dish in analytical balance. Let's denote the weight measured as (W1).

- Now we should have to decide what should be the volume of sample to be taken for analysis.
- Volume may be estimated either from values of specific conductance or general thumb rule.
- In general, select a sample volume that will yield residue between 2.5 and 200 mg after drying.
- Using pipette transfer 75mL of unfiltered sample in the porcelain dish.
- Switch on the oven and allowed to reach 105°C. Check and regulate oven and furnace temperatures frequently to maintain the desired temperature range.
- Place it in the hot air oven and care should be taken to prevent splattering of sample during evaporation or boiling.
- Dry the sample to get constant mass. Drying for long duration usually 1 to 2 hours is done to eliminate necessity of checking for constant mass.
- Cool the container in a desiccator. Desiccators are designed to provide an environment of standard dryness. This is maintained by the desiccant found inside. Don't leave the lid off for prolonged periods or the desiccant will soon be exhausted.
- Keep desiccator cover greased with the appropriate type of lubricant in order to seal the desiccator and prevent moisture from entering the desiccator as the test glassware cools.
- We should weigh the dish as soon as it has cooled to avoid absorption of moisture due to its hygroscopic nature.

14.7 CALCULATION

Initial weight of the Crucible (W₁) Final weight of the Crucible + sample (W₂) Weight of residue (W)

Amount of total solids present in the sample

$$= \dots g$$

= g
= W₂ - W₁ g
= $\frac{1000 * 1000w}{v}$

W = weight of total residue in (mg). (Therefore multiply W with 1000)

 \vee = \vee olume of the sample (mL)(To convert mL to L)

=.....mg/L

The readings are required to be tabulated.

14.7.1 TABLE

Description	Weight (g)

Description		Weight (g)
Initial Weight of the Crucible (g)		35. 4323
Final Weight of the Crucible + sample (g)		35. 4739
Weight of residue(g)		0. 0416
Volume of the Sample (mL)		75. 0
Total Solids (mg/L)	TS	555.0

<u>Specimen Calculation:</u>

 $W_{1} = 35.4323 g$ $W_{2} = 35.4739 g$ V = 75.0 mLWeight of residue (g) W = W_{2} - W_{1} = 35.4739 - 35.4323 = 0.0416 g

Weight of residue in mg (To convert W (g) to W (mg), multiply W (g) with 1000) $W (mg) = 0.0416 \times 1000$ = 41.6mg

Multiply the weight of the dry solids (in mg) by 1,000 mL/L to convert the sample size from mL to L.

 $\frac{\text{Total Solids (mg/L)}}{V = \text{Volume of the sample (mL) (To convert mL to L, multiply by 1000)}}$ = 41.6 mg/75 mL = 0.555 mg/mL $= 0.555 \text{ mg/mL} \times 1,000 \text{ mL/L}$ = 555 mg/L

Evaluation and Quick Problems

The determination of total solids in wastewater gives an idea about

- a) the foulness of the sewage
- b) pH of the sewage
- c) temperature of the sewage
- d) colour of the sewage

The evaporating dishes needs to be cleaned and dried at _____ to remove the existing organic content.

- a) 100° C
- b) 250° C
- **c)** 450° C
- **d)** 550° C

Sewage contains about 99% of _____.

- a) water
- b) solids
- c) clay
- d) microbes

The sewage contain

- a) suspended and dissolved solids.
- b) no solids
- c) only dissolved solids
- d) only suspended solids
- . The major dissolved substances in natural water are comprised of
 - a) iron, manganese, silica and nitrate
 - b) calcium, magnesium, sodium, bicarbonate, sulfate and chloride
 - c) all anions
 - d) all cations

The hard water

- a) is corrosive
- b) forms scales
- c) is tasteless
- d) is costly

The hard water consumes more soap for cleaning purposes.

- a) True
- b) False

Use

Important parameter in wastewater

- Used to measure the quality of wastewater influent and effluent as well as monitor treatment processes
- **Typical SS Values**
- Marine waters 5-80mg/L
- River waters 0–200mg/L,
- Stormwaters 80–100mg/L,
- Raw sewage 200–350mg/L,

Treated sewage 100-200mg/L,

2.0 Turbidity

Test for turbidity is often performed of natural bodies and potable water rather than SS. Nature of solids and secondary effect is of greater importance

Turbidity is a measure of the extent to which light is absorbed or scattered by suspended material. f(size and surface characteristics of suspended material)

2.0 Turbidity

- 1 Sources:
- Erosion of clay, silts, rock fragments and metal oxides
- Vegetable fiber and microorganisms
- Soaps, detergents and emulsifying agents
- 2 Impact
- Aesthetically displeasing
- Creates adsorption sites for chemicals that cause taste and odor
- Shield organisms from disinfection
- Interfere with light penetration in streams and lakes

2.0 Turbidity

Measurement

- -Standard electric bulbs produce a light directed through the sample.
- In absorption mode light passing through the sample is measures
- *In scattering mode light a*t 90 degrees is *measured.*
- Turbidity readings are measured in FTU where F refers to the standard *Formazin*
- NTU Nephelometry Turbidity Unit used to indicate the test is run according to scattering principle
- EPA Standard for drinking water is 1 FTU





PROCEDURE CHART





2.6.1 PREPARATION OF REAGENTS

1. Hydrazine Sulphate

- Weigh accurately 1 g of hydrazine sulphate and dissolve it in turbidity free distilled water.
- Take 100 mL standard measuring flask and place a funnel over it.
- Transfer it to a 100 mL standard flask and make up to 100 ml using turbidity free distilled water.

2. Hexamethylene Tetramine

- Weigh accurately 10 g of Hexamethylene tetramine and dissolve it in turbidity free distilled water.
- Take 100 mL standard measuring flask and place a funnel over it.
- Transfer it to a 100 mL standard flask and make up to 100 ml using turbidity free distilled water.

3. Standard 4000 NTU Solution

- Mix 5 mL of hydrazine sulphate solution and 5 mL of Hexamethylenetetramine solution in a 100 mL standard measuring flask.
- Allow the mixture to stand for 24 hours.
- After 24 hours, make up the volume to 100 mL using turbidity free distilled water.
- The standard 4000 NTU solution is ready.



3.0 Colour

Sources

- Leaves, wood etc pick up tannins, humic acid leading to yellowish-brown colour
- 2. Iron oxides reddish
- 3. Manganese Oxides brown of blackish
- Industrial Waste textile and dyeing operations, pulp and paper production, food processing, chemical production, mining, refining and slaughter house operations

3.0 Colour

- Impact
- Aesthetically displeasing
- Not suitable for many operations as textile and paper production
 - True colour can exert a chlorine demand

Measurement

Colour comparison with a series of standard colour materials after apparent colour is removed. Units of measurement – TCU (true colour units) For colours with yellowish-brown hues special spectrophotometric techniques are used Note: Smaples should be measured within 72 hrs to avoid biological and physical changes

4.0 Taste and Odor

Taste & Odor are closely related. Substances that produce an odor in water often impart taste. The reverse is not often true.

• Source:

- -Metals, minerals, salts form soil
- -End products from biological reactions
- -Inorganic produce taste e.g. Alkaline bitter taste; metallic salts impart salty or bitter taste
- -Organics produce taste and odor e.g. Petroleum-based products; biological decomposition of organics (sulphur – rotten egg smell); Synergistic effect of chlorine and organics

4.0 Taste and Odor

- Impact
- Aesthetically displeasing (associate odor and taste with contamination)

Measurement Assignment
5.0 Temperature

One of the most important parameters in natural surface waters. It influences the number and type of species present and their rate of activities; effect most chemical reactions; affect solubility of gases e.g oxygen decrease with increase temp. 8mg/L @ 25 degree Celsius

Sources

 Influence by ambient temperatures i.e. surrounding atm. Shallow water bodies experience greater changes

- Dissipation of waste heat by industries
- Removal of forest canopy

5.0 Temperature

- Impacts
- Cooler waters have wider diversity of biological species
- Biological activities reduces at lower temperature i.e. utilization of food; growth; reproduction
- Increase of 10 degree Celsius can result in double activities – Accelerated growth of algae leading to cell clusters in mats. Secretion of oils and dead algal cells impart taste and odor
- Reduction in oxygen levels affect fishes
- Increase viscosity with decrease temperature
- Maximum density occur at 4 degree Celsius. density and temperature affect planktonic MO



National Primary Drinking Water Regulations

Contaminant	MCL or TT ¹ (mg/L) ²	Potential health effects from long-term ³ exposure above the MCL	Common sources of contaminant in drinking water	Public Health Goal (mg/L) ²
OC Acrylamide	TT*	Nervous system or blood problems; increased risk of cancer	Added to water during sewage/ wastewater treatment	zero
OC Alachlor	0.002	Eye, liver, kidney or spleen problems; anemia; increased risk of cancer	Runoff from herbicide used on row crops	zero
R Alpha/photon emitters	15 picocuries per Liter (pCi/L)	Increased risk of cancer	Erosion of natural deposits of certain minerals that are radioactive and may emit a form of radiation known as alpha radiation	zero
IOC Antimony	0.006	Increase in blood cholesterol; decrease in blood sugar	Discharge from petroleum refineries; fire retardants; ceramics; electronics; solder	0.006
IOC Arsenic	0.010	Skin damage or problems with circulatory systems, and may have increased risk of getting cancer	Erosion of natural deposits; runoff from orchards; runoff from glass & electronics production wastes	0
IOC Asbestos (fibers >10 micrometers)	7 million fibers per Liter (MFL)	Increased risk of developing benign intestinal polyps	Decay of asbestos cement in water mains; erosion of natural deposits	7 MFL
OC Atrazine	0.003	Cardiovascular system or reproductive problems	Runoff from herbicide used on row crops	0.003
IOC Barium	2	Increase in blood pressure	Discharge of drilling wastes; discharge from metal refineries; erosion of natural deposits	2
OC Benzene	0.005	Anemia; decrease in blood platelets; increased risk of cancer	Discharge from factories; leaching from gas storage tanks and landfills	zero
OC Benzo(a)pyrene (PAHs)	0.0002	Reproductive difficulties; increased risk of cancer	Leaching from linings of water storage tanks and distribution lines	zero
IOC Beryllium	0.004	Intestinal lesions	Discharge from metal refineries and coal-burning factories; discharge	0.004

OC Carbofuran	0.04	Problems with blood, nervous system, or reproductive system	r Leaching of soil fumigant used on rice and alfalfa	0.04
OC Carbon tetrachloride	0.005	Liver problems; increased risk of cancer	r Discharge from chemical plants and other industrial activities	zero
D Chloramines (as Cl ₂)	MRDL=4.0 ¹	Eye/nose irritation; stomach discomfort anemia	; Water additive used to control microbes	MRDLG=41
OC Chlordane	0.002	Liver or nervous system problems; increased risk of cancer	Residue of banned termiticide	zero
D Chlorine (as Cl ₂)	MRDL=4.0 ¹	Eye/nose irritation; stomach discomfort	Water additive used to control microbes	MRDLG=41
D Chlorine dioxide (as ClO ₂)	MRDL=0.81	Anemia; infants, young children, and fe pregnant women: nervous system effect	tuses of Water additive used to control is microbes	MRDLG=0.81
DBP Chlorite	1.0	Anemia; infants, young children, and fe pregnant women: nervous system effect	tuses of Byproduct of drinking water is disinfection	0.8
OC Chlorobenzene	0.1	Liver or kidney problems	Discharge from chemical and agricultural chemical factories	0.1
IOC Chromium (total)	0.1	Allergic dermatitis	Discharge from steel and pulp mills; erosion of natural deposits	0.1
IOC Copper	TT ³ ; Action Level = 1.3	Short-term exposure: Gastrointestinal distress. Long-term exposure: Liver or kidney damage. People with Wilson's Disease should consult their personal doctor if the amount of copper in their water exceeds the action level	Corrosion of household plumbing systems; erosion of natural deposits	1.3
M Cryptosporidium	TT'	Short-term exposure: Gastrointestinal il (e.g., diarrhea, vomiting, cramps)	Iness Human and animal fecal waste	zero
LEGEND		_		
Disinfectant	100	Inorganic Chemical	Organic Chemical	
DBP Disinfection Byproduct	М	Microorganism	R Radionuclides	

Contaminant	MCL or TT ¹ (mg/L) ²	Potential health effects from long-term ³ exposure above the MCL	Common sources of contaminant in drinking water	Public Health Goal (mg/L)²
IOC Cyanide (as free cyanide)	0.2	Nerve damage or thyroid problems	Discharge from steel/metal factories; discharge from plastic and fertilizer factories	0.2
OC 2,4-D	0.07	Kidney, liver, or adrenal gland problems	Runoff from herbicide used on row crops	0.07
OC Dalapon	0.2	Minor kidney changes	Runoff from herbicide used on rights of way	0.2
OC 1,2-Dibromo-3- chloropropane (DBCP)	0.0002	Reproductive difficulties; increased risk of cancer	Runoff/leaching from soil fumigant used on soybeans, cotton, pineapples, and orchards	zero
OC o-Dichlorobenzene	0.6	Liver, kidney, or circulatory system problems	Discharge from industrial chemical factories	0.6
OC p-Dichlorobenzene	0.075	Anemia; liver, kidney or spleen damage; changes in blood	Discharge from industrial chemical factories	0.075
OC 1,2-Dichloroethane	0.005	Increased risk of cancer	Discharge from industrial chemical factories	zero
OC 1,1-Dichloroethylene	0.007	Liver problems	Discharge from industrial chemical factories	0.007
OC cis-1,2-Dichloroethylene	0.07	Liver problems	Discharge from industrial chemical factories	0.07
OC trans-1,2- Dichloroethylene	0.1	Liver problems	Discharge from industrial chemical factories	0.1
OC Dichloromethane	0.005	Liver problems; increased risk of cancer	Discharge from drug and chemical factories	zero
OC 1,2-Dichloropropane	0.005	Increased risk of cancer	Discharge from industrial chemical factories	zero
OC Di(2-ethylhexyl) adipate	0.4	Weight loss, liver problems, or possible reproductive difficulties	Discharge from chemical factories	0.4
OC Di(2-ethylhexyl) phthalate	0.006	Reproductive difficulties; liver problems; increased risk of cancer	Discharge from rubber and chemical factories	zero
OC Dinoseb	0.007	Reproductive difficulties	Runoff from herbicide used on soybeans	0.007

National Secondary Drinking Water Regulation

National Secondary Drinking Water Regulations are non-enforceable guidelines regarding contaminants that may cause cosmetic effects (such as skin or tooth discoloration) or aesthetic effects (such as taste, odor, or color) in drinking water. EPA recommends secondary standards to water systems but does not require systems to comply. However, some states may choose to adopt them as enforceable standards.

Contaminant	Secondary Maximum Contaminant Level
Aluminum	0.05 to 0.2 mg/L
Chloride	250 mg/L
Color	15 (color units)
Copper	1.0 mg/L
Corrosivity	noncorrosive
Fluoride	2.0 mg/L
Foaming Agents	0.5 mg/L
Iron	0.3 mg/L
Manganese	0.05 mg/L
Odor	3 threshold odor number
pH	6.5-8.5
Silver	0.10 mg/L
Sulfate	250 mg/L
Total Dissolved Solids	500 mg/L
Zinc	5 mg/L

Environmental Engineering

Chemical Water-Quality Parameters

Dr. Ahmed N Bdour

Summary Chemical Water-Quality Parameters

- Total Dissolved Solids
- Alkalinity
- Hardness
- Fluoride
- Metals
 - Nontoxic
 - Toxic

- Organics
 - Biodegradable
 - -Nonbiodegradable
- Nutrients
 - Nitrogen
 - Phosphorus

Total Dissolved Solids

Solvent action of water on solids, liquids and gases





Total Dissolved Solids

- Evaporation as discussed earlier
- Approximated by determining the electrical conductivity of the water - specific conductance (SC) milliSiemens per meter (mS/m)



SC= f (valence, mobility, relative
 number of ions, temperature)

Specific conductance measures ionized substances ONLY.

Thus, SC and TDS are not related one to one. – Constant – 0.055 to 0.09

 SC is used qualitatively to monitor changes in streams and treatment processes

Total Dissolved Solids

Total dissolve solids does not make distinction among the constituents

Used in the measurement of water and wastewater as a gross measure of dissolved substances



Not often suitable for water intended for potable supply, agriculture and some industrial processes

рН

- Balance of H and OH ions in water. These ions have an electric charge
- Measuring pH is determining the balance between H and OH
- Most fish tolerate between 5-9
- Most natural lakes are alkaline and becomes acidic with time as organics decay resulting on CO₂ and thus carbonic acid
- Synergy where two or more substances combine to produce effects greater than their sum
- E.g. 2 + 2 = 4 but synergistically, 2 + 2 is greater than 4. Synergy is mathematically impossible
- Normal pH values in sea water are about 8.1 at the surface and decrease to about 7.7 in deep water.



Alkalinity – the quantity of ions in water that will react to neutralise hydrogen ions .

Alkalinity is not a pollutant. It is a total measure of the substances in water that have "acid-neutralizing" ability. Don't confuse alkalinity with pH.

Alkalinity is thus a measure of the ability of water to neutralize acids

pH measures the strength of an acid or base; alkalinity indicates a solution's power to react with acid and "buffer" its pH — that is, the power to keep its pH from changing.

To illustrate, we will compare two samples of pure water and buffered water. Absolutely pure water has a pH of exactly 7.0. It contains no acids, no bases, and no (zero) alkalinity. The buffered water, with a pH of 6.0, can have high alkalinity. If you add a small amount of weak acid to both water samples, the pH of the pure water will change instantly (become more acid). But the buffered water's pH won't change easily because the Alka-Seltzer-like buffers absorb the acid and keep it from "expressing itself."

Carbonates, Bicarbonates and Hydroxide compounds, Borates, silicates

from

Dissolution of minerals from soil and atmosphere



Phosphates from detergents in WW, fertilizers and insecticides from agricultural land

Hydrogen Sulfide and ammonia from microbial decomposition of organics

Sources
Impacts
Measurements
Use

Carbonates, Bicarbonates and Hydroxide compounds- most abundant

(1) CO_2 [free carbon dioxide] + $H_2O <----> H_2CO_3$ [carbonic acid]

(2) H₂CO₃ <----> H⁺ + HCO₃⁻ [bicarbonate ion]

(3) $HCO_{3^{-}} < ----> H^{+} + CO_{3^{-2}}$ [carbonate ion]

(4) $CO_3^{2-} + H_2O < ----> HCO_3^{-} + OH^{-} + [Hydroxide]$

The bicarbonate ion can be used as a source of carbon for algae results in an increase in OH⁻ ions = pH 9 to 10

Relative quantity of alkalinity is pH dependent

Alkalinity imparts a bitter taste in large quantities

Reacts with many cations in water resulting in precipitates which foul pipes





Titrating the water with an acid and determining the equivalent

Alkalinity is expressed as mg/L of CaCO₃

Every 1mL of 0.02N H₂SO₄ will neutralize 1mg of alkalinity as CaCO₃



Use

- Alkalinity is important for fish and aquatic life because it protects or buffers against pH changes
- Variable in Water and WW Treatment
- makes water less vulnerable to acid rain

Hardness

	Sources
	Impacts
	Measurements
	Use

- Hardness is defines as the conc. of multivalent metallic cations in solution
- The major divalent cations of most natural waters are calcium (Ca⁺²) and magnesium (Mg⁺²). Hardness is usually a measure of the sum of these two ions. Other divalent cations such as iron, manganese, strontium and aluminum may also contribute to hardness.
- Hardness is classified as Carbonate (equivalent to alkalinity) and noncarbonate hardness

Hardness

Sodium soap reacts with multivalent metallic cations to form a ppt., thereby loosing their surfactant properties. Thus representing an economic loss to water users



- Lathering only occur after all hardness ions have ppt. The water is then soft. The ppt adheres to surfaces. Boiler scales cause fouling of water heaters and hot water pipes.
- Magnesium hardness when associated with magnesium sulphate has a laxative effect

Hardness



 Measurements are done by Spectrophotometric techniques or chemical Titration

- Analysis for hardness is commonly made on natural waters and waters intended for potable use.
- Soft <50mg/L
- Moderately Hard 50 150 mg/L
- Hard 150 300 mg/L
 - Very Hard > 300 mg/L

Note values expressed as CaCO3

Fluoride

- Fluoride is seldom found in
 appreciable quantities in surface water
 and appear in GW in only few
 geological regions
- Conc. Of 1.0 mg/L help to prevent dental cavity
- Conc. >2.0mg/L results in discoloration of teeth
- Conc. > 5mg/L may cause bone fluorosis and skeleton abnormalities
- WHO recommended limit 1.5 mg/L

Metal

- All Metals are soluble to some extent in water. Only metals that harmful in small quantities are considered toxic.
- Source- dissolution from natural deposits, domestic, industrial and agri discharges
- Measurements AAS or Titration

Introduction

Non-Toxic Metal

Toxic Metals

- Calcium Previously discussed
- Magnesium Previously discussed
- Sodium most common health hazard in excessive amounts, corrosive
- Iron (0.3 mg/L) & Manganese (0.05)- small quantities cause colour problems; energy source for some bacteria
- Aluminum low quantities natural waters
- Copper & Zinc synergetic when both are present in small amts, can be toxic to many biological species



Organics

Many organics are soluble in water Source of Organics ;

1) natural sources – decay products of organic solids

2) human activity- WW discharge or Agri practices

Dissolved organics are divided into;

- 1) Biodegradable
- 2) Non-biodegradable

Biodegradable Organics

Organics that can be utilized for food by naturally occurring MO, within a reasonable length of time. E.g. Starches; fats; protein; alcohols; acids; aldehydes; esters.

Microbial Utilization can be accompanied by–
1. Oxidation (Addition of Oxygen or removal of Hydrogen) or
2. Reduction – (Addition of Hydrogen or removal of Oxygen)
NOTE: Both can occur simultaneously, but if Oxygen is present it dominates



Organics



Biodegradable Organic Processes

Aerobic – (oxygen present) – end products are stable and acceptable Anaerobic – (oxygen absent) – end products are unstable and objectionable

The oxygen-demanding nature of biodegradable organics is most important in natural water systems. If oxygen utilization is more rapid than replenishment from say Atm, then anaerobic conditions result.

The amt of oxygen consumed during microbial utilization of organics is called *Biochemical Oxygen Demand (BOD).*

BOD – is measured by determining the oxygen consumed from a sample placed in an air tight 300mL bottle and incubated at 20° C for 5 days **NOTE : light must be excluded to prevent algal growth = production of oxygen**

Organics



Sample must be diluted with organic free oxygen saturated water. Note: Sat conc. For oxygen @ 20 degrees approx. 9mg/L

BOD of Diluted Sample, $BOD = DO_1 - DO_F / P$

Where DO_I and DO_F are the initial and final dissolved oxygen conc. (mg/L) and P is the decimal fraction of the sample in the 300 mL bottle.

NOTE: Final DO must not be less than 2 or more than 7 for reliable results

Work example



Non biodegradable -

Some organic materials are resistant to degradation. Woody plants - E.g. Tannic and lignic acid, cellulose and phenols, They degrade so slowly, that they are considered refractory.

Molecules with exceptionally strong bond – polysaccharides; benzene e.g. Alkayl benzene sulfonate ABS causes frothing and foaming WWTP

Organics that are toxic to MO – organic pesticides (cumulative toxins); industrial chemicals, hydrocarbon that have combined with chlorine.

e.g. -Organic insecticides are usually chlorinated hydrocarbons – aldrin, dieldrin

- Herbicides – 2,4-dichlorophenoxyacetic acid



Measurement

Non-biodegradable organics is measured by the Chemical Oxygen Demand , COD or the Total Organic Carbon analysis, TOC.

TOC and COD also measures the biodegradable organics therefore, the BOD must be subtracted.

Non -biodegradable Organics = COD or TOC - BOD

Nutrients



Nutrients are essential to the growth and reproduction of plants and animals and aquatic species. Those required in most abundance by aquatic species is : Carbon; Nitrogen and Phosphorus

Carbon is readily available from many sources e.g. Atm; alkalinity; decay products of organic matter. Nitrogen and Phosphorus are usually limited. Human activity has resulted in excess N and P

Nitrogen

Sources

1. Nitrogen is a constituent of proteins, chlorophyll and many biological compounds.

These are broken down into simple forms upon death of plants and animals by bacteria. E.g. Protein – amino acid - ammonia (NH3) – Nitrite NO2-(if oxygen is present oxidized) – Nitrate NO3⁻ – reconstituted into living organic matter by photosynthesis.

Nutrients



2. Other sources include animal waste, chemical fertilizers and WW discharges in the form of ammonia and ammonium

Impact

-These can be oxidized to nitrates by soil bacteria. Oxidation of ammonia and ammonium too nitrite and nitrate results in an increase COD.

-Nitrate poisoning – nitrite causes oxygen starvation

-Algal Bloom

Measurements

Test for ammonia and organic nitrogen is done on WW; Test for nitrate on cleanwater samples and treated WW



Sources

Like nitrogen, phosphates pass through the cycle of decomposition and photosynthesis. It is used extensively in fertilizers, a constituent of animal waste. Agri runoff is the major source as well as municipal WW. Phosphates are used in detergents and in industries (boiler water conditioning – removal of calcium)

Impact

-In great quantities, phosphate causes rapid growth of aquatic plants

- Affects WT systems – interfere with chemical coagulation

Environmental Engineering

Biological Water Quality Parameters

Dr. Ahmed N Bdour

Summary Biological Water Quality Parameters

Pathogens

Bacteria Viruses

Protozoa

Helminths

• Pathogen Indicators

Pathogens

A body of water hosting large numbers of species with well balanced numbers of individuals is considered to be a healthy system.

Based on their known tolerance for a given pollutant, certain organisms can be used as an indicator of pollution

Pathogen – Capable of infecting or transmitting diseases to humans.

They require a host for growth and reproduction. They can be transported in natural waters . Many are able to survive in waters and maintain their infectious capability for long periods. These waterborne pathogens include species of bacteria, viruses, protozoa and helminths (parasitic worms)

Pathogens

- **Bacteria** Bacteria are single-cell microorganisms usually colorless. It is a completely self-contained and self-reproducing unit. When the time is right, bacterium will split its DNA and RNA genetic material in two. Separate cell walls will build up around these two new bacteria. Bacteria are rod shape (bacilli); spherical (cocci) or spiral-shaped (spirilli).
- Gastrointestinal disorder are common symptoms of most diseased transmitted by waterborne pathogenic bacteria

Ninety-nine percent of all known bacteria are considered beneficial to humans, or at least harmless.


Bacteria







Spherical, rodlike, spiral





Pathogens

- Virus Smallest biological structure known to contain all the genetic information necessary for their own reproduction. Symptoms associated with waterborne viral infection usually involve disorders of the nervous system rather than the gastrointestinal tract.
- e.g. polio (inflammation of the gray matter of the spinal cord) and hepatitis
- Although standard disinfection practices are known to kill viruses, confirmation of effective disinfection is difficult owing to the small size and lack of quick and conclusive test.
- This is the major concern with recycling of WW

VIRUSES





FUNGI













Pathogens

- **Protozoa** The lowest form of animal life. They are unicellular organisms more complex in their functional activity than bacteria or viruses. They are complete, self contained organisms that can be free-living or parasitic, pathogenic or nonpathogenic, microscopic or macroscopic.
- They are highly adaptable and widely distributed in natural waters however, only few are pathogenic
- Infections are usually characterize by gastrointestinal disorders milder to that of bacteria.
- Under adverse environmental circumstances, aquatic protozoa form cysts which are difficult to disinfect. Usually complete treatment is needed including filtration.

Pathogens

Helminths – The life cycles of parasitic worms often involved two or more animal hosts, one of which can be human, and water contamination may result from their waste. Contamination can also be via snails and insects.

Modern WT systems are very effective in destroying helminthal pathogens. They pose hazards primarily to persons expose to untreated water. E.g. sewerage plant operators, swimmers in lakes polluted from cattle feedlots.

Pathogen Indicators

Analysis of water for all the known pathogens would be a time consuming and expensive task. Therefore the purity of water is usually checked using **indicator organisms**.

- An indicator organism is one whose presence presumes that contamination has occurred and suggest the nature and extent of the contamination. The ideal indicator organism should have the following characteristics:
- Be applicable to all types of water
- Present when pathogens are present
- Absent when pathogens are absent
- Easily identified and analyzed
- Not be a pathogen for safety of personnel

The fecal coliform group of organisms are best suited as indicator organisms as they

- 1. Native to the intestinal track of warm blooded animals
- 2. They are excreted in large numbers
- 3. They are nonpathogenic
- 4. Composed of several strains of bacteria principally Escherichia coli, E coli
- 5. Can survive for longer times outside the host than pathogens

There are other coliform groups which flourish outside intestinal track. Native to soil and decaying vegetation. Their presence can indicate the presence of helminths from soil.

Pathogen Indicators

The quality of drinking water is determined based on the Total Coliform i.e. Fecal Coliform plus Nonfecal Coliform

Test for Fecal Coliform is performed on WW

Measurement

Membrane filter technique – Sample is filtered through a membrane 0.45 microns. Bacteria that remains on the filter is placed in a selective media to promote growth while inhibiting growth of other species. It is incubated for 24hrs. The resulting visible colonies are counted. Results are reported in organisms / 100mL of water.

Waterborne diseases

- Communicable diseases which may be transmitted by water
 - Bacterial infection
 - Typhoid, salmonellosis, dysentery
 - Viral infection
 - Hepatitis, poliomyelitis
 - Protozoal infections
 - Giardia and Cryptants

Waterborne diseases

 Infections are normally caused and spread through the fecal and urinary discharges of sick persons and carriers, also animals and soils may be considered as sources of protozoa and bacteria.

Inorganic contaminants

- Includes both suspended and dissolved materials
- Problems associated, generally are
 - Undesirable for esthetic reasons
 - Ability to shield microorganisms from disinfectants
 - Health effects
- Examples: aluminum, arsenic, barium, cadmium, chromium, fluoride, lead, mercury, nitrate, selenium, and silver.
- EPA has established the so called Maximum Contaminant Level (MCL) for primary pollutants which are generally toxic

Inorganics

- Aluminum associated with neuropathological disorders such as Alzheimer's disease as well as physiological problems among dialysis patients.
- Radionuclides like radium-226 and others are also included in primary standards.
- Arsenic: well-known poison (fatal at high doses).
- Barium: soluble form and very toxic
- Cadmium and chromium: cause acute or chronic toxicity depending on the concentration.
- Fluoride: high concentration discoloration and loss of teeth and embitterment of bones.
- Lead and mercury: affect the nervous system
- Nitrate: interfere with oxygen transfer in the blood of infants
- Selenium: dental problems

Radionuclides

- Widely distributed in nature
- MCLs range from 20,000 pCi/L for hydrogen-3 (part curies per liter) to 5 pCi/L for radium
- Uranium-238, the commonest isotope of uranium, soluble in mg/L range
- It is more dangerous as a chemical toxin to the liver than a source of radioactivity
- Turbidity is a measure of presence of suspended solid material which can be removed by filtration, coagulation, sedimentation.

Organic contaminants

- Associated with color, taste, or odor, in some cases may be toxic or carcinogenic.
- Chlorinated hydrocarbons: used as pesticides and herbicides,
 - persistent in nature and within human bodies.
 - Many shown to produce carcinogenic effects in laboratory animals.

Organic contaminants

- Trihalomethans:
 - May enter water from industrial processes,
 - The most common source is through chlorination of water
 - Chloroform is the most common occurring of trihalomethans
 - Carcinogenic

Organic contaminants

- Volatile Organic chemicals (VOCs)
 - Industrial chemicals
 - Found in both SW and GW
 - Carcinogenic

Natural waters

- All natural water consists of some dissolved minerals
 - Cations: sodium, potassium, calcium, magnesium, iron, and manganese
 - Anion: bicarbonate, carbonate, sulfate, and chloride.
- EPA has established secondary standard called Recommended Contaminate Level (RCL), usually they are not toxic.

Dissolved Gases

- Nitrogen, oxygen, carbon dioxide, hydrogen sulfide, and methane.
- Hydrogen sulfide: produced by reduction of sulfates, dissolution of pyrites or anaerobic decomposition of organic matter.
- It has a rotten-egg odor in low concentration
- Poisonous in high concentration
- Contribute to corrosion of metal and concrete

Dissolved Gases

- Carbon dioxide is dissolved from the atmosphere and produced by decomposition of organic matter
- Soluble in water form carbonic acid
- Oxygen exists in atmosphere and decreased by biological and chemical reactions.
 - Absent in groundwater and badly contaminated surface water
 - Generally added for treatment processes
 - It contribute to corrosion of metals under some conditions.

Liability for unsafe water

- Producers are required to test the water in their systems to be guaranteed for safe use in any purpose.
- Failure to provide an adequate supply (quantity and quality) is a legal issue.

Characteristics of waterborne epidemics

- Widespread outbreaks of disease are often attributed to water systems
- Exception to this rule may occur if water from several sources is used in the systems and only one source is contaminated
- Outbreaks in the past were attributed to the use of untreated water, particularly cross-connections.

Watershed and reservoir protection

- EPA requires that all public supplies that drawn from surface sources be filtered unless very stringent criteria with regard to quality and protection are met.
- Rules should be applied
 - Recreational use should be permitted only when there is a real need for such use and the need can be supplied by other bodies of water
 - Use should be controlled by caretakers
 - Picnics and camping should be restricted to areas with garbage and toilet facilities
 - Swimming and other water contact sports should be restricted to areas at least 2 km distance from the source
 - Non contact recreation such as fishing, boating, and haunting should be restricted to areas at least 200 m from the intake

Groundwater and well protection

- May be contaminated by surface water during floods and by percolation of waste material through the soil.
- Careful construction of wells can prevent contamination which require that the casting be grouted down to the first impervious stratum.
- Leaking sewers, septic tanks are all potential points of pollution.

Protection within the treatment and distribution systems

- Careful design of treatment system will ensure no mixing of potable and nonpotable water by
 - avoiding bypass around the treatment units
 - Wall construction between treated and untreated waters
 - Plants must have adequate chemical supplies to prevent any interruptions in supply resulting from weather or natural disasters
 - All pipes should be made of iron and be installed above the ground
 - Treated water reservoir must be covered and air inlets must be screened to exclude insects

Protection within the treatment and distribution systems

- Within distribution systems
 - Continuous maintenance of a residual disinfectant concentration in the water supply.
 - Such systems are most likely contaminated by cross-connections which need close inspection and maintenance



March, 5th, 2014

What are Wastes?

Basel Convention Definition of Wastes

"Substances or objects which are disposed of or

- are intended to be disposed of or
- are required to be disposed of by the provisions of the law"

Classification of Solid Wastes according to their Properties

Bio-degradable

can be degraded (paper, wood, fruits and others); produce biogas, fertilizer, etc...

Non-biodegradable

cannot be degraded (plastics, bottles, old machines, cans, styrofoam containers and others)

AND

Combustible

organic (paper, wood, food waste, etc.); recover energy

Non-combustible

inorganic (glass, metal and others)

Sources of Solid Wastes



Households



Commerce and Industry





Agriculture



FIGURE 8-1

Solid waste produced: varying per capita figures.

Objectives of SWM

- The first objective of solid waste management is to remove discarded materials from inhabited places in a timely manner:
 - to prevent the spread of disease,
 - to minimize the likelihood of fires, and
 - to reduce aesthetic insults arising from putrefying organic matter.
- The second objective, which is equally important, is to dispose of the discarded materials in a manner that is environmentally acceptable.



Figure 3-1. The Solid Waste Management Hierarchy



Processing & Recovery

- Classification
- Separation
- Size Reduction
- Moisture Control
- Recycling of Resource Materials
- Recovery of Energy

Recycling

- Is the reprocessing of wastes to recover an original raw material.
 - At its lowest and most appropriate technological level, the materials are separated at the source by the consumer.
 - This is the most appropriate level because it requires the minimum expenditure of energy.
 - Generally, the recycling options available to a municipality for residential use include:
 - 1. drop-off centers
 - 2. curbside collection
 - 3. material processing facility
 - 4. material transfer stations leaf/yard waste compost bulky waste collection and processing
 - 5. tire recovery
Composting

- Compost is a humus-like material that results from the aerobic biological stabilization of the organic materials in solid waste.
- Compost is useful as a soil conditioner. In this role compost will:
 - 1) improve soil structure,
 - 2) increase moisture-holding capacity,
 - 3) reduce leaching of soluble nitrogen, and
 - 4) increase the buffer capacity of the soil.
- It should be emphasized that compost is not a valuable fertilizer. It contains only 1 percent or less of the major nutrients, such as nitrogen, phosphorus, and potash. Thus, only a limited market exists for compost.

INCINERATION

- Incineration has been used to reduce the bulk (size & weight) of the solid waste.
- Although the solid waste may have some heat value, it is normally quite wet and is not selfsustaining in combustion until it is dried.
- Conventionally, auxiliary fuel is provided for the initial drying stages.
- Some type of air pollution control device is required because the large amount of particulate matter generated in the combustion process (plus gases).

DISPOSAL BY SANITARY LANDFILL

The sanitary landfill is defined as

- a land disposal site employing an engineered method of disposing of solid wastes on land in a manner that minimizes environmental hazards.
- This is achieved by:
 - 1. spreading the solid wastes to the smallest practical volume, and
 - 2. applying & compacting *cover material* at the end of each day.

Site Selection

- 1. Availability of cover material
- 2. Haul distance and time
- 3. Hydrology
- 4. Climate (better dry area)
- 5. Buffer areas around the site (for example, high trees on the site perimeter)
- 6. Proximity of major roadways
- 7. Traffic patterns and congestion
- 8. Historic buildings. endangered species, wetlands, and similar environmental factors.

Site Preparation

- The plans and specifications
- Operations:
 - > grading the site area,
 - constructing access roads and fences, and
 - installing signs, utilities & operating facilities.
- On-site access roads should be of all-weather construction and wide enough to permit two-way truck travel.
- All sanitary landfill sites should have
 - □ electric, water, and sanitary services.
 - Telephone or radio communications.

Equipment

- A wide variety of equipment is available from which to select the proper type and size needed for an efficient operation.
- The size, type, and amount of equipment required at a sanitary landfill depends on:
 - 1. the size and method of operation,
 - 2. quantities and time of solid waste deliveries, and
 - 3. the experience and preference of the designer and equipment operators.
 - 4. the availability and dependability of service from the equipment.





Environmental Considerations

Vectors (carriers of disease),
Water and air pollution,
should not be a problem in a properly operated and maintained landfill.

Important factors in achieving insect, rodents and fire control:

- 1. well-compacted solid wastes
- 2. well-compacted cover material (soil)
- 3. good housekeeping, and
- 4. timely (daily) covering of the solid waste.



FIGURE 8-12

Municipal solid waste landfill, natural clay site. (*Note:* Drawing is not to scale; size of landfills may vary, and cover slope may exceed limit by approved design.) (*Source:* Michigan Department of Natural Resources.)

Environmental Engineering

Water treatment Spring 2022

Water Pollution and Water Quality



Water is a basic necessity of nature and humans.

We use water for:

- drinking
- food preparation
- washing
- growing crops
- industrial processes
- recreation
- ... and in many more activities.

Different uses require different level of purity.

In addition, we have to make sure that natural water bodies such as rivers, lakes and estuaries remain healthy habitats for the ecosystems they contain.

How much water is there on	the planet?			
Location	Volume (km ³)	Distribution of fresh and saline water		
Oceans	1,350,000,000			
Polar ice caps and glaciers	29,000,000			
Groundwater	8,300,000	ſ	Туре	Average residence time
Freshwater lakes	125,000		Atmosphere	9 days
Saline lakes and inland seas	104,000		Rivers	2 weeks
Soil and subsoil	67,000		Soil moisture	months
Atmospheric moisture	13,000			decades to centuries
Stream channels	3,000		Challow groundwater	10s to 100s years
Living organisms and biomass	1,000			
			Opper ocean	120 years
			Oceanic abyss	3,000 years
Desidence time of water male cules			Deep groundwater	up to 10,000 years
by water type		→	Antarctic ice cap	> 10,000 years





The major forms of water-quality problems are:

Oxygen-depleting substances

Nitrogen: Power plants (NO_x), municipal wastewater, farm runoff, fertilizers *Phosphorus*: municipal wastewater, fertilizers, detergents

Pathogens

untreated or poorly treated sewage

Toxic organics

pesticides, herbicides

Toxic metals

from A to Z, esp. Arsenic, Cadmium and Mercury

Suspended solids (siltation)

soil erosion, industrial processes



(Mines & Lackey, Fig. 8.3 page 176)

REMINDER

Often, pollution in surface waters is not measured in terms of the concentrations of the individual contaminants but is measured in terms of their aggregate potential for oxygen depletion. This is called the *Biochemical Oxygen Demand* (**BOD**).

Substances contributing to BOD are food for bacteria, and the more the bacteria feed on these, the more they also take oxygen (like us humans, who both eat and breathe).

Organic matter + $O_2 \rightarrow$ new cells + CO_2 + H_2O + *etc*.

The definition is:

1 mg/L of BOD will, after uptake by bacteria, decrease the DO level by 1 mg/L.

Note: 1 mg/L of BOD may correspond to more or less than 1 mg/L of the offensive substance.

BOD is determined in the laboratory by measuring the depletion of dissolved oxygen in the contaminated water placed in a closed container, over the course of several days (usually 5 days).

Ensuring water quality

Two components to water quality:

- 1. Safe drinking \rightarrow treatment of surface or subsurface water for consumption
- 2. Safe release \rightarrow treatment of municipal sewage and industrial wastewater

Historically, the design and operation of treatment systems for both drinking water and wastewater were activities conducted as a branch of civil engineering, because it involves some hydraulics. It was called *Sanitary Engineering*.

Environmental Engineering grew out of sanitary engineering as additional issues arose, including air quality, solid-waste disposal, hazardous waste, *etc*.

Regulations in the US

Triple concern

- Health of people who drink the water
 - avoidance of cholera, typhoid fever, gastroenteritis, etc.
- Aesthetics
 - water color, hardness, taste, odor
- Quality of water in the environment dissolved oxygen, salt content, habitat





- 1969: Cuyahoga River in Ohio catches on fire; other highly visible problems
- 1970: Establishment of the Environmental Protection Agency (EPA)
- 1972: Clean Water Act (CWA)
- 1974: Safe Drinking Water Act (SDWA)

CWA regulates discharges in rivers, lakes, estuaries and wetlands by means of discharge permits and effluent standards.

The concern is to keep outdoor waters "swimmable and fishable".

SDWA establishes water quality standards for all public water distribution systems that serve an average of 25 or more people daily.

- *Primary standards* are enforceable maximum contaminant levels for the protection of human health.
- · Secondary standards are non-enforceable guidelines for aesthetic effects.



Water and wastewater systems in settled areas. In older cities, storm and sanitary sewers may still be combined, leading to untreated but diluted wastewater releases after heavy rain.







	Concentration	Desired concentration
Contaminant	in wastewater	after treatment
Total solids (TS)	average 720 mg/L	
Total dissolved solids (TDS)	200 – 1000 mg/L	
Total suspended solids (TSS)	100 – 350 mg/L	30 mg/L
Volatile suspended solids (VSS)	165 mg/L	0 mg/L
BOD (5-day, 20°C)	100 – 300 mg/L	30 mg/L
Nitrogen	20 – 80 mg/L	10 mg/L(*)
Phosphorus	5 – 20 mg/L	2 mg/L(*)
Chlorides	50 mg/L	varies by type
Sulfates	30 mg/L	
Alkalinity	2 meq/L	
Toxic chemicals	varies	zero
Pathogens	10 ⁷ – 10 ⁸ per 100 mL	< 200 counts/mL
Volatile organic compounds (VOCs)	0.1 – 0.4	minimal

Typical composition of municipal wastewater and the desired level of treatment

(*) depends on permit, based on receiving water body What does it look like?

For drinking water treatment ...





Reverse osmosis filter

Drinking water treatment plant in Saskatoon, Saskatchewan



Water treatment

Water Treatment – Preparation of water for drinking and municipal distribution (

Consumers in industrialized countries expect safe drinking water, that is:

- Clear
- Colorless
- Odorless
- Free of harmful chemicals
- Free of pathogens.

Natural water, however, rarely exhibits these properties.

Type of impurity	Specific constituents	Typical concentration
Major inorganic constituents	Usually in ionic form: calcium, chloride, fluoride, iron, manganese, nitrate (NO ₃ ⁻), sodium, sulfur	1 – 1000 mg/L
Minor inorganic constituents	Arsenic, cadmium, copper, lead, mercury, nickel, zinc, <i>et</i> c.	0.1 – 10 μg/L
Natural organic compounds	Biological detritus (Total Organic carbon = TOC)	0.1 – 20 mg/L
Anthropogenic organic compounds	Synthetic organic chemicals, agricultural, industrial & household chemicals (benzene, vinyl chloride, PCBs, PCE, TCE)	from 1 μ g/L to tens of mg/L
Living organisms	Bacteria, algae, viruses	millions

(Mihelcic & Zimmerman, Table 10.1)

Polychlorinated biphenyls (PCBs) are a group of manmade chemicals. They are oily liquids or solids, clear to yellow in color, with no smell or taste. PCBs are very stable mixtures that are resistant to extreme temperature and pressure. PCBs were used widely in electrical equipment like capacitors and transformers

Tetrachloroethylene (PCE) is a synthetic chemical that is widely used for dry cleaning

Trichloroethylene (TCE) is a halocarbon commonly used as an industrial solvent

Arsenic

Naturally occurring arsenic is widespread, and in many places of the world, arsenic is present in the groundwater. The World health Organization (WHO) has set a drinking-water guideline for arsenic of 10 μ g/L (= 10 ppb_m).

Long-term exposure to arsenic via drinking-water causes cancer of the skin, lungs, urinary bladder, and kidney, as well as other skin changes such as pigmentation changes and thickening (hyperkeratosis).

Increased risks of lung and bladder cancer and of arsenic-associated skin lesions have been observed at drinking-water arsenic concentrations of less than 0.05 mg/L.







Water Softening = Hardness Removal

Hardness of water is caused by 2+ ions, primarily Ca⁺⁺ and Mg⁺⁺, usually associated with the carbonate ions (HCO₃⁻ and CO₃⁻⁻) or sulfate ions (SO₄⁻⁻). It is a common occurrence with groundwater.

So-called complexation agents can be added to prevent the 2+ ions from precipitating. Better, hardness can be removed, which softens the water.



Example of process: The lime-soda ash softening process

Recarbonation

- □ After adding lime and/or soda ash, treated water will generally have a pH greater than 10.
- □ It is necessary to lower the pH to stabilize the water and prevent deposition of carbonate scale on filter sand and distribution piping .
- Recarbonation is the most common process used to reduce pH. This procedure adds carbon dioxide to water after softening. Generally, enough carbon dioxide is added to reduce the pH of the water to less than 8.7.

Disinfection

Purpose:

To reduce risk of disease transmission associated with either drinking or waste water.

Objective:

To kill or inactivate microorganisms.

<u>Methods:</u>	Boiling of water	Very effective	Very energy intensive
	Irradiation with UV light	Limited efficacy	Cheap and convenient Requires clear water
	Chemical disinfection by chlorine or chlorinated compound	Very effective Leaves lasting residuals	Cheap to expensive May create harmful by-products
	Chemical disinfection by ozone	Very effective	Quite expensive No residual left

Disinfection by chlorine

The active ingredient that kills microorganisms is hypochlorous acid, HOCI.

HOCI must be made in the water from a chlorinated precursor. The most common method is the injection of pure chlorine gas, Cl₂.

More expensive but safer than handling chlorine gas is the use of sodium hypochlorite (NaOCI - commonly called bleach) or calcium hypochlorite $(Ca(OCI)_2)$, a solid.

U.S. standards for drinking water:

- minimum contact of 45 minutes
- minimum residual chlorine concentration of 1.1 mg/L
 - (from initial dose of 2 to 5 mg/L)

U.S. practice for end of wastewater treatment:

- injection of 40 to 60 mg/L.

Chlorine chemistry in pure water

Let us consider the use of chlorine gas as the disinfection method.

First, Cl₂ in gas (from compressed bottle, handled with care!) penetrates the water, following Henry's Law:

 $Cl_{2(g)} \leftrightarrow Cl_{2(aq)}$ with $K_H = 0.062$ M/atm at 25°C

Aqueous Cl₂ reacts rapidly with water to form hypochlorous acid:

$$Cl_2 + H_2O \leftrightarrow HOCI + H^+ + CI^-$$

with constant

$$K = \frac{[\text{HOC1}][\text{H}^+][\text{C1}^-]}{[\text{C1}_2]} = 5 \times 10^{-4} \text{ M}^2$$

The preceding two reactions are highly tilted to the right, meaning that chlorine gas most easily goes into hypochlorous acid in the water.

active ingredient

However, hypochlorous acid HOCI is not just consumed in killing microorganisms; it also decays spontaneously into:

with constant

$$K_2 = \frac{[\text{H}^+][\text{OCl}^-]}{[\text{HOCl}]} = 2.6 \times 10^{-8} \text{ M}$$

The hypochlorite ion OCI⁻ is much less potent as a disinfectant than HOCI.

To keep the previous reaction tilted to the left (in favor of HOCI and against OCI⁻), the pH must be controlled.



Figure 6.D.1 The fraction of hypochlorous species (HOCl + OCl⁻) that is present as undissociated hypochlorous acid (HOCl), versus pH.
Environmental Chemistry

Part (1)

In biological systems

Dr. Ahmed N Bdour

Organic substances:

contain Carbon (C)

- Carbohydrates:
- provide energy for cells (all organisms).
- Major sources of carbohydrates are rice, grains, potatoes and fruits.
- Many organisms produce their own carbohydrates through photosynthesis.



Proteins and Amino acids:

- used for growth and repair of tissues in organisms.
- Used to make parts of cells (cell membrane) and cell products (enzymes, hormones).
- Major sources of proteins are meat, eggs, dairy products, legumes, and nuts.



- Fats (lipids):
- used for energy storage and protection of organs.
- Major sources of fats are vegetable oils, nuts oils, some dairy products and animal tissue.











Nucleic acids:

control cell activities, found in DNA



 Inorganic substances (also called minerals or elements): do not contain carbon

- Macronutrients: needed in relatively large amounts (vs micronutrients)
- Other important inorganic substances: sodium, iron, iodine

Nutrient	Plants	Animals
*Nitrogen (N)	 Composition of protein and chlorophyll Leaf and stem growth <i>Nitrogen cycle: lightning and bacteria fixate free nitrogen</i> 	 Composition of proteins and nucleic acids Growth and repair of tissues
*Phosphorus (P)	 Root and flower growth Cellular respiration and photosynthesis 	 Composition of bones, teeth, DNA Metabolic reactions
*Potassium (K)	Disease resistanceChlorophyll production	 Muscle contraction and nerve impulses
Magnesium (Mg)	 Composition of chlorophyll and photosynthesis 	 Formation of bones and teeth Absorption of calcium and potassium
Calcium (Ca)	Cell wallCell division	 Bones and teeth Blood clotting Muscle and nerve function
Sulfur (S)	 Fruit and grain production 	 Protein synthesis/ Enzyme activation

Forms of Matter Synthesized by Plants

- Plants synthesize carbohydrates through photosynthesis
- Occurs in the chloroplasts which are found in leaf cells
- Examples include glucose, sucrose (table sugar) and starch
- Plants also make proteins, amino acids, fats and nucleic acids from nutrients in the soil through various mechanisms inside the cell.

Forms of Matter Synthesized by Animals

- Animals can synthesize a few carbohydrates (glycogen for energy storage)
- Consume most of what they need by eating food
- Animals synthesize the proteins, amino acids, fats and nucleic acids that they need from nutrients in food

Factors Affecting Health and Organisms Distribution in the Environment:



Level of dissolved oxygen depends on:

- Temperature
- Turbulence due to wind or the speed of water
- The amount of photosynthesis by plants and algae in the water
- The number of organisms using up the oxygen

Dissolved oxygen (ppm or mg/L)	Invertebrates
8	Large numbers of diverse invertebrates
6	Mayflies, stoneflies, and beetles begin to disappear
4	Freshwater shrimp, midge larvae, and worms can survive
2	Midge larvae and some worms can survive



pH or Acidity

- Normal rain has a pH of 5.6. When the pH falls to less then 4.5, most fish disappear.
- In some areas, acidic precipitation builds up as snow and ice in the winter, which can cause spring acidic shock.



Acids and Bases

Acids and Bases can be defined by their properties (operational definition)

•Acids

- Blue litmus to red
- pH < 7
- High conductivity
- Taste sour
- Neutralize bases
- Reactive with active metals

eg. Zn or Mg to form $H_{2(g)}$

•Bases

- Red litmus to blue
- pH > 7
- High conductivity
- Taste bitter
- Neutralize acids
- Feels slippery
- Ionic compounds

Acid - Base Indicators

- Indicators
 - Substances that change color when the acidity changes
 - Synthetic dyes, plant compounds
 - When changing from its acid form to its basic form it will be a blend of its 2 colors.
 - Eg. Litmus at pH < 6 is red pH > 8 is blue pH 6-8 is purple



pH meters

 Digital pH meters can give an accurate pH.



Acids & Bases

- Acids react with metal (corrosion) and produce hydrogen gas.
- Acids can react with skin tissue and cause an acid burn.
- Bases are often used in cleaning substances (ammonia, soap, lye)
- Strong bases can also cause serious burns.

Biodegradation: Biochemical Reaction

- Biodegradation: when living organisms break up material.
 - Example: bacteria break down a dead animal.
 - Other organisms that biodegrade are algae, fungi, protozoans and earthworms.
- These organisms produce enzymes to break apart most organic substances.
- This can be done aerobically (in oxygen) or anaerobically (not in oxygen).

Biodegradation: Biochemical Reaction

• Factors that affect *biodegradability*:

– temperature, moisture, pH.

- Biodegradation slows down in cold temperatures, when moisture is scare, and in very acidic or basic environments
- Paper, grass clippings, and food wastes are *biodegradable*.
- Plastics, metals and glass are not biodegradable.



Organism	Substrate	Nutrient Source
Mould	Loaf of bread	Carbohydrates in the bread
Anemone	Rocks in the ocean	Water-borne organisms (using tentacles)
Grassland	Soil	Decaying plant and animal material and minerals
Fish	Freshwater pond	Smaller fish and other organisms
Algae	Snow or other freezing material	Photosynthesis

Chemistry of Nitrogen in Microorganisms



- Nitrification (*Nitrobacter*) - $NH_3 + (3/2)O_2 \rightarrow NO_2^- + H_2O + H^+$
- Denitrification (Pseudomonas)
 - $2\mathbf{NO_3^+} + 12\mathbf{H^+} + 10\mathbf{e^-} \rightarrow \mathbf{N_2^+} + 6\mathbf{H_2O^-}$



- Only runs under anaerobic conditions: wetlands & swamps
- Those are disappearing with development.

Pollution and pollutants

- A pollutant is any material or energy that can cause harm to a living thing.
- Pollution is a change to the environment that that produces conditions that harm living things.
- A pollutant may not always cause pollution.

How much is that?

- The amounts of substances are often said as percents.
- Percent by weight is usually found by taking the grams of a chemical divided by the total grams of the substance x 100%.
- %weight = 5 g in 100g = 5% by weight
 - 5 g in 500g = 1% by weight
- It's like finding your average on a test.

But what if amounts are really small?

 If amounts are small, much smaller than 1% we use different units.

- We might use
 - parts per million instead of per hundred (ie.
 Percent)
 - Or maybe parts per billion.

Concentration of Pollutants

 The concentration of chemical substances in the environment can be measured in

 parts per million, parts per billion

- Parts per million (ppm):
 - one unit of an element or chemical can be found in one million units of solution.
 - 1 ppm equals 1 milligram per litre (1 mg/L).

Concentration of Pollutants

- Parts per billion (ppb):
 - one unit of an element or chemical can be found in one billion units of solution (One drop of water in a swimming pool is about 1 ppb).

Common Units

- Mass per volume (mg/L; mg/m³)
 Moles per volume (mol/L = M; mol/m³)
- Mass per mass (mg/kg)Moles per weight (mol/kg)
- ppm (parts per million mass)
- ppm (parts per million volume) gasses only

Parts per million (ppm)

<u>Used for very low or dilute concentrations</u> Usually it simplifies to mg/kg = 1 ppm. If aqueous :

1 kg of water = 1L or 1000mL therefore

1 mg/L also = 1 ppm

Q. If 2.2 mg of dissolved O_2 is found in 250mL of water, what is the ppm of oxygen in the water?.

A. Start the question as a ratio,

Change the units to get mg/kg or mg/L

Concentration = 2.2 mg = 2.2 mg = 8.8 mg = 8.8 ppm250 mL 0.250L L TOXICITY

The Danger in the Dose

 Toxicity is the ability of a chemical to cause harm of a living system: human, animal, plant or microbe

 Acute Toxicity has serious symptoms after 1 dose

Chronic Toxicity has symptoms after the chemical accumulates over time.

Lethal Dose 50 (LD50)

- LD50 is the dose of a chemical that will kill 50% of the population it's applied to.
- Different chemicals have different LD50s.
- The Gov't has the responsibility of "acceptable risk" for a substance. Small doses may be o.k.
- If rats die from a chemical would it still be ok for humans.

How is the toxicity of a substance expressed?

The terms LD₅₀ (lethal dose) or LC₅₀ (lethal concentration) are used to express the toxicity of a substance. The lower the number, the more toxic the substance.

We have the LD₅₀ or LC₅₀ is determined by the concentration or dose of a material (g/kg) that results in the death of 50% of a sample group of laboratory animals.

Toxicity rating for LD or LC50?

Non-toxic: >15 g/kg (> quart)

Slightly toxic: 5-15 g/kg (pint to a quart)

Moderately toxic: 0.5-5 g/kg (fluid ounce to a pint)

Very toxic: 50-500 mg/kg (teaspoon to an ounce)

Extremely toxic: 5-50 mg/kg (7 drops to a teaspoon)

Super-toxic: <5 mg/kg (<7 drops)</pre>

From:

"Occupational Toxicology", Michael S. Bisesi, Ph.D., R.S., C.I.H., 1992



OSHA definition of toxic and highly toxic material

Exposure Route	Toxic	Highly Toxic
Oral LD50	50-500 mg/kg	<50 mg/kg
Inhalation LC50	200-2000 ppm/air	<200 ppm/air
Skin Contact LD 50	200-1000 mg/kg	<200 mg/kg

Occupational Safety and Health Administration (OSHA)
What types of responses are there to toxins?

Acute vs. Chronic

Acute – the response is immediate and typically reversible

Chronic – the response is delayed or accumulative and is typically not reversible

Examples:

Acute	Chronic
Absorption	Ingestion
Absorption of phenol through the skin creating a chemical burn	Consumption of lead causing damage to the kidneys
Inhalation	Inhalation
Inhalation of formaldehyde causing irritation to mucus membranes	Inhalation of asbestos causing cancer to the lungs



Local vs. Systemic

 $\mathcal{L}ocal$ – the effect occurs at the point of contact

Systemic – effect occurs away from the point of contact, typically to an organ or organ system

Examples:	
Local	Systemic
Contact with acid creating a chemical burn	Consumption of lead causing damage to the kidneys
Ozone exposure causing lung irritation	Exposure to hydrogen fluoride causing pulmonary edema
Aldehyde splash in the eyes.	Exposure to arsine causing hemolysis of re- blood cells

Classification of toxins

- Anesthetic (ethanol)
- Asphyxiant (carbon monoxide)
- Carcinogen (asbestos)
 - Hemotoxin (benzene)
 - Hepatotoxin (carbon tetrachloride)
- Irritant (ozone)

- Nephrotoxin (lead)
- Neurotoxin (mercury)
 - Pneumotoxin (cadmium)
 - Sensitizer (formaldehyde)
 - Teratogen (ethylene oxide)

Introduction to

Environmental Chemistry

Part (2)

Chemistry of Pollutants

Dr. Ahmed Bdour

Pollution and pollutants

- A pollutant is any *material or energy* that can cause harm to a living thing.
 - Pollution is a change to the environment that that produces conditions that harm living
 - things.

– Why?

A pollutant may not always cause pollution.

Introducing Chemicals into the Environment: Pollutants

Fertilizer application in agriculture:

- nitrate, phosphate and potassium are added to soil as fertilizer, and dissolve in water.
- Some will run off into streams and lakes.
 - Fertilizer labels: 15-30-15 means 15% N, 30% P, 15% K

Solid Waste:

chemicals can move into the soil when it rains and
gases from incinerators can pollute the air. *Multi-media pollutant*

Water Pollutants

Wastewater:

- dissolved and un-dissolved materials from your house (sewage),
- both organic and inorganic.
- Treated water may contain nitrogen or phosphorus from the breakdown of sewage during treatment.
- Applies to both municipal & industrial
 - wastewater.

Water Pollutants

- With all of the above processes, chemical concentrations are changed.
- In rivers and lakes, nitrate and phosphate levels increase
 Result can be *eutrophication:* over-enrichment of a water body with nutrients, resulting in excessive growth of organisms and depletion of oxygen concentration







Pollutants

• Spraying:

- herbicides/fungicides are used to control weeds, and
- pesticides/insecticides are used to control unwanted insects.
- Spraying is not very precise, some of these chemicals end up in the atmosphere and our water system
- Smog (common in cities) can react with water vapour to produce acid rain.

Pollutants

Industrial Processes:

- electrical power generation,
- mineral processing and
- Chemicals (e.g. fertilizer) production.
- In natural gas processing to remove sour gas (hydrogen sulfide), sulphur dioxide is released into the air (causes acid rain).

Chemical pollutants

There are more than 100, 000 synthetic chemicals that are in daily use:

- 1. solvents
- 2. detergents
- 3. dyes and varnishes
- 4. additives in plastics and textiles
- 5. chemicals used for construction
- 6. antifouling agents
- 7. herbicides, insecticides, fungicides
- 8. Pharmaceuticals
- 9. Others ...

Ozone Layer

Ozone in the Stratosphere

 \approx 16 - 50km above the Earth's Surface

acts as a blanket preventing harmful radiation that can marked affect living material from reaching the surface of the Earth.

ozone layer

- The ozone layer is a natural part of our atmosphere. It acts like a protective sun screen by blocking harmful ultraviolet (UV) rays from the sun.
 - Certain chemicals—such as chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), and halons—can damage the ozone layer. These can cause holes to form in the layer and allow more UV rays to reach the earth's surface. Increased exposure to UV rays is dangerous for people, animals, and plants.

Chemicals that damage the ozone

layer

- known as ozone-depleting substances (ODS), are used in:
 - commercial, home and vehicle air conditioners, and refrigerators,
 - foam blowing agents,
 - solvents,
 - aerosol spray propellants,
 fire extinguishing agents, and
 chemical reactants

Effects of Reduction in Ozone

- Effects of Reduction
- 1% Reduction In $O_3 \Rightarrow 2\%$ increase in UV-B*
 - Skin sunburns, tans, Skin cancer
- Absorbed by DNA \implies DNA damage
 - Possible eye cataracts (cloudiness or opacity)
 - Interferes with photosynthesis
 - Organisms in 1st 5metre of the Oceans at risk (phytoplankton in particular)

* UV-B lamps are lamps that emit a spectrum of ultraviolet light of 290-320 nanometers

Chlorofluorocarbons & Ozone

- Destruction of the Ozone Layer discovered in 1970's
- Due to CFC's (Chlorofluorocarbons)
 - First synthesized Swartz (1892)

 $CCI4 + xHF \longrightarrow CCI(4-x)Fx + HCI$

Used as refrigerants 1928 (Midgely & Henne)
Aerosol Propellants & Air conditioners

Ozone Destruction

Destruction $CFCl_3 \longrightarrow Cl^{\bullet}$ Chlorine (UV-C, UV-B) Radical

 $Cl^{\bullet} + O_{3} \implies O_{2} + ClO^{\bullet}$ $ClO^{\bullet} + O^{\bullet} \implies Cl^{\bullet} + O_{2}$ $ClO^{\bullet} + ClO^{\bullet} \implies ClOOCl (relatively stable)$

Troposphere Contamination by pollutants

Air pollution in troposphere (photochemistry)

- $NO_2 + O_2 + hv \rightarrow NO + O_3$ • $O_3 + hv \rightarrow O + O_2$
- $O + H_2O \rightarrow 2 OH$ [OH] ~ 10^6 molecules/cc
- OH radical is dominant oxidizer in troposphere!



Air pollutants: Smog

- "Smoke and fog," a term from London episode 1952.
- Engine exhaust components
 - 1. CO, NO, unburnt hydrocarbons
 - 2. Lean mix minimizes CO, hc, maximizes NO
 - 3. Rich mix minimizes NO, maximizes CO, hc
 Run a little rich and catalytically kill CO to CO₂
 - $\mathrm{OH} + \mathrm{CO} + \mathrm{O_2} \rightarrow \mathrm{CO_2} + \mathrm{HO_2}$
 - Peroxides like PeroxyAcetylNitrate (PAN)result compound containing an oxygen—oxygen (organic and inorganic)

Muti-media pollutants:

Acid Rain

Natural Acidity, CO₂(aq)

P_{CO2} = 370 ppmv, pH 5.6

SO₃ & N₂O₅ are strong acid anhydrides.

Vulcanism, sour crude, and ore smelting produce

SO₃;

- Nature is a minor polluter.

– CaSO₄ & H_2SO_4 recovery are economical.

pH 4 recorded in (now dead) lakes !



Greenhouse Effect: Carbon Cycle first

Natural

- 2.5×10¹² ton in atmosphere vs. 1.3×10¹⁴ in sea.
 10¹¹ ton yr⁻¹ exchange gives ~25 yr
 - residency.
 - So oceans are the perfect sink for excess
 - CO₂.
- 10^{13} ton in biosphere exchange 6×10^{10} ton yr⁻¹.

Anthropogenic

- Fuel burn at 10% of photosynthesis
 - -decay exchange increases atmospheric CO₂.
- Seas *can* absorb but only eventually.

- Pollutants are carried through the air by dispersion.
 The pollutant is released from a source (a factory), is scattered in various directions (dispersion), and then falls to the ground or water (deposition).
- Wind direction and speed will influence where the pollution lands.
- When pollution combines with rain or snow it is not usually carried as far.

- Pollutants are carried through the soil through the process of leaching.
- The pollutant dissolves in water (for example fertilizer, herbicide, pesticide), and then moves downward through the soil.
- The type of soil will affect how much leaching

occurs.

- Soils with a lot of clay (not porous) do not allow water to soak through (prevents leaching).
- Soils that are very porous (sandy soils) allow water to soak through (allow leaching).
- Some pollutants react with substances in the soil and are neutralized.
- Acid rain can be neutralized by basic soils (soils high in calcium carbonate).

- Pollutants that move through the soil can then enter the groundwater.
- Groundwater is water held within porous rock below the soil.
 - If you use water from a well, you are using groundwater.
- The porous nature of the rock allows the groundwater to move great distances, and carry pollutants with it.
 The more porous the rock, the faster the pollutants will move.

- Pollutants can also move in surface water (runoff, rivers, streams).
 - Pollutants that dissolve easily in water will be carried a long way.
 - Pollutants that don't dissolve well
 - will settle in the river or stream bottom and
 - accumulate causing problems for the organisms.

- <u>Examples</u> on pollutants which would transfer in the environment (air, water, soil):
 - 1. minerals in rocks,
 - 2. organic substances,
 - 3. leached substances from landfills,
 - 4. leakage from underground storage and pipelines,
 - 5. industrial products,
 - 6. de-icers (salts),
 - 7. microorganisms from improperly maintained septic tanks,
 - 8. household chemicals ..

Dilution: reduces the concentration of the pollutant by mixing the polluting substance with large quantities of air or water

municipal & industrial effluents urban storm water runoff surface runoff irrigation water runoff

dispersion

disease-causing bacteria & viruses

salts (calcium bicarbonate, sodium chloride, sodium sulfate, etc.)

nutrients (nitrogen, phosphorus, carbon, etc.)

pesticides (herbicides, insecticides, etc.)

heavy metals (lead, zinc, copper, mercury, etc.)

sediment

sedimentation

Figure 3.5 Substances released into a river are dispersed and diluted, or they are deposited on the bottom and become part of the sediment.

dilution

death of disease-causing bacteria & viruses

> ingestion by animals

uptake by plants

Environmental Awareness

- As scientists & engineers, we are morally obliged to consider the consequences of our acts.
- We synthesize a molecule for profit but must consider its fate when discarded.
 - E.g., plastic bottles now biodegrade and are no longer immortal.
 - E.g., non-chlorinated refrigerants now cool food without sacrificing the Ozone Layer.

Air Quality Indoor vs Outdoor Issues and Technologies

Prof. Ahmed Bdour

Spring 2021

Air Quality Issues and Technologies Quality of the air Climate issues Excessive greenhouse gases Chemicals that humans breathe Toxic, potentially fatal Global warming Change in precipitation patterns Harmful to lungs Change in vegetation Causing cancer Rising sea level (thermal expansion) Chemicals harmful to non-humans Harmful to breathing animals Other climatic changes Harmful to vegetation & habitats Melting of sea ice (climate feedback) Impacting water quality Melting of land ice (glaciers) Harmful to aquatic life Rising sea level (added water) Affecting buildings & monuments More extreme weather Affecting visibility



The greenhouse effect

passes through the clear atmosphere

Most radiation is absorbed by the earth's surface and warms it

Some solar radiation is reflected by the earth and the atmosphere

Some of the infrared radiation passes through the atmosphere, and some is absorbed and re-emitted in all molecules. The effect of this is to warm the earth's surface and the lower atmosphere.

> Infrared radiation is emitted from the earth's surface

Source: U.S. Environmental Protection Agency (public domain)
Annual Greenhouse Gas Emissions by Sector





3.2%

3.9%

4.4%

4.7%

A distinction

A distinction needs to be made between indoor and outdoor (personal vs. ambient) air quality.

In the United States, indoor, personal air quality is mostly regulated by the Occupational Safety & Health Administration (OSHA) whereas outdoor, ambient air quality is the purview of the Environmental Protection Agency (EPA).

Indoor air quality is addressed, in large parts, at the time of building planning via design of heating and ventilation needs. In industrial settings, air quality is also addressed in relation to the equipment used by workers.

Leaving indoor air quality issues to building planners and ventilation mechanical engineers, the air section of this course is (except for the following few slides) exclusively concerned with outdoor, ambient air pollution and its preventative treatment.

Indoor Air Quality

According to the EPA, people spend on average 90% of their time indoors. Thus, most of the air they breathe is indoor air, and indoor air quality is of primary importance to human health.

The risks are:

- Disease from airborne bioaerosols (germs in the air; ex. after someone sneezing)
- Odors
- Allergic reactions.



Besides human health, indoor air quality is important in museums for the preservation of valuable pieces of art, and some studies have shown that some indoor air pollutants can affect electronic boards in computers.

PRIMARY SOURCES OF INDOOR AIR POLLUTION



Indoor Air Pollutants

(Mihelcic & Zimmerman, Section 12.4.3)

Pollutant	Source	Permissible Exposure Limit	Short-Term Exposure Limit
Carbon monoxide	Stoves, furnaces	50 ppm	400 ppm
Formaldehyde	Carpets, particle board, finishes	0.75 ppm	2 ppm
Particulate Matter	Cooking, carpets, materials processing	5 mg/m ³	
Volatile Organic Compounds (VOCs)	Solvents, cleaning products, personal-care products	Compound specific	
Radon	Diffusion from underground rocks and soil	100 pCi/L	
Ozone	Photocopiers, printers, air-cleaning devices	0.1 ppm	0.3 ppm
Biological agents (bioaerosols)	Mold, fungi, pets	No exposure	
Tobacco smoke	Cigarettes, cigars, pipes	No exposure	
Asbestos	Wall insulation, floor/ceiling tiles, fireproofing	0.1 fiber/cm ³	

Modeling of indoor air quality is most often performed using a CMFR mass balance, for one room at a time or for the building as a whole.

V = volume of control volume $V\frac{dC}{dt} = Q_{ventilation}C_{in} - Q_{ventilation}C + E - KVC$ (in L) C = concentration of substance (in g/L) Q = volumetric flux of fluid (in L/s) S = sum of sources or emissions (in g/s) K = decay constant (in 1/s)Usually, Indoor emissions a day-night oscillation Exhaust Pollutant removal by Mechanical equipment, if any - Adhesion to surfaces Conditioning of air before venting in rooms (Outdoor air in a home without mechanical ventilation) Air residence time $\theta = \frac{V}{Q_{ventilation}}$ is the primary control parameter.

CMFR: are control volumes for which spatially uniform properties may be assumed

Worst-case scenario in a modeling study:

Dominance of indoor emission E over import $Q_{ventilation}C_{in}$ and removal KVC

Approximate solution is:

$$V\frac{dC}{dt} = Q_{ventilation}C_{in} - Q_{ventilation}C + E - KVC$$

$$C \approx \frac{E}{Q_{ventilation}} = \frac{E\theta}{V}$$

Air-quality problems vary with scale

System	Length scale	Time scale	Examples
Indoor environment	10 m	1 hour	Radon in basement Tobacco smoke Airplane cabin air
Industrial plumes	1 km	10 minutes	Toxic organics Mercury and other metals
Urban airshed	10 to 100 km	day-night cycle	Ground-level ozone (smog) Carbon monoxide Particulate matter
Regional / continental	1000 km	several days to a week	Acid deposition
Planetary atmosphere	20,000 km	decades to centuries	Nuclear plant accidents Stratospheric ozone depletion Climate change



... and still 50 years later ...



Riders of a local message delivery company in Los Angeles being outfitted with protective gas masks in the fall of 1955.

At the 1958 Air Pollution Conference, Dr. James P. Dixon, Health Commissioner of Philadelphia said :

"If gas masks are not to become as common in a hundred years as shoes are today in the civilized world, we should do well to heed our somewhat submerged instincts of self-preservation and remember that – whatever other uses man may devise for it – air is essentially for breathing."



For a summary and helpful presentation, see <http://www.epa.gov/oar/caa/>.



Distinction: Primary vs. Secondary pollutants

A primary pollutant is one emitted by an identifiable source.

A secondary pollutant is not emitted from a source but formed from precursors through chemical reactions taking place in the atmosphere.

Note:

CO₂ is not to be mentioned here. It is not a pollutant. It is a greenhouse gas.



(Formerly found at http://www.epa.gov/apti/course422/ap3.html)

Criteria Pollutants



You need to know this list!

P P and S	Incomplete combustion From combustion, esp. automobile engines	Impairs oxygen-carrying capacity of blood → Asphyxiation & brain damage Respiratory irritant (asthma) Compromised immunity Visibility impairment Acid deposition
P and S	From combustion, esp. automobile engines	Respiratory irritant (asthma) Compromised immunity Visibility impairment Acid deposition
ostly S		-
	From NO and NO ₂	Lung, throat and eye irritant Reduced resistance to infection Damage to vegetation
P	Sulfur in fuels, esp. coal and diesel	Respiratory irritant Heart attack Acid deposition; reduced visibility
P and S	Industrial combustion Other industrial activities	Visibility impairment Respiratory impairment
and S	Industrial processes Lead pipes, solder	Blood poisoning; hypertension Kidney damage; cancer Mental retardation
	P P and S and S	P Sulfur in fuels, esp. coal and diesel P and S Industrial combustion Other industrial activities and S Industrial processes Lead pipes, solder For a Mihe





Figure 7.A.4 Ozone, nitric oxide (NO), and nitrogen dioxide (NO₂) mole fractions for a day in the Los Angeles air basin (November 4, 1984). The maximum 8-hour average ozone concentration is 97 ppb, which exceeds the 80 ppb standard. Time 0 corresponds to midnight.





The EPA has set National Ambient Air Quality Standards (NAAQS) for these six criteria pollutants.

Pollutant	Standard	Туре
Carbon monoxide (CO)		
8-hour average	9 ppm (10 mg/m ³)	Primary
1-hour average	35 ppm (40 mg/m ³)	Primary
Nitrogen dioxide (NO ₂)		
annual average 1-hour average	53 ppb (100 μg/m³) 100 ppb	Primary & Secondary Primary
Ozone (O ₃)		
8-hour average	70 ppb (157 μg/m³)	Primary & Secondary
Particulate Matter ≤ 10 µm (PM ₁₀)		
24-hour average	150 μg/m ³	Primary & Secondary
Particulate Matter ≤ 2.5 μm (PM_{2.5})		
annual average	12 μg/m³	Primary
annual average	15 μg/m³	Secondary
24-hour average	35 μg/m³	Primary & Secondary
Sulfur dioxide (SO ₂)		
3-hour average	0.5 ppm	Secondary
1-hour average	75 ppb	Primary
Lead (Pb)		
rolling 3-month average	0.15 μg/m ³	Primary & Secondary

www.epa.gov/criteria-air-pollutants/naaqs-table



Newark, NJ

Hazardous Air Pollutants

Hazardous air pollutants, also called air toxics, are those pollutants that are known or suspected to cause **cancer** or other serious health effects, such as reproductive effects or birth defects, or adverse environmental effects.

Examples of air toxic pollutants include *benzene* (from gasoline), *mercury* (from coal combustion and fluorescent lamps), *perchloroethylene* (from dry cleaning facilities), *methylene chloride* (a solvent used in industry).

Some affect humans by direct respiration, others settle and fall in water, affecting people when they drink. On rare occasions, effect is through skin exposure (dermal contact).

Hazardous Air Pollutants (HAPs) are not covered by national ambient air quality standards because they tend not to be uniformly present in the atmosphere but to be in greater concentrations near their sources. Hence, they are not subject to routine monitoring in the air. Instead, emissions are monitored at the source.



Two-prong strategy:

1. Control emissions, with goal of reduction

- Command & Control requiring use of *Best-Available ControlTechnology* (BACT)
- Incentives (cap-n-trade of emissions)

2. Control of ambient concentrations: Six criteria pollutants - National Ambient Air Quality Standards (NAAQS)

Distinction:

Primary pollutant:	emitted directly from a source	
	(source can be regulated)	

Secondary pollutant: formed in the air by chemical reactions from precursor species (no source to be regulated – need to go after chemical precursors)

Emission Factor Modeling

Basic idea

A source emitting a pollutant has a certain level <u>A</u> of activity (action per time). This activity level leads to a certain amount <u>E</u> of emission (amount emitted per time). The factor of proportionality is called the

Emission Factor (EF), ratio of amount emitted per action.

Example

An industrial boiler emits 0.6 kg of CO per 1,000 L of oil burned. EF = 0.6 kg CO/ 1,000 L fuel

So, if the activity level of the boiler is 120,000 L of oil consumed per day, then A = 120,000 L/day, and the emission is E = (0.6 kg CO / 1,000 L)x(120,000 L/day) = 72 kg CO per day.

Correction

There may be an emission-control device installed that reduces the outgoing emission by an efficiency factor η (% of emission captured).

 $\rightarrow \frac{\text{Formula}}{E = A \times EF \times (1 - \eta)}$

Fuel type	Bituminous coal (pulverized) (1.8% sulfur)	Diesel oil (#6 'residual') (2% sulfur)	Natural gas
Heating value:	24.2 kJ/g	41.7 MJ/L	38.3 MJ/m ³
Emission factors:			
Particulates	31 kg/ton	2.9 kg/m ³	16-80 kg/10 ⁶ m ³
SO ₂	35 kg/ton	38 kg/m ³	9.6 kg/10 ⁶ m ³
NŌx	10.5 kg/ton	8 kg/m³	8800 kg/10 ⁶ m ³
со	0.3 kg/ton	0.6 kg/m ³	640 kg/10 ⁶ m ³
Non-methane organics	0.04 kg/ton	0.09 kg/m ³	23 kg/10 ⁶ m ³
Methane	0.015 kg/ton	0.03 kg/m ³	4.8 kg/10 ⁶ m ³

Example

A coal-fired power plant burns bituminous coal with a 1.8% sulfur content by weight. To produce 1 MW of electricity, this plant burns 12 tons of coal per day. The plant is equipped with a wet scrubber that captures 95% of the SO_2 from combustion.

How much SO₂ does the plant release per day when it generates 350 MW of electricity?

Answer

Activity = $A = (350 \text{ MW}) \times (12 \text{ tons coal} / \text{day} \cdot \text{MW}) = 4,200 \text{ tons coal} / \text{day}$

Emission Factor = EF = 35 kg SO₂ / ton of coal (from preceding table)

```
Emission-control efficiency = \eta = 95% = 0.95
```

```
Emission = E = A \times EF \times (1 - \eta)
= (4,200 tons coal / day) × (35 kg SO<sub>2</sub> / ton coal) × (1 - 0.95)
= 7,350 kg SO<sub>2</sub> /day
```



Gaseous Emission-Control Technologies (Air-Quality Technology)





Two different approaches:

- Pollution Prevention at the source the better alternative
- Treatment of fumes as they are formed the classical approach

Technology	Pollutants ^a	Description and comment	
Absorption	H ₂ S, SO ₂ , HCl, VOCs	A spray scrubber or packed column maintains a high gas-liquid contact area; especially effective for water-soluble species that can be converted to nonhazardous form in water	
Adsorption	VOCs	Contact is promoted between gas and granular sorbent material, such as activated carbon, so that pollutant molecules adhere to surfaces; often the method of choice for controlling nonpolar organics; can be effective when low trace levels of contamination (ppb-ppm) must be achieved; effective in processing large air volumes with dilute contaminants	
Incineration	VOCs	Waste gases are burned to convert H to H ₂ O, C to CO ₂ ; commonly applied for low to medium levels of contamination with pure hydrocarbons or oxygenated organics	
Catalytic redox	NO, CO, VOCs	Solid catalyst is used to increase rate of reaction and convert elements to less hazardous forms; common application is the three-way catalyst used in motor vehicles	
Condensation	VOCs	Phase change from gas to liquid is caused either by cooling or increasing pressure; requires high gas-phase concentration of species with significant recovery value and high boiling point cannot achieve very low gas-phase concentrations, so sometim used as pretreatment technique	
Membrane recovery	VOCs	Organic vapors are separated from air by flowing gas past membranes that are more permeable to organics than to air; advanced, newly emerging technology	

Table 7.C.2 Treatment Technologies for Gaseous Air Pollutants

"Illustrative examples rather than an exhaustive list.

(Nazaroff & Alvarez-Cohen, Table 7.C.2, page 444)



For a three-way catalyst to function correctly, the air-to-fuel ratio must be maintained within a very narrow band. To maintain that ratio, a closed-loop control system monitors the composition of exhaust gases and sends corrective signals to the air-to-fuel metering system. (After Powell and Brennan, 1988)



Techniques to remove particles from an air stream

Device	Particle size	Collection mechanism and application
Settling chamber	>~20 µm	Separates particles from a gas stream by gravity; used to treat very dirty air streams that contain very coarse particles
Cyclone	$> \sim 1 \mu m$	Separates particles by inertia in a vortex flow; common pretreatment process ahead of electrostatic precipitator or fabric filter
Scrubber	>~1 µm	Wet collector; induces collisions between particles and water droplets to remove particles from gas stream by inertia; may be used for combined collection of particles and water-soluble gases
Electrostatic precipitator	All	Creates electrostatic charge on particles so they can be removed by an electric field; high-efficiency device that is used to treat stack gases in industrial processes
Filter	All	Air flow is forced through matrix of fibers, capturing particles by a combination of Brownian motion, physical straining, interception, and impaction; high efficiency possible; applied for treating waste gases and for removing particles from air before use

Table 7.C.1 Control Devices for Capturing Particulate Air Pollutants

(Nazaroff & Alvarez-Cohen, Table 7.C.1, page 443)

Cyclone Separators and their Design

(Nazaroff & Alvarez-Cohen, pages 445-447 augmented) (Mihelcic & Zimmerman, Section 12.8.1)

Low-pressure drop cyclone at Rochester Asphalt Plant (Victor, NY)

A cyclone used in a woodshop (Lebanon, NH)



Cyclone separators have been used in the United States for about 100 years, and are still one of the most widely used of all industrial gas-cleaning devices. The main reasons for the wide-spread use of cyclones are that they are inexpensive to purchase, they have no moving parts, and they can be constructed to withstand harsh operating conditions.

Cyclone Design

(Adapted from Air Pollution Control by C. D. Cooper & F.C. Alley, 1986)

Typically, a particulate-laden gas enters tangentially near the top of the cyclone, as shown schematically in the left figure. The gas flow is forced into a downward spiral simply because of the cyclone's shape and the tangential entry.

Another type of cyclone (a vane-axial cyclone – see right figure) employs an axial inlet with fixed turning vanes to achieve a spiraling flow.

Centrifugal force and inertia cause the particles to move outward, collide with the outer wall, and then slide downward to the bottom of the device. Near the bottom of the cyclone, the gas reverses its downward spiral and moves upward in a smaller inner spiral. The cleaned gas exits from the top through a "vortex-finder" tube, and the particles exit from the bottom of the cyclone through a pipe sealed by a springloaded flapper valve or rotary valve.



Dust Out



Advantages of cyclones:

Low capital cost (few parts, easy to assemble) Ability to operate at high temperatures (all metal parts) Low maintenance requirements (no moving parts).

Disadvantages of cyclones:

Low collection efficiencies (especially for very small particles) \rightarrow cyclones used almost exclusively for particles > 5 μ m. High operating costs (power required to overcome large pressure drop). Cyclones by themselves are generally not adequate to meet stringent air pollution regulations, but they serve an important purpose. Their low capital cost and their maintenance-free operation make them ideal for use as pre-cleaners for more expensive final control devices such as baghouses or electrostatic precipitators. In addition to use for pollution control, cyclones are used extensively in process industries. For example, they are used for recovering and recycling certain catalysts in petroleum refineries, for recovering freeze-dried coffee in food processing plants, and for capturing saw dust in a lumber shop.

Cyclones have often been regarded as low-efficiency collectors. However, efficiency varies greatly with particle size and cyclone design. Advanced design work has greatly improved cyclone performance. Some cyclone manufacturers advertise cyclones that have efficiencies greater than 98% for particles larger than 5 microns, and others that routinely achieve efficiencies of 90% for particles larger than 15 – 20 microns.

In general, operating costs increase with efficiency (higher efficiency requires higher inflow pressure), and three categories of cyclones are available: high efficiency, conventional, and high throughput.

Typical efficiency curves for these three types of cyclones are presented in the figure.


Standard Cyclone Dimensions

Extensive work has been done to determine in what manner dimensions of cyclones affect performance. In some classic work that is still used today, Shepherd and Lapple (1939, 1940) determined "optimal" dimensions for cyclones. Subsequent investigators reported similar work, and the so-called "standard" cyclones were born.

All dimensions are related to the body diameter of the cyclone so that the results can be applied generally.

The table on the next slide summarizes the dimensions of standard cyclones of the three types mentioned in the previous figure. The side figure illustrates the various dimensions used in the table.

Standard cyclone dimensions

	Cyclone						
	High Efficiency		Conventional		High Throughput		W
	(1)	(2)	(3)	(4)	(5)	(6)	• <u>·</u>
Body Diameter, D/D	1.0	1.0	1.0	1.0	1.0	1.0	н Н
Height of Inlet, H/D	0.5	0.44	0.5	0.5	0.75	0.8	+
Width of Inlet, W/D	0.2	0.21	0.25	0.25	0.375	0.35	
Diameter of Gas Exit, D_e/D	0.5	0.4	0.5	0.5	0.75	0.75	
Length of Vortex Finder, S/D	0.5	0.5	0.625	0.6	0.875	0.85	
Length of Body, L_b/D	1.5	1.4	2.0	1.75	1.5	1.7	
Length of Cone, L_c/D	2.5	2.5	2.0	2.0	2.5	2.0	
Diameter of Dust Outlet, D_d/D	0.375	0.4	0.25	0.4	0.375	0.4	



SOURCES:

Columns (1) and (5) = Stairmand, 1951; columns (2), (4) and (6) = Swift, 1969; column (3) and sketch = Lapple, 1951.

To be collected, particles must strike the wall within the amount of time that the gas travels in the outer vortex. The *gas residence time* in the outer vortex is

The Lapple model for N calculation

$$\Delta t = \text{path length / speed} = \pi D N / V_i$$

where

 Δt = time spent by gas during spiraling descent (sec)

D = cyclone body diameter (m or ft)

- V_i = gas inlet velocity (m/s or ft/s) = Q/WH
- Q = volumetric inflow (m³/s or ft³/s)

W = width of inlet (m or ft).

N number of effective turns

The maximum radial distance traveled by any particle is the width of the inlet duct W. The centrifugal force quickly accelerates the particle to its terminal velocity in the outward (radial) direction, with the opposing drag force equaling the centrifugal force. The terminal velocity that will just allow a particle initially at distance W away from the wall to be collected in time is

$$V_t = W/\Delta t$$

where V_t = particle drift velocity in the radial direction (m/s or ft/s).

$$N = \frac{1}{H} \left(L_b + \frac{L_c}{2} \right)$$

$$V_i = \frac{Q}{WH}$$

The particle drift velocity is a function of particle size.

Assuming Stokes regime flow (drag force = $3\pi\mu d_p V_t$) and spherical particles subjected to a centrifugal force mv^2/r , with m = mass of particle in excess of mass of air displaced, $v = V_i$ of inlet flow, and r = D/2, we obtain

$$V_t = \frac{(\rho_p - \rho_a) d_p^2 V_i^2}{9 \,\mu D}$$

where

- V_t = terminal drift transverse velocity (m/s or ft/s)
- d_p = diameter of the particle (m or ft)
- ρ_p = density of the particle (kg/m³)
- ρ_a = air density (kg/m³)
- μ = air viscosity (kg/m.s).

Substitution of the 2nd equation into the 3rd eliminates Δt . Then, setting the two expressions for V_t equal to each other and rearranging to solve for particle diameter, we obtain

$$d_p = \left[\frac{9\,\mu W}{\pi \,N \,V_i \left(\rho_p - \rho_a\right)}\right]^{1/2}$$

It is worth noting that in this expression, d_p is the size of the smallest particle that will be collected if it starts at the inside edge of the inlet duct. Thus, in theory, all particles of size d_p or larger should be collected with 100% efficiency.

Note that the units must be consistent in all equations. One consistent set is m for d_p , R and W; m/s for V_i and V_t ; kg/m.s for μ ; and kg/m³ for ρ_p and ρ_a . An equivalent set in English units is ft for d_p , R and W; ft/sec for V_i and V_t ; Ibm/ft.sec for μ ; and Ibm/ft³ for ρ_p and ρ_a . The preceding equation shows that, in theory, the smallest diameter of particles collected with 100% efficiency is directly related to gas viscosity and inlet duct width, and inversely related to the number of effective turns, inlet gas velocity, and density difference between the particles and the gas.

In practice, collection efficiency does, in fact, depend on these parameters. However, the model has a major flaw: It predicts that *all* particles larger than d_p will be collected with 100% efficiency, which is incorrect. This discrepancy is the result of all our approximations.

Lapple (1951) developed a semi-empirical relationship to calculate a "50% cut diameter" d_{pc} , which is the diameter of particles collected with 50% efficiency. The expression is

$$d_{pc} = \left[\frac{9\,\mu W}{2\pi\,N V_i\,(\rho_p - \rho_a)}\right]^{1/2}$$

where d_{pc} = diameter of particle collected with 50% efficiency.

Note the similarity between the last two equations. The only difference is a factor 2 in the denominator.



Particle collection efficiency versus particle size ratio for standard conventional

Lapple then developed a general curve for standard conventional cyclones to predict the collection efficiency for any particle size (see side figure).

If the size distribution of particles is known, the overall collection efficiency of a cyclone can be predicted by using the figure.

Theodore and DePaola (1980) then fitted an algebraic equation to the curve, which makes Lapple's approach more precise and more convenient for application to computers. The efficiency of collection of any size of particle is given by

$$\eta_{j} = \frac{1}{1 + (d_{pc} / d_{pj})^{2}}$$

= collection efficiency of particles in the *j*th size range ($0 < \eta_i < 1$) d_{pi} = characteristic diameter of the *j*th particle size range (in μ m).

The overall efficiency, called performance, of the cyclone is a weighted average of the collection efficiencies for the various size ranges, namely

$$\eta = \frac{\sum \eta_j m_j}{M}$$

where

 η = overall collection efficiency (0 < η < 1)

 m_j = mass of particles in the *j*th size range

 \dot{M} = total mass of particles.

Example of Cyclone Analysis

Given:



Solution $N = \frac{1}{H}$	$\left(L_b + \frac{L_c}{2}\right) =$	6 V	$V_i = \frac{Q}{WH} = \frac{Q}{Q}$	$\frac{Q}{0.125 D^2} = 2$	1200 m/min =	= 20 m/s $\frac{+}{+}$			ø
$d_{pc} = \sqrt{1}$	$\frac{9}{2\pi}\frac{\mu V}{NV_i(\rho_p)}$	$\frac{W}{(1-\rho_a)} = \sqrt{\frac{1}{2}}$	$\frac{9}{2\pi} \frac{0.25\mu}{6V_i(\rho_p - \frac{1}{1 + (d_{pc}/d_{pj})^2})}$	$\frac{D}{(\rho_a)} = 5.79$	$0 \times 10^{-6} \mathrm{m} = 5.7$	79 μ m			c
	Size range	Average size	Collection	Mass	Contribution	$\eta = \frac{\sum \eta_j m_j}{M}$	++		
	(1n µm)	$(in \mu m)$	efficiency η	fraction m/M	to performance $\eta \times m / M$	Body Diameter.	1.0	1.0	1.0
	0-2	1	2.9%	0.01	0.029%	D/D Height of Inlet,	0.5	0.44	0.5
	2-4	3	21.1%	0.09	1.903%	H/D Width of Inlet,	0.2	0.21	0.25
	4-6	5	42.7%	0.10	4.268%	W/D Diameter of Gas Exit,	0.5	0.4	0.5
	6-10	8	65.6%	0.30	19.678%	$D_{e'}D$ Length of Vortex Finder, S/D	0.5	0.5	0.625
	10-18	14	85.4%	0.30	25.613%	Length of Body, L_{r}/D	1.5	1.4	2.0
	18-30	24	94.5%	0.14	11.953%	Length of Cone, L/D	2.5	2.5	2.0
	30 - 50	40	97.9%	0.05	4.897%	Diameter of Dust Outlet, D_d/D	0.375	0.4	0.25
	50 - 100	75	99.4%	0.01	0.994%	<u>.</u>			
				1.00	70.6%				

Two distinct approaches in cyclone analysis

1. Performance analysis

The cyclone exists – All dimensions and characteristics are known. The engineer calculates its collection efficiency (η).

2. Design analysis

The cyclone needs to be chosen for a given task. A target performance (η) is imposed. Typically, the engineer knows the amount of air flow (Q), & characteristics of particles (range of d_p 's, mass fractions m_j/M). The engineer needs to determine the type of cyclone needed (conventional, high-throughput, ...) the required size of the device (diameter D).

Note: Design analysis usually necessitates an iterative approach. (Successive guesses until the required performance is achieved.)

Membrane Processes

Environmental Engineering

110401457

Dr. Ahmed Bdour Spring 2020/2021

Membrane Processes - Overview

What is a Membrane?

 The membrane can be defined essentially as a barrier, which separates two phases and restricts transport of various chemicals in a selective manner.

Membrane Separation Technology

- A membrane separation system separates an influent stream into two effluent streams known as the permeate and the concentrate.
- The permeate is the portion of the fluid that has passed through the semi-permeable membrane.
- The concentrate stream contains the constituents that have been rejected by the membrane.



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Membrane Processes - Overview

The main membrane processes are

- Dialysis
- -Electro-dialysis
- -Reverse osmosis

Driving forces that cause mass transfer of solutes are:

- -Difference in concentration (dialysis)
- -Difference in electric potential (electro-dialysis)
- -Difference in pressure (reverse osmosis)

Dialysis

- ≻Theory
 - Dialysis depends on separating solutes of different ionic or molecular size in a solution by means of a selectively permeable membrane.
 - The driving force for dialysis is the difference in the solute concentration across the membrane

The mass transfer of solute through the membrane is given by

$M = KA\Delta C$

- M = mass transferred per unit time (gram/hour)
- K = mass transfer coefficient [gram/(hr-cm²)(gram/cm³)]
- -A = membrane area (cm²)
- $-\Delta C$ = difference in concentration of solute passing through the membrane (gram/cm³)



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Sylvia S. Mader, Inquiry into Life, 8th edition. Copyright © 1997 The McGraw-Hill Companies, Inc. All rights reserved.



Applications of Dialysis

In environmental engineering, Dialysis is not used to an appreciable extent.

- In industrial applications, Dialysis can be used to recover Sodium Hydroxide from textile wastewater.
- Dialysis is limited to small flows due to small mass transfer coefficient (K)

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Electro-Dialysis

>Theory

- This process depends on the presence of an electrical filed across the selectively permeable membrane.
- The driving force is an electromotive force (electrical potential)
- When electromotive force is applied across the permeable membrane:
 - An increased rate of ion transfer will occur
 - This results in decrease in the salt concentration of the treated solution
- The process demineralizes (removes dissolved solids)
 - Brackish water and seawater to produce fresh water
 - Tertiary effluents

How it Works?

> When direct current is applied to electrodes:

- All cations (+vely charged) migrate towards cathode
- All anions (-vely charged) migrate towards anode
- Cations can pass through the cation-permeable membrane (C) but can not pass through (A)
- Anions can pass through the anions-permeable membrane (A) but can not pass through (C)

>Alternate compartments are formed

For the solution of the solution
Ionic concentration in compartments is less than or greater than that in the feed solution



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Reverse osmosis - Defenition

- It is the process of forcing a solvent (like water) from a region of high solute (such as salts of Soudium, Potasium, etc...) concentration through a membrane to a region of low solute concentration by applying a pressure in excess of the osmotic pressure.
- It is the reverse of the normal osmosis process, which is the natural movement of solvent from an area of low solute concentration, through a membrane, to an area of high solute concentration when no external pressure is applied.
- The membrane here is semipermeable, meaning it allows the passage of solvent but not of solute.

Reverse osmosis – How it works

- Reverse osmosis occurs when the water is moved across the membrane against the concentration gradient, from lower concentration to higher concentration.
- To illustrate, imagine a semipermeable membrane with fresh water on one side and a concentrated aqueous solution on the other side. If normal osmosis takes place, the fresh water will cross the membrane to dilute the concentrated solution.
- In reverse osmosis, pressure is exerted on the side with the concentrated solution to force the water molecules across the membrane to the fresh water side.





Reverse osmosis – Osmotic Pressure

The osmotic pressure of solutions of electrolytes may be determined by the following equation:

$$\pi = \phi v \frac{n}{V} RT$$

Where;

- π = osmotic pressure
- φ = osmotic coefficient
- v = number of ions formed from one molecule of electrolyte
- n = number of moles of electrolyte
- V = volume of solvent
- R = universal gas constant
- T = absolute temperature

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Reverse osmosis – Osmotic Pressure

- The osmotic pressure for see water, which has 35,000 mg/l dissolved solids, is 397 psi (2740 kPa) at 25°C.
- It can be assumed that an increase of 1000 mg/l salt concentration results in an increase of approximately 11.3 psi (78 kPa) in osmotic pressure.
- For example, the osmotic pressure of a solution that has 23,000 mg/l of TDS is:

$$\pi = 23,000 \times \frac{11.3}{1000} = 260 \text{ psi}$$

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Reverse osmosis – Flux

- The main design parameter for a reverse osmosis unit are the production per unit area of membrane and water quality.
- The production is measured by the flux of water through the membrane (gal/day-ft² or l/day-m²).
- The flux is related to the pressure by the following equation:

$$F_w = K(\Delta p - \Delta \pi)$$

Where

 F_w = water flux (gal/day-ft² or l/day-m²)

K = mass transfer coefficient (gal/d-ft²-psi or l/d-m²-kPa)

 Δp = pressure difference between feed and product water (psi or kPa)

 $\Delta \pi$ = osmotic pressure difference between feed and product water (psi or kPa)

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Prepared by: Dr. AN Bdour

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Reverse osmosis – Flux

- The membrane flux value furnished by manufacturer is usually for 25°C. Temperature variations causes the flux to vary. Therefore, membrane area correction (A_T/A_{25}) should be considered as the following:
 - For 10°C,1.58; 15°C, 1.34; 20°C, 1.15; 25°C, 1.00; 30°C, 0.84
- The term (A_T/A_{25}) is the ratio of the areas required for temperatures of T°C and 25°C.

Reverse osmosis – Flux

- The flux value will gradually decrease during the lifetime of a membrane which occurs in all membranes and is permanent.
- The membrane must be replaced when the flux has reached the minimum acceptable level set by the membrane manufacturers.
- Usually, the life span of a membrane is from few months to several years.
- Pre-treatment of the raw water is essential to make sure that the membrane serves its design lifetime.
- Pre-treatment includes removal of turbidity and other impurities, adjusting the pH, removal of chlorine for some types of membrane materials, adjusting temperature, etc...

Types of Reverse Osmosis Membranes

The most common membrane materials are polyamide thin film composites (TFC) or cellulose-type membranes.

TFC membranes are:

- More costly, but have greater strength and durability than cellulose-types
- · They have higher total dissolved solids (TDS) rejection rates
- Are more resistant to microbial attack and are more tolerant of high pH
- Deteriorate in chlorinated water.
- Cellulose type membranes are:
 - less costly than TCF membranes
 - Can tolerate chlorine which is commonly used for disinfection of drinking water.
- Another type of membrane is a sulfonated polysulfone (SPS) membrane.
 - tolerant of chlorine and can withstand higher pH levels
 - are more costly than cellulose-types and less effective than TFC membranes
 - SPS membranes can be used in RO systems when the water is soft and pH is high



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Reverse Osmosis - Example

Example 14.2 page 406:

A reverse osmosis unit is to demineralize 760,000 l/d of tertiary treated effluent. Pertinent data are as follows: mass transfer coefficient = $0.2068 \text{ l/(d-m^2)}(\text{kPa})$ at 25°C, pressure between the feed and product water = 2400 kPa, osmotic pressure difference between the feed and product water = 310 kPa, lowest operating temperature = 10° C, and $A_{10C} = 1.58 A_{25C}$. Determine the membrane area required.

Reverse Osmosis - Example

Solution:

The water flux is given by equation (14.6):

 $F_w = K(\Delta p - \Delta \pi)$

 $F_w = [0.2068 \text{ l/(d-m^2)(kPa)}] \times (2400 \text{ kPa} - 310 \text{ kPa})$ = 432.21 l/(d-m²) at 25°C

The area is given by: A = $(760,000 \text{ l/d})/(432.21 \text{ l/(d-m^2)}) = 1758.4 \text{ m}^2 \text{ at } 25^{\circ}\text{C}$

The area at 10°C is given by: $A_T/A_{25} = 1.58$, therefore: A (at T=10°C) = $A_{25 C} \times 1.58 = 1758.4 \times 1.58 = 2780 \text{ m}^2$

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Environmental Engineering CIVE457

The World Federation of Engineering Organizations

WFEO MODEL CODE OF ETHICS

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I. BROAD PRINCIPLES

Ethics is generally understood as the discipline or field of study dealing with moral duty or obligation

- set of governing principles or values which in turn are used to judge the appropriateness of particular conducts or behaviors
- Professions that have been given the privilege and responsibility of self regulation, including the engineering profession, have tended to opt sets of underlying principles as codes of professional ethics which form the basis and framework for responsible professional practice

- The Code is <u>based on broad principles of truth</u>, <u>honesty and trustworthiness</u>, respect for human <u>life and welfare</u>, fairness, openness, competence and accountability
- Issues regarding the environment and sustainable development know no geographical boundaries. The engineers and citizens of all nations should know and respect the environmental ethic. It is desirable therefore that engineers in each nation continue to observe the philosophy of the Principles of Environmental Ethics delineated in Section III of this code

II. PRACTICE PROVISION ETHICS.

Professional engineers shall:

- hold paramount the safety, health and welfare of the public and the protection of both the natural and the built environment in accordance with the Principles of Sustainable Development; ²
- promote health and safety within the workplace;
- offer services, advise on or undertake engineering assignments only in areas of their competence and practice in a careful and diligent manner;
- act as faithful agents of their clients or employers, maintain confidentially and disclose conflicts of interest;

II. PRACTICE PROVISION ETHICS.

- keep themselves informed in order to maintain their competence, strive to advance the body of knowledge within which they practice and provide opportunities for the professional development of their subordinates and fellow practitioners;
- conduct themselves with fairness, and good faith towards clients, colleagues and others, give credit where it is due and accept, as well as give, honest and fair professional criticism;
- be aware of and ensure that clients and employers are made aware of societal and environmental consequences of actions or projects and endeavor to interpret engineering issues to the public in an objective and truthful manner;
- present clearly to employers and clients the possible consequences of overruling or disregarding of engineering decisions or judgments;
- report to their association and/or appropriate agencies any illegal or unethical engineering decisions or practices of engineers or others.

III. ENVIRONMENTAL ENGINEERING ETHICS

- Engineers, as they develop any professional activity, shall:
 - try with the best of their ability, courage, enthusiasm and dedication, to obtain a superior technical achievement, which will contribute to and promote a healthy and agreeable surrounding for all people, in open spaces as well as indoors;
 - strive to accomplish the beneficial objectives of their work with the lowest possible consumption of raw materials and energy and the lowest production of wastes and any kind of pollution;
 - discuss in particular the consequences of their proposals and actions, direct or indirect, immediate or long term, upon the health of people, social equity and the local system of values;

- study thoroughly the environment that will be affected, assess all the impacts that might arise in the structure, dynamics and aesthetics of the ecosystems involved, urbanized or natural, as well as in the pertinent socioeconomic systems, and select the best alternative for development that is both environmentally sound and sustainable;
- promote a clear understanding of the actions required to restore and, if possible, to improve the environment that may be disturbed, and include them in their proposals;
- reject any kind of commitment that involves unfair damages for human surroundings and nature, and aim for the best possible technical, social, and political solution;
- be aware that the principles of eco-systemic interdependence, diversity maintenance, resource recovery and inter-relational harmony form the basis of humankind's continued existence and that each of these bases poses a threshold of sustainability that should not be exceeded.

الرقي بمهنة الهندسة وتمكين المهندسين والمؤسسات الهندسية من الوصول إلى الحلول المُثلي ورفع مستوى الأداء وتشحيع الإيداع والإيتكار لتحقيق مكانة مرموقة	
دولياً، وتعزيز مكانة و كرامة و قيم مهنة الهندسة بما ينعكس على خدمة ورقى ورفاهية المجتمع المبنية على القواعد والأخلاقيات والإلتز امات التالية:) כ
وي معتبي المهنية على كفاءة وجدارة الخدمات التي أقدمها، كما أبتعد عن منافسة الآخرين بشكل غير عادل	.)
أن أسعى لتنمية قدراتي وكفاءتي الشخصية، كما أوفر فرص التطوير المهني للمهندسين و الفنيين العاملين تحت إشر افي	۲.
أن ألتزم بتعزيز القيم والمبادئ الأساسية لأخلاقيات مهنة الهندسة وترسيخها في المجتمع مع التزامي في المجتمع مع التزامي في محادا م	۳_
وكراهة المهنة محلي و علمي . أن أتصرف في المسائل المهنية كوكيل حريص لصاحب العمل ، و أن أتجنب أي تعارض في المصالح .	.٤
أن أحرص عند تقديم أفكاري و أرائي و قراراتي أن تكون بطريقة موضوعية وصادقة وفي مجال تخصصي وخبراتي المهنبة.	.°
أن أسعى عند تقديم خدماتي المهنية إلى الأخذ بأعلى معايير السلامة وحماية البيئة تحقيقا للمصلحة العامة للفرد والمجتمع"	۲.

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- أما قواعد وأخلاقيات ممارسة مهنة الهندسة فهي:
- القاعدة الأولى : يبني المهندس سمعته المهنية على كفاءة وجدارة الخدمات
 التي يقدمها، كما يبتعد عن منافسة الآخرين بشكل غير عادل.
- القاعدة الثانية : يسعى المهندس لتنمية قدراته وكفاءته الشخصية، كما يوفر
 فرص التطوير المهني للمهندسين و الفنيين العاملين تحت إشرافه.
- <u>القاعدة الثالثة</u>: يلتزم المهندس بتعزيز القيم والمبادئ الأساسية لأخلاقيات
 مهنة الهندسة وترسيخها في المجتمع مع إلتزامه في تصرفاته بالأساليب التي تدعم وتعزز مكانة وأمانة وكرامة المهنة محليا و عالميا.
 - القاعدة الرابعة : يتصرف المهندس في المسائل المهنية كوكيل حريص
 لصاحب العمل ، وعليه أن يتجنب أي تعارض في المصالح.
- <u>القاعدة الخامسة</u> : يحرص المهندس عند تقديم أفكاره و أراءه و
 قراراته أن تكون بطريقة موضوعية وصادقة وفي مجال تخصصه وخبراته المهنية.
- القاعدة السادسة
 يسعى المهندس عند تقديم خدماته المهنية إلى الأخذ
 بأعلى معايير السلامة وحماية البيئة تحقيقا للمصلحة العامة للفرد و المجتمع.