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INTEGRATED WASTE MANAGEMENT FOR A SMART CITY

FOCUSSED ON MSW, C&D AND E-WASTE MANAGEMENT

BRAJESH KUMAR DUBEY
DEPARTMENT OF CIVIL ENGINEERING

Method for Calculating the Heating Value of a Waste: Dulong Equation

$$BTU/lb = 145C + 610(H - \frac{1}{8}O) + 40S + 10N$$

C, H, O, S, N are percent of those elements respectively

Do not factor in water as part of the hydrogen and oxygen content. Factor water separately.

During this week (Week-3)

- Municipal Solid Waste Characteristics – Continued from previous week
- Example problems, data analysis, statistics
- Solid Waste Management Rules -2016

Example: What is the Heat Value of PVC

PVC = $C_2H_1Cl_1$

$$\%C = \left[\frac{2(12)}{2(12)+1(1)+1(35.45)}\right] = 39.7\%$$

$$\%H = \left[\frac{1(1)}{2(12)+1(1)+1(35.45)}\right] = 1.65\%$$

Conceptual Waste Composition for Combustion Potential Characterization

The fixed carbon content is the carbon found in the material which is left after volatile materials are driven off.

- Plug into Dulong Equation:

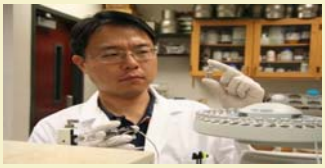
$$BTU/lb = 145(39.7) + 610(1.65)$$
$$= 6763\ BTU/lb$$

Example Heat Values

Item	BTU/lb
Wood	4700-7000
MSW	5000-6200
Paper	7000-8000
Tires	14000

How do you measure concentration?

- Must use a chemical test method
- RCRA chemical test methods: SW846
- ASTM Methods
- Standard Methods for Water and Wastewater (AWWA)



Waste characterization by chemical methods

Objective of Chemical Analysis

- Determine the "amount" of a chemical of interest that occurs in a particular environmental sample
- How do you measure *amount*?
  - Concentration (mg/L, mg/kg, ppm, ppb)
  - Fraction or percent
  - Wet or dry basis

Chemical Composition

- Waste may be characterized by specific chemicals:
  - e.g. paper
    - cellulose
    - hemicellulose
    - lignin
  - e.g. Hazardous Waste Sludge
    - TCE, Benzene, lead, arsenic etc.

Concentration Units

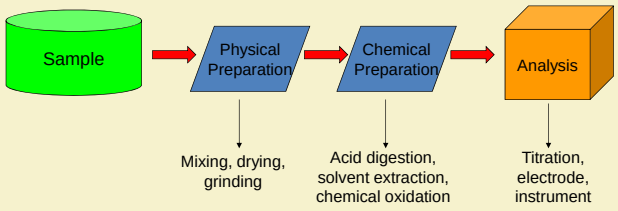
- Most common concentration units encountered:
  - mg/L (liquids, wastewaters)
  - mg/kg (solids, soils)
- Note: mg/L = ppm; mg/kg = ppm
- Note: 1% = 10,000 ppm

You need to be familiar with the use of ppm and ppb, but it is always best to use the actual units when possible (to avoid confusion).

Chemical Analysis Procedures

- Direct chemical measurement
  - Titration of sample for alkalinity or hardness
- Use of a sensor or an instrument
  - pH meter, chromatograph
- In many, some form of sample "preparation" will be necessary

Sample Preparation & analysis



स्वच्छ भारत
एक कदम स्वच्छता की ओर

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Methods

- How do you know which methods to use?
- Often spelled out directly in the regulations.
- Several standardized method collections
  - Standard methods
  - SW-846
  - ASTM (formerly American Society for Testing and Materials)

Chemical Analysis Procedures

- Direct chemical measurement
  - Titration of sample for alkalinity or hardness
- Use of a sensor or an instrument
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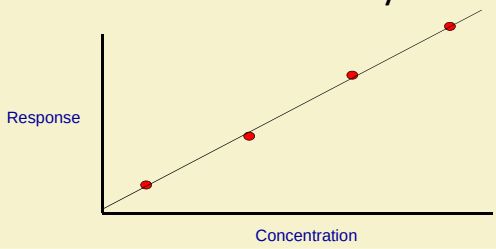
Instrumental Analysis

- Many different instruments have been developed to measure the concentration of pollutants in environmental samples
- These instruments give a "response" that correlates the amount of sample present
- Responses:
  - Increase in conductivity
  - Absorbance of light
  - Emission of light

Instrumental Analysis



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Quality Assurance / Quality Control (QA/QC) Plan

QA project plans are list of detailed activities performed at each stage of the dredged material evaluation and outline project-specific data quality objectives that should be archived for field observations and measurements, physical analyses, laboratory chemical analyses, and biological tests.

- Standard Operating Procedures
- Sampling strategy and procedures
- Sample custody
- Calibration procedure and frequency
- Analytical procedures
- Data validation, reduction and reporting
- Internal QC checks
- Performance and system audits
- Preventive maintenance
- Calculation of data quality indicators
- Corrective actions

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Instrumental Analysis

- Spectrophotometers – Measure absorption of light at specific wavelengths
- Some chemicals are directly proportional to absorbance
- Many methods that were developed based on color changes in titrations can be measured using absorbance

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Quality Control/Quality Assurance

- QA/QC
- Designed to make sure that the data you gather are sufficiently accurate, precise, and repeatable
- Mechanisms
  - Blanks
  - Spikes
  - Replicates

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Method Detection Limit (MDL)

- "The minimum concentration of a substance that can be measured and reported with 99% confidence that the analyte concentration is greater than zero and is determined from analysis of a sample in a given matrix type containing the analyte" (EPA, 1992)

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Method Detection Limit (MDL)

- MDL = $t_{(n-1, \alpha=0.99)}(S)$

where,

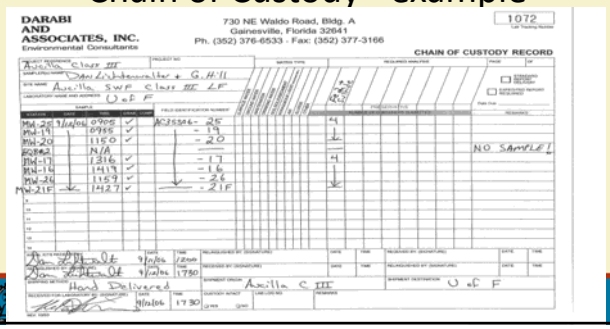
$t_{(n-1, \alpha=0.99)}$ = one-sided critical t-value at 99% level

n = number of sample

S = standard deviation

MDL can be calculated by multiplying standard deviation by one sided critical t-value at 99% level. Different t-value should be applied by number of sample. EPA recommends that number of sample would be greater than 7 to make MDL confident.

Chain of Custody - example


DARABI AND ASSOCIATES, INC.
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Ph. (352) 376-6533 · Fax: (352) 377-3166
CHAIN OF CUSTODY RECORD
1072

Method Detection Limit (MDL) - example

Sample No.	Analysis results (mg/L)
1	12.11
2	12.02
3	12.21
4	12.06
5	12.57
6	12.42
7	12.09
8	12.32

Ion Exchange Chromatograph

Ion exchange chromatograph is used to analyze liquid samples for dissolved ionic or polar materials by charge properties

Method Detection Limit (MDL) - example

- N = 8
- Standard deviation = 0.19
- $t_{(7, \alpha=0.99)}$ = 3.00

MDL = 0.19 X 3.00 = 0.57 mg/L

MDL at given results is 0.57 mg/L. It indicates that 0.57 mg/L would be minimum concentration you can trust with 99% confidence level.

Gas Chromatograph

Gas chromatograph is an instrument to separate complex gas or liquid samples to single components. Injected samples are separated in gas phase (mobile phase) through the column. Separated components are detected by various types of detector such as flame-ionized detector (FID) and thermal conductivity detector (TCD).

Gas Chromatograph / Mass Spectrometry

GC/MS is a GC equipped with mass spectrometry as a detector. After complex chemicals are separated through a GC column, separated components are fragmented by high energy source in a mass spectrometry. With size and patterns of fragments, components can be identified.

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Inductively Coupled Plasma (ICP)

ICP-AES is used to analyze elements such as heavy metals and cations using an inductively coupled plasma (ICP).

Each element can be recognized by electromagnetic radiation produced by excited atoms at a wavelength of a particular element.

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High-Performance Liquid Chromatograph (HPLC)

Like other chromatograph, an HPLC is also used to separate complex chemicals to single components. Unlike a GC, HPLC uses liquid as a mobile phase. Separated components can be detected by UV-Vis absorbance detector. Since an HPLC can handle only liquid sample, more complex and greater molecular-weight chemicals can be analyzed.

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Atomic Absorption Spectrometer

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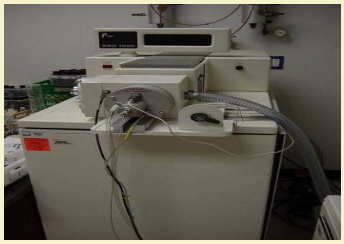
Liquid Chromatograph /Mass Spectrometry



Like GC-MS, LC-MS is a LC equipped with mass spectrometry as a detector. An LC-MS can be used to analyze large molecules such as pharmaceutical products and protein.

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Working with Concentrations

- Must be able to convert from chemical concentration based on dry weight and chemical concentration based on wet (or total) weight.

Example

- You have two waste components:

Sludge, 100 mg/kg (wet) Pb
Solids Content = 10%

Wood Chips, 300 mg/kg (wet) Pb
Moisture Content = 20%

Example

- Sludge has a total arsenic concentration of 0.6 mg/kg based on total weight.
- Moisture content of sludge is 80%
- Dry weight arsenic concentration is:

$$\frac{0.6\ mg\ arsenic}{1\ kg\ wet\ sludge} \times \frac{1\ kg\ wet\ sludge}{0.2\ kg\ dry\ sludge} = 3.0 \frac{mg\ As}{kg\ dry\ sludge}$$

Example (continued)

- If you mix the components in a 50/50 mix by total weight, what is the Pb concentration in the dry sludge?

Working with Concentrations

- You should be able to find the average concentration of mixed waste streams

Example (continued)

$$\frac{\frac{100\ mg\ Pb}{1\ kg\ wet\ sludge} \times 50\ kg\ wet\ sludge + \frac{300\ mg\ Pb}{1\ kg\ wet\ wood} \times 50\ kg\ wet\ wood}{50\ kg\ wet\ sludge \times \frac{0.1\ kg\ dry\ sludge}{1\ kg\ wet\ sludge} + 50\ kg\ wet\ wood \times \frac{0.8\ kg\ dry\ wood}{1\ kg\ wet\ wood}}$$

$$X = 444 \frac{mg\ Pb}{kg\ dry\ waste}$$

Working with Concentrations

- Must be able to go back and forth between "total" and "leachable" concentrations.

Example (continued)

$$\frac{X\ mg\ Pb}{1\ kg\ soil} \times \frac{0.1\ kg\ soil}{2\ L\ Leachate} = 5.0\ \frac{mg\ Pb}{L}$$

$$X = 100\ \frac{mg\ Pb}{kg\ soil}$$

Example

- You have a soil contaminated with lead based paint debris.
- Below what total concentration (mg/kg) would you know that the soil is not a toxicity characteristic hazardous waste for lead?

Note

- You could do the same thing for SPLP and compare to groundwater standards
- You could also assume that only a fraction leached
- You could calculate the opposite direction

Example (continued)

- Toxicity Characteristic Concentration for lead = 5 mg/l
- TCLP uses 100 g of waste and 2,000 g (2 L) of leaching fluid (20:1 liquid to solid ratio)

Statistical Calculations are Often Needed when Working with Concentrations

- Since concentration results are often directly used as part of regulatory decision-making (i.e. is it a hazardous waste, is it a safe to be land applied), it is necessary to perform a statistical analysis.

What is the Chemical Concentration of a Waste?

- Very rarely are wastes or contaminated soils completely homogenous with respect to chemical concentration.
- You must collect and analysis multiple samples to determine what some "representative" concentration is.
- The more heterogeneous the matrix, the more samples may be needed to accurately describe the "representative" concentration.

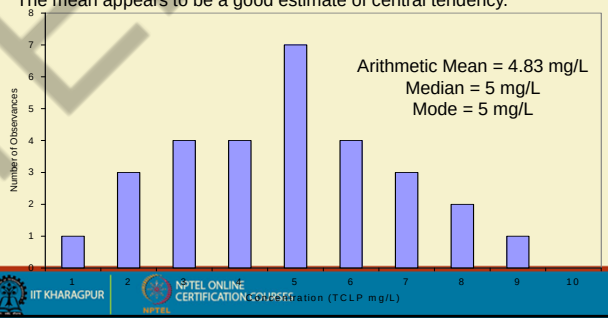
The Type of Distribution Dictates How You Calculate the Central Tendency

- Consider the following data set for some TCLP results (in mg/L)
  - 3, 2, 3, 5, 4, 4, 5, 7, 8, 1, 6, 2, 5, 9, 6, 5, 7, 7, 3, 4, 2, 8, 5, 4, 5, 6, 6, 3, 5
  - N = 29

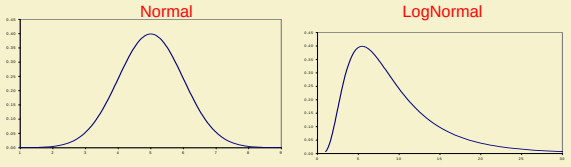
What is the Representative Concentration?

- Some estimate of the central tendency
  - The mean (the average)
  - The median (the middle number)
  - The mode (the most common number)
  - Some upper or lower confidence limit
- Must consider
  - The sample distribution
  - What the data will be used for

The resulting histogram has a similar shape as a normal distribution. The mean appears to be a good estimate of central tendency.



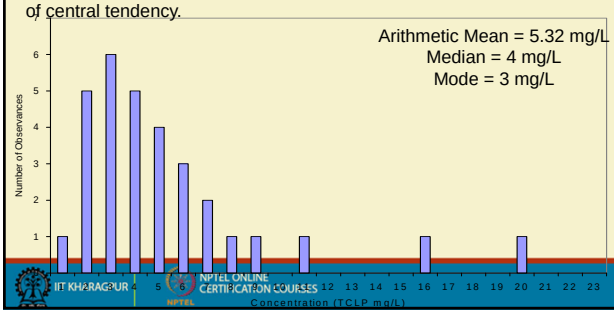
Sample Distributions



The Type of Distribution Dictates How You Calculate the Central Tendency

- Consider a different data set, again for some TCLP results (in mg/L)
  - 3, 5, 2, 5, 3, 3, 4, 3, 7, 1, 7, 2, 4, 9, 5, 5, 11, 6, 2, 6, 2, 8, 4, 2, 4, 6, 16, 4, 20, 3, 3
  - N = 31

The resulting histogram gives the appearance that it might be a log-normal distribution. The mean appears to be somewhat less reliable as an estimate of central tendency.



Previous Data Sets

- Data set II
  - Arithmetic mean = 5.32 mg/L
  - Standard deviation = 4.10
  - Variance = 16.8
- It is likely that the data are not normally distributed

It is Important to Check for Normalcy

- A quick test may be used to assess whether the data are normally distributed:
- Is the mean greater than the standard deviation and the variance?
- If the mean is not greater than both, the data set is probably not normally distributed.

How Do You Handle Data that are Not Normal?

- First step, check to see whether the data are log-normally distributed
- Environmental data are often log-normally distributed
- Perform a log transform on the data and check for normality again.

Previous Data Sets

- Data set I
  - Arithmetic mean = 4.83 mg/L
  - Standard deviation = 2.0
  - Variance = 4.0
- It is likely that the data are normally distributed

Transformed Data

- Transformed Data Set #2
  - Arithmetic mean = 1.46
  - Standard deviation = 0.65
  - Variance = 0.42
- The mean of the transformed data is greater than the standard deviation and variation of the transformed data. It is thus reasonable to treat the original data as log-normally distributed.

Geometric Mean

- When the mean of the transformed data is transformed back, this is known as the geometric mean.
  - Geometric mean of data set II: 4.28 mg/L

Incorporating Uncertainty

- We need to factor in this uncertainty.
- Calculate the upper confidence limit (UCL).
- The UCL is a conservative estimate of the mean that takes into account uncertainties in the data set.
- It is associated with some degree of statistical significance, e.g., 95% UCL.

What if the Data are Neither Normally or Log-Normally Distributed?

- Find another distribution
- Use a more advanced statistical method (e.g. a nonparametric method)

$$UCL_{1-\alpha} = \text{Mean} + t_{\alpha, n-1} \frac{\text{Standard Deviation}}{\sqrt{\text{number of samples}}}$$

Student t statistic

Incorporating Uncertainty

- Assume that the TCLP results presented for data sets 1 and 2 were for lead. The TC limit is 5 mg/L.
- The arithmetic mean for data set I (4.83 mg/L) and the geometric mean for data set II (4.28 mg/L) were less than 5 mg/L.
- These were based on a limited number of samples, and thus may be somewhat different than the true mean.

Example

- For data set I, find UCL at 95%.

Note: Higher than TC Limit

$$UCL_{1-0.05} = 4.83 + 1.701 \frac{2.0}{\sqrt{29}} = 5.46$$

T statistic at 0.05 level and 28 degrees of freedom

Example

- For data set II, find UCL at 95%.
  We must used transformed data.

$$UCL_{1-0.05} = 1.46 + 1.697 \frac{0.65}{\sqrt{31}} = 1.65$$

$$e^{1.65} = 5.19$$

T statistic at 0.05 level and 30 degrees of freedom

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Data Below the Detection Limit

- In many cases, sample results will be below the analytical instrument's detection limit.
- If you have BDLs in your sample set, you must handle them appropriately with statistics. You can not just neglect them; they say something valuable about the data.

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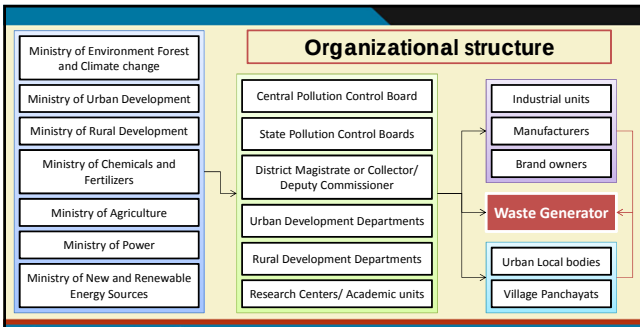
Options for Handling Samples Below the Detection Limit

- Assume to be zero
- Assume to be the detection limit
- Assume to be ½ the detection limit
- Other more rigorous statistical approaches

Organizational structure



Areas of Application	Waste Generators
Urban local body (ULB), Census towns, Notified areas and industrial townships	Every household
Areas under the control of **Indian Railways**, **Ports** and **harbours, airports/ airbases**	Event organizers
State and Central government organisations **special economic zones**, Defence establishments	Street Vendors
Places of **pilgrims** and **religious and historical importance** as may be notified by respective State government from time to time	Market Associations
Every domestic, institutional, commercial and any other non residential solid waste generator situated in the areas.	Hotels and restaurants
	Resident welfare Associations
	Gated Community having area more than 5000 sq.m

Duties of waste generators

- ***segregate and store the waste generated*** by them in three separate streams namely bio-degradable, non biodegradable and domestic hazardous wastes.
- The ***sanitary waste*** should ***wrapped in the pouches*** provided by the manufacturers or brand owners shall placed in the bin meant for dry waste or non- bio-degradable waste;
- No waste generator ***shall throw, burn or burry the solid waste generated by him, on streets, open public spaces*** outside his premises or in the ***drain or water bodies***.

Duties of waste generators

- **Construction and demolition waste** generated in their premises shall be disposed as per C&D waste rules 2016.
- **Horticulture waste and garden waste** as and when generated, in his own premises and shall be disposed as per the instructions of local bodies.
- Every **street vendor** shall keep **suitable containers for storage of waste generated** during the course of his activity and shall deposit such waste at waste storage depot or container or vehicle as notified by the local body.

Duties of waste generators

- All waste generators shall ***pay such user fee*** for solid waste management, as specified in the bye-laws of the local bodies.
- No person shall ***organize an event or gathering*** of more than ***one hundred persons*** at any unlicensed place
  - without intimating the local body, at ***least three working days*** in advance
  - The organiser of such event shall ensure ***segregation of waste at source***
  - Further, ***hand over segregated waste*** to waste collector or agency as specified by the local body.

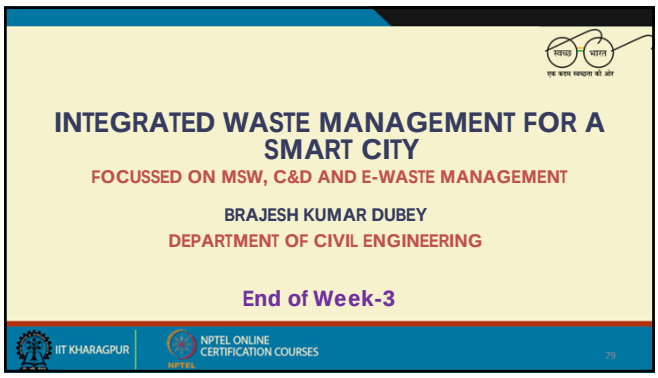
Duties of waste generators

- **Resident welfare** and **market associations**, **gated communities** and **institutions** with more than ***5,000 sqm area***, **hotels and restaurants** in partnership with the local body should ensure
  - segregation of waste at source as prescribed in these rule
  - Facilitate collection of ***segregated waste in separate stream***
  - Handover ***recyclable material*** to either authorised waste pickers or recyclers.
  - The ***bio-degradable waste*** shall be processed, treated and disposed off through ***composting or bio-methanation*** within the premises.
  - The ***residual waste*** shall be given to the **waste collectors or agency** as directed by the local body.

Duties of MoEF &CC

- The Ministry shall be responsible for over all ***monitoring the implementation*** of these rules in the country.
- It shall constitute a ***Central Monitoring Committee*** under the ***Chairmanship of Secretary***, MoEF &CC, comprising officer not below the rank of Joint Secretary or Advisor
- This Committee shall meet at least ***once in a year*** to monitor and review the progress. The Committee shall be ***renewed every three years***.

Central Monitoring Committee members	
Ministry of Urban Development	Urban Development Departments of three State Governments by rotation
Ministry of Rural Development	Three Urban Local bodies by rotation
Ministry of Chemicals and Fertilizers	Two census towns by rotation by rotation
Ministry of Agriculture	Two subject experts, FICCI and CII
Central Pollution Control Board	Rural Development Departments from two State Governments by rotation
Three State Pollution Control Boards or Pollution Control Committees by rotation	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