Problem solving in solid waste engineering

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Preface

Many books and text material are to be found addressing solid waste generation sources, methods of collection, treatment technology, reuse and final disposal. Nevertheless, rather very few, if any, books deal with practical problems of municipal solid waste and solutions.

This book has been written to cover material outlined in the 3-credit hour course of “solid and hazardous waste management, ENV-462” for senior fourth year engineering students of the Environmental Engineering Department of the College Of Engineering At Dammam University. The named course contents included: Types and sources of solid waste; chemical and physical properties of municipal and industrial refuse; solid waste collection methods; solid waste treatment and disposal techniques with emphasis on: landfill disposal, incineration, composting and pyrolysis; salvage, reclaiming, and recycle operations; economics of disposal methods; advantages and disadvantages of each; special and hazardous waste handling; operation and management of solid and hazardous waste programs.

Objectives of the book are intended to fulfill the main learning outcomes for students enrolled in the course, which included the following:

- Enlighten the state of the art in technology, organizational and legislative developments and practices of handling solid wastes.
- Discussing in depth financial burdens of municipal solid waste and benefits as well as solutions.
- Help students to make informed decisions in their professional activities. Thus, assisting them in defining and implementing integrated solutions to the challenges posed by solid wastes in an urban environment.
- Support students to establish a solid waste management, SWM, system that is capable of functioning not only in situations where sufficient resources are available but also under the more challenging conditions usually prevailing in large cities in low-income countries.
- Acquisition of knowledge by learning new concepts in solid waste management, final disposal, recycling and reuse.
- Cognitive skills through critical thinking and problem solving.
- Numerical skills through application of knowledge in basic solid waste kinetics and mathematical models.
- Student becomes responsible for their own learning through solution of assignments, home works, exercises and report writing.

Knowledge to be acquired from the course is expected to incorporate:

- Quantifying and characterizing MSW in the Kingdom of Saudi Arabia, KSA, and to understand properties commonly associated with MSW.
- Describing tasks and logistics of MSW collection, to analyze collection systems, and to become familiar with principals and theory behind the use of transfer stations.
- Describing the components of a sanitary landfill and processes which take place in a landfill aerobic reactor.

- Doing basic design calculations associated with MSW systems.
- Describing the most common waste processing techniques and their application areas.
- Identifying concepts of MSW reduction, reuse and recycling.
- Develop a strategy to deal with special wastes, hazardous and health care wastes.
- Knowledge of behavior and properties of solid wastes and concepts of engineering control and treatment principles.
- Collection of data, analysis and interpretation.

Cognitive skills to be developed are expected to incorporate the following:

- Capturing ability of reasonable scientific judgment and concepts of appropriate decision making.
- Students will be able to apply the knowledge of behavior and properties of solid waste materials that they have learnt in this course in a practical environmental engineering domain.
- Students should be able to design and apply necessary procedures and precautions to produce durable and environmentally usable solid waste products.
- Students will be able to understand the use and application of control materials and components in solid waste collection, treatment, disposal and integrated management.

Solid waste and garbage disposal constitutes a huge responsibility for the producer, community and governmental municipality or authority responsible for its collection, sorting, treatment and final disposal. If the concerned authority did not have good management for its disposal, it exposes itself to environmental, political, economic and social problems. This is due to many interrelated factors such as:

- Quantity produced
  - Garbage piles up on roads, streets and parks producing foul odors.
- Social disturbances
  - MSW causes great inconvenience to residents, neighboring area and surroundings.
  - Hurt sightseeing.
  - Expel tourists and limit their entry to the region.
  - Disturbs peace and coexistence of collective tribal in rural areas, villages and cities.
  - Unpleasant and undesirable odors resulting from bacterial decomposition of organic materials of components of the waste.
- Health problems
  - Harm workers and patrons.
  - Introduces sickness to children and animals.
  - Breeding areas for rats, mice, vermin, fleas and flies and vectors that transmit infectious diseases, and outbreaks of diseases such as plague.
  - Endemic and epidemic, raising rates of death, destruction, and loss of crops and cattle.
  - Direct and indirect spread of epidemics and diseases through waste accumulation in settlements (plague, malaria, dengue fever, typhus, cholera).
  - Burning of solid waste leads to increased air pollution and respiratory diseases.
- Engineering malfunctions

    - Disrupt traffic.
    - Risk of flooding and contamination of water resources.
- Environmental concerns
    - Introduces pollutants and contaminants to waterways.
    - Ill environmental impact and pollution of water, air and soil.
    - Environmental pollution resulting from household waste, street cleaning and dumps areas .... etc..
    - Bio-chemical and microbiological pollution of ground and surface water due to unregulated disposal of waste.
    - Air pollution and the presence of organic and inorganic toxic materials, especially in industrial solid waste.

"Problem solving in solid waste engineering" is primarily designed as a supplement and a complementary guide to municipal solid waste engineering. Nonetheless, it can be used as an independent problem solving text in solid waste collection, treatment and disposal. The book targets university students and solid waste engineering candidates taking first degree courses in environmental, civil, mechanical, construction and chemical engineering or related fields. The manuscript is expected to be of beneficial use to postgraduate students and professional engineers. Likewise, it is hoped that the book will stimulate problem solving learning and facilitate self-teaching. By writing such a script it is hoped that the included worked examples and problems will ensure that the booklet is a valuable aid to student-centered learning. To achieve such objectives immense care was taken to present solutions to selected problems in a clear and distinct format using step-by-step procedure and explanation of the related solution utilizing necessary methods, approaches, equations, data, figures and calculations.

The author is grateful to all those authors, writers, researchers and scientists whose methods, procedures, techniques and models have been used throughout the text for solving worked examples. The author acknowledges the inspiration, motivation and stimulus help offered to him by Dean Dr. Abdul-Rahman ben Salih Hariri, Dean College of Engineering of University of Dammam. The author is very fortunate, blessed and thankful to have had such[1] a bright, smart and dedicated group and class of students. Their existence, enthusiasm and dedication inspired teaching. Besides, it has been a real pleasure and enjoyment advising and mentoring such fine young promising future scientists. Special and sincere vote of thanks would go to Mr. Mugbil ben Abdullahi Al-Rowais the director of Dammam University Press and his supreme technical staff for the neat typing of the book.

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Al-Thugba, AlKhobar, October 2012

[1] Abdulaziz Al-Abdulkarim, Abdullah Al-Hamed, Abdulaziz Al-Qahtani, Abdulaziz Al-Ghawinem, Abdullah Al-Khamis, Ahmed Al-Safi, Ibrahim Al-Rashid, Ibrahim Al-Shaygi, Mohammed Al-Hosan, Mohamed Al-Khadra, Muhammed Al-Rayaan, Naif Al-Qahtani, Saad Al-Qahtani, Shaheen Al-Dossary, Sultan Al-Rubaish.

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Chapter One
Solid waste classification and quantities

Solid waste may be defined as a heterogeneous mass of throwaways from the urban community, as well as the more homogeneous accumulations of agricultural, industrial and mineral wastes. Otherwise it may be defined as materials that do not represent major outputs of market product, and serve no productive or consumptive purpose to its producer, which justifies its disposal. Generally, a solid waste represents those things which are unwanted, useless and not needed by someone.

There are many sources of solid waste, garbage and sweeping which include: agriculture, mining, building and construction, industry, housing, homes, offices, open markets, restaurants, hospitals, shops, educational institutions ... etc. Solid waste may be classified as:

- Municipal solid waste from a community, MSW, having mixed household and residential waste, garbage, food waste and recyclables (such as: newspapers, aluminum cans, milk cartons, plastic soft drink bottles, steel cans, corrugated cardboard, other material collected by the community).
- Household hazardous waste.
- Commercial waste which may contain many of the same items as generated by household waste. It can arise from design health facilities, hotels, maintenance workshops and warehouses, markets, offices, stores, shops, printing institutions, rest houses, restaurants … etc.
- Yard (or green) waste originating with individual households and animal waste.
- Street refuse, litter and waste from community trash cans produced by individuals, cleanliness of streets, streets, parks and playgrounds sweeping, thrown on the side of the road from users (sweeping), municipal containers, debris and rubble, dead animals (small animals such as: cats and dogs, and big animals such as: horses, sheep, donkeys and cattle), damaged cars placed on both sides of the road.
- Bulky refuse items and white waste (Such as: bicycles, furniture, old and used cars, damaged vehicles, refrigerators and gas and electric stoves, rugs, etc.).
- Construction and demolition waste and ruins of buildings..
- Industrial refuse from places of construction, manufacturing, Sources of metals production and processing, mining, refineries, chemical plants and power plants. It may contain bricks, concrete, dust, stones, mortar, outputs of: refrigeration and air conditioning, plumbing, electricity, water and phone ... etc.
- Solid waste from waste treatment, purification plants, industrial wastewater treatment processes and air pollution control plants.
- Hazardous waste from radioactive materials, chemical, biomaterial, hospitals and medical waste, pathological and infectious, remains of experimental animals, corpses, remnants of drugs, poisons and chemicals and containers
- Agriculture waste, field crops and different farm types from: planting, harvesting of fields, livestock farms producing dairy, meat, slaughterhouses ... etc.

- Other products of the information revolution from damaged computers, peripherals and software CDs, CD-plastic ... etc..

Table (1.1) gives examples of main sources and types of production units of solid waste and garbage.

Table (1.1): Sources and types of production units of solid waste [2,4,6,10,24,25,46].

Source of waste	Production units	Type of solid waste
Residential/Domestic/ municipal	Single-family, multi-family dwellings, houses, low-medium-, and high rise apartments, villa, and housing.	Food waste, rubbish, garbage, ashes, special waste.
Commercial	Stores, shops, restaurants, markets, office buildings, motels, print shops, auto repair shops, medical facilities, …etc.	Food waste, rubbish, ashes, demolition and construction waste, special waste, hazardous waste.
Industrial	Construction, fabrication, light and heavy manufacturing, oil refineries, chemical plants, mining, logging, power plants, demolition, …etc.	Food waste, rubbish, ashes, demolition and construction wastes, special waste, hazardous waste.
Square and open areas	Roads, streets, alleys, parks, playgrounds, beaches, bathing and recreational areas, squares, highways, gardens	Special waste, rubbish.
Agricultural	Field and row crops, fruit orchards vineyards squares, diaries, butter and cheese, laboratories experimental fields, feedlots, farms, … etc.	Spoiled food wastes, agricultural waste, rubbish, hazardous materials.
Treatment plant sites	Water, wastewater, industrial treatment processes, … etc.	Treatment plant wastes, principally composed of residual sludges.

Equation 1.1 gives a rough estimate for amount of municipal solid waste or refuse generated from a community.

MSW, municipal solid waste = (refuse) + construction and demolition waste + leaves + bulky items (1.1)

or,

$$(MSW) = (refuse) + (C\ and\ D\ waste) + (leaves) + (bulky\ items) \quad (1.2)$$

Refuse can be defined in terms of as-generated and as-collected solid waste. The refuse generated includes all of the wastes produced by a household. Often some part of the refuse, especially organic matter and yard waste, is composted on premises. The fraction of refuse that is generated but not collected is called diverted refuse. The as-generated refuse is always larger than the as-collected refuse, and the difference is the diverted refuse, see equation 1.3.

$$(As\text{-}generated\ refuse) = (As\text{-}collected\ refuse) + (Diverted\ refuse) \quad (1.3)$$

Example (1.1)

A certain community produces the following quantities of solid waste on an annual basis:

Fraction	Tons per year
Mixed house waste	250
Recyclables	30
Commercial waste	50
Construction and demolition debris	135
Leaves and miscellaneous	40

Generated recyclables are collected separately and processed at a materials recovery plant. Both mixed household and commercial wastes are taken to the municipality landfill, as do the leaves and miscellaneous solid wastes. The C and D wastes are used to fill a large ravine. Calculate percentage of diversion.

Solution

1) Given: MSW annual quantities in tons.
2) If the calculation is on the basis of MSW, the total waste generated is 505 tons per year. If everything not going to the landfill is counted as having been diverted, the diversion is calculated as
$$\text{Diversion} = \frac{(30+135+40)}{505} \text{x}100 = 41\%$$
3) This is an impressive diversion. But if the diversion is calculated as that fraction of the refuse (mixed household and commercial waste) that has been kept out of the landfill by the recycling program, the diversion is
$$\text{Diversion} = \frac{(30)}{250+50} \text{x}100 = 10\%$$
4) This is not nearly as impressive, but a great deal more honest.

Exercise (1.1)

1) Select a short research project on solid waste for a certain locality (municipal, industrial, commercial, agricultural, hazardous ... etc.). Write briefly about the following:
   - Selection of research topic and justification.
   - Research objectives, hypothesis and assumptions

- Research methodology
- Materials and methods for selected research area with emphasis on: SW sources and characteristics, collection, segregation, sorting, treatment, final disposal and reuse and recycling.
- Results and discussions
- Conclusions and recommendations
- References.

Exercise (1.2)

1) A community produces the following on an annual basis:

Fraction	Tons per year
Mixed house waste	230
Recyclables	25
Commercial waste	45
Construction and demolition debris, C&D	120
Leaves and miscellaneous	50
Treatment plant sludges	5

The recyclables are collected separately and processed at a materials recovery facility. The mixed household waste and the commercial waste go to the landfill, as do the leaves and miscellaneous solid wastes. The sludges are dried and applied on land (not into the landfill), and the C & D wastes are used to fill a large ravine. Calculate the diversion**.**

Chapter Two
Municipal solid waste properties

Properties of solid waste affect design of solid waste collection systems, treatment and disposal, operation, management and performance of units. Valuable MSW properties may constitute: physical, chemical and biological properties. Physical and material properties of solid waste affect design of storage equipment, its transfer, transpiration and treatment. They may include: grain size, material components, use of material, degree of purity, contents of solid waste, moisture content, grain size calorific value, density, mechanical properties, degree of decomposition … etc.. Chemical properties may include: chemical composition, chemical content … etc.

Benefits of MSW properties may be summarized as follows:

- Quantifying amounts of waste and hazardous materials generated when considering disposal by landfilling.
- Assessment of useful organic materials for production of beneficial gas.
- Estimating amount of energy when recycling or if materials or energy recovery by combustion is the objective.
- Knowledge of hazardous and harmful substances that may be present in solid waste for its sorting and disposal.
- Knowledge of useful material for incineration and energy access.

Properties of MSW of significance and interest include the following:

1) Physical properties:
    a. Composition by identifiable items (steel cans, office paper, etc.).
    b. Weight.
    c. Moisture content.
    d. Particle size and grain size distribution.
    e. Heat and calorific value.
    f. Density.
    g. Angle of stability.
    h. Mechanical properties to evaluate alternative processes and options for energy recovery by focusing on: pressure stress, stress-strain curve for some materials and modulus of elasticity.
2) Chemical properties:
    a. Chemical composition: carbon, hydrogen, concentration of metals.
    b. Proximate analysis.
    c. Fusing point of ash.
    d. Ultimate analysis (major elements).
    e. Compositional analysis.
    f. Calorimetry.
    g. Energy content.
    h. Volatile solids lost upon ignition.
    i. pH value.

j. Toxic elements.
k. Nutrients (carbon, nitrogen and phosphorus).
3) Biological properties (biodegradability).

1) Physical properties of solid waste

Moisture content

The moisture content becomes important when the refuse is processed into fuel or when it is fired directly. Moisture content influences many MSW properties of importance. The extent of this effect depends on the material. When the moisture level exceeds 50%, the high organic fraction can undergo spontaneous combustion if the material is allowed to stand undisturbed.

Moisture content, on wet basis, is found as presented in equation 2.1.

$$M = \frac{W_w - W_d}{w_w} \times 100 \qquad (2.1)$$

Where:
M = Moisture content, percent (on a wet basis), %
W_w = Initial (wet) weight of sample.
W_d = Final (dry) weight of the sample.

Moisture content may be evaluated on a dry weight basis as shown in equation 2.2.

$$M_d = \frac{W_w - W_d}{w_d} \times 100 \qquad (2.2)$$

Where:
M_d = Moisture content, percent (on a dry basis), %

Table (2.1) gives moisture content of uncompacted refuse components.

Table (2.1): Moisture content of uncompacted refuse components [2,6,10,24,25,46].

component	Moisture content	
	Range	Typical
Residential		
Aluminum cans	2 - 4	3
Cardboard	4 - 8	5
Fines (dirt, etc.)	6 - 12	8
Food waste	50 - 80	70
Glass	1 - 4	2
Grass	40 - 80	60
Leather	8 - 12	10
Non-ferrous Metal	2 - 4	2
Leaves	20 - 40	30
Paper	4 - 10	6
Plastics	1 - 4	2
Ferrous metals	2 - 6	3
Rubber	1 - 4	2
Steel cans	2 - 4	3
Textiles	6 - 15	10
Wood	15 - 40	20
Yard waste	30 - 80	60
Garden trimmings	30 - 80	60
Commercial		
Food waste	50 - 80	70
Mixed organics	10 - 60	25
Mixed	10 - 25	15
Wooden shipping crates and plant scales	10 - 30	30
Construction (mixed)	2 - 15	8
Dirt, ashes, bricks ... Etc.	6 - 12	8
Municipal waste	15 - 40	

Example (2.1)

A residential waste has the components presented in the table. Estimate its moisture concentration using the typical values.

Component	%
Tin cans	10
Paper	40
Rubber	20
Food waste	20
Garden waste	10

Solution

1) Given: Waste components and percent moisture.
2) Assume a wet sample weighing 100 lb. Set up the tabulation below:

Component	Percent	Moisture from table	Dry weight (based on 100 lb.)
Tin cans	50	3	48.5
Paper	20	6	18.8
Rubber	20	2	19.6
Food waste	10	70	9.3
Total	100		

3) The moisture content (wet basis) would then be = (100 – 96.2)/100 = 3.8 %

Particle size

The most accurate expression of particle-size distribution is graphical. Nonetheless, several mathematical expressions are used. In water engineering, the particle size of filter sand is expressed using the uniformity coefficient, defined as presented in equation 2.3.

$$UC = \frac{D_{60}}{D_{10}} \qquad (2.3)$$

Where
UC = Uniformity coefficient.
D_{60} = Particle (sieve) size where 60% of the particles are smaller than that size.
D_{10} = Particle (sieve) size where 10% of the particles are smaller than that size.

Permeability of compacted waste

Hydraulic conductivity of compacted wastes governs movement of liquids and gases in a sanitary landfill. Coefficient of permeability may be determined as presented in equation 2.4.

$$K = C_d^2 \frac{\gamma}{\mu} = k \frac{\gamma}{\mu} \qquad (2.4)$$

Where:
K = Coefficient of permeability.
Cd = Constant or shape factor, dimensionless.
γ = Specific weight of water.
μ = Dynamic viscosity of water.
k = Intrinsic permeability (or specific) = C_d^2 (Typical values for the intrinsic permeability for compacted solid waste in a landfill are in the range between about 10^{-11} and 10^{-12} m^2 in the vertical direction and about 10^{-10} m^2 in the horizontal direction).

Apparent density

Apparent density may be used in estimating amount of solid waste in some cases and to assess requirements of a sanitary landfill cover material. Apparent density of solid waste and garbage varies greatly with exerted pressure, degree of compaction, level of economic development, concentration of produced waste products, geographic location, and season of the year and storage time.

Overall bulk density for a mixture of materials in a container may be estimated by knowing bulk density of each substance separately. For a mixture of two materials A and B, the bulk density of the mixture can be estimated as shown in equation 2.5.

$$\rho_C = \rho_{A+B} = \frac{\rho_A . V_A + \rho_B . V_B}{V_A + V_B} \qquad (2.5)$$

Where:
$\rho_c = \rho_{A+B}$ = Bulk density of the mixture of A and B.
ρ_A = Bulk density of material A.
ρ_B = Bulk density of material B.
V_A = Volume of material A.
V_B = Volume of material B.

Bulk density of the mixture of materials can also be estimated by the mass of materials from equation 2.6.

$$\rho_{A+B} = \frac{M_A + M_B}{\frac{M_A}{\rho_A} + \frac{M_B}{\rho_B}} \qquad (2.6)$$

Where:
M = Mass of the material (pounds or tons in the American Standard System or kilograms or tonnes in the SI system)[2].

Angle of Repose

The angle of repose is the angle to the horizontal to which the material will stack without sliding. Sand, for example, has an angle of repose of about 35^o, depending on the moisture content. Because of variable density, moisture, and particle size, the angle of repose of shredded refuse can vary from 45^o to greater than 90^o.

Size of reduction in volume (Reduction volume)

In design and operation when packaging or compacting solid waste in a landfill it is of value computing size of reduction in volume as outlined in equation 2.7.

$$F = \frac{V_c}{V_o} \qquad (2.7)$$

Where:
F = Volume of reduction (remaining ratios of original size as a result of compaction).
V_o = Original Size (initial).
V_c = Volume after compaction

Relationship of reduction volume to apparent density can be found from equation 2.8.

[2] 1 Ton = 2000 lb and 1 Tonne = 1000 kg.

$$F = \frac{V_c}{V_o} = \frac{M/\rho_c}{M/\rho_o} = \frac{\rho_c}{\rho_o} \qquad (2.8)$$

Where:

ρ_o = Original apparent density.

ρ_c = Apparent density after compaction.

Example (2.2)

For illustrative purposes only, assume that refuse has the following components and bulk densities:

Component	Percentage (by weight)	Uncompacted bulk density (lb/ft^3)
Miscellaneous paper	50	3.81
Garden waste	25	4.45
Glass	25	18.45

Assume that the compaction in the landfill is 1200 lb/yd^3 (44.4 lb/ft^3). Estimate the percent volume reduction achieved during compaction of the waste. Estimate the overall uncompacted bulk density if the miscellaneous paper is removed.

Solution

1) Given: components and bulk densities.
2) The overall bulk density prior to compaction is.

$$\rho_{(A+B+C+D)} = \frac{M_A + M_B + M_C + M_D}{\frac{M_A}{\rho_A} + \frac{M_B}{\rho_B} + \frac{M_C}{\rho_C} + \frac{M_D}{\rho_D}}$$

$$= \frac{50 + 25 + 25}{\frac{50}{3.81} + \frac{25}{4.45} + \frac{250}{18.45}} = 4.98\, lb/ft^3$$

3) The volume reduction achieved during compaction is

$$F = \frac{\rho_o}{\rho_c} = \frac{4.98\, lb/ft^3}{44.4\, lb/ft^3} = 0.11$$

4) So the required landfill volume is approximately 11% of the volume required without compaction. If the mixed paper is removed, the uncompacted density is

$$\rho_{(A+B+D)} = \frac{M_A + M_B + M_D}{\frac{M_A}{\rho_A} + \frac{M_B}{\rho_B} + \frac{M_D}{\rho_D}}$$

$$= \frac{25 + 25}{\frac{25}{4.45} + \frac{25}{18.45}} = 7.18\, lb/ft^3$$

$$F = \frac{\rho_o}{\rho_c} = \frac{7.17\ lb/ft^3}{44.4\ lb/ft^3} = 0.16$$

Material Abrasiveness

MSW and refuse consists of different types of abrasive particles and grains such as sand, glass, metals and rocks. Removal of this abrasive material is often necessary prior to some operations (such as pneumatic conveying) can become practical.

4) Chemical properties of solid waste

Chemical properties of solid waste are of value in economics of material or energy recovery. Chemical components of solid waste have significant variability and change due to the heterogeneity of solid waste, geographical location and temporal changes. Typically, solid wastes represent a combination of semi-moist combustible and noncombustible materials. When using solid waste as a fuel its chemical properties of significant include: proximate analysis, fusing point of ash, ultimate analysis (major elements) and energy content.

Fusion point of ash

The fusion point of ash may be defined as that temperature at which the ash resulting from the burning of waste will form a solid (clinker) by fusion and agglomeration. Typical fusion temperatures for the formation of clinker from solid waste range from 1100 to 1200^{o}C.

Proximate analysis

Proximate analyses are to determine percentage (fraction) of volatile organic organics and fixed carbon in solid waste and garbage (fuel).

Ultimate analysis

Ultimate analysis uses the chemical makeup of the fuel to approximate its heat value and it depends on elemental composition.

Volatile solids

Volatile solids can be estimated upon ignition at temperature of 550 ^{o}C for 4 hours and then cooling in a dryer. Loss in weight represents volatile organics, which includes disintegrating organic material and non-decombosable material as reflected in equations 2.9 and 2.10.

Loss in weight = Volatile Organics (2.9)

VO = D + ND (2.10)

Where:
VO = Volatile Organics.
D = Disintegrating organic material.
ND = Non-decombsaple material.

Heat value of refuse

Heat value of refuse is of paramount importance in resource recovery. Heat value is expressed as British thermal unit per pound, Btu[3]/lb, of refuse, or kJ/kg in the SI system. Heat value of refuse and other heterogeneous materials may be measured with a calorimeter. A calorimeter is a device in which a sample is combusted and the temperature rise is recorded. Knowing the mass of the sample and the heat generated by the combustion, the Btu/lb is calculated.

The most popular method using ultimate analysis is the DuLong equation, which originally was developed for estimating the heat value of coal.

Energy values of solid waste and garbage can be estimated by using DuLong equation as shown in equation 2.11.

$$\frac{KJ}{kg} = 337C + 1428\left(H - \frac{O}{8}\right) + 9S \qquad (2.11)$$

Where:
C = Carbon, (%).
H = Hydrogen, (%).
O = Oxygen, (%).
S = Sulfur, (%).

The DuLong formula is cumbersome to use in practice, and it does not give acceptable estimates of heat value for materials other than coal. Total energy content may be determined using the modified DuLong formula as presented in equation 2.12.

$$\frac{BTU}{lb} = 145C + 610\left(H2 - \frac{O2}{8}\right) + 40S + 10N \qquad (2.12)$$

Where:
Btu/lb[4] = Total energy.
C = Carbon, percent by weight.
H_2 = Hydrogen, percent by weight.
O_2 = Oxygen, percent by weight.
S = Sulfur, percent by weight.
N = Nitrogen, percent by weight.

Table (2.3) is an illustration of ideal data for final analysis of components of a combustible municipal solid waste.

Another equation for estimating the heat value of refuse using ultimate analysis is illustrated in equation 2.13.

$$Btu/lb = 144\ C + 672\ H + 6.2\ O + 41.4\ S - 10.8\ N \qquad (2.13)$$

[3] 1 Btu = heat necessary to raise the temperature of 1 lb of water 1°F
[4] (Btu/lb) x 2.326 = kJ/kg

Where

C, H, O, S, and N = Weight percentages (dry basis) of carbon, hydrogen, oxygen, sulfur, and nitrogen, respectively, in the combustible fraction of the fuel. The sum of all of these percentages has to add to 100%.

Formulas based on compositional analyses are an improvement over formulas based on ultimate analyses. One such formula is indicated in equation 2.14.

$$Btu/lb = 49R + 22.5(G+ P) - 3.3W \quad (2.14)$$

Where

R = Plastics, percent by weight of total MSW, on dry basis.
G = Food waste, percent by weight of total MSW, on dry basis.
P = Paper, percent by weight of total MSW, on dry basis.
W = Water, percent by weight, on dry basis.

Using regression analysis and comparing the results to actual measurements of heat value, an improved form of a compositional model is suggested by equation 2.15.

$$Btu/lb = 1238 + 15.6R + 4.4P + 2.7G - 20.7W \quad (2.15)$$

Where

R = Plastics, percent by weight, on dry basis.
P = Paper, percent by weight, on dry basis.
G = Food wastes, percent by weight, on dry basis.
W = Water, percent by weight, on dry basis.

Table (2.3): Ideal data for final analysis of components of a combustible municipal solid waste [2,4,6,10,24,25,46].

	Percentages by mass (on dry bases)					
Component	Carbon	Hydrogen	Oxygen	Nitrogen	Sulfur	Ash
Food waste	48.0	6.4	37.6	2.6	0.4	5.0
Paper	43.5	6.0	44.0	0.3	0.2	6.0
Cardboard	44.0	5.9	44.6	0.3	0.2	5.0
Plastics	60.0	7.2	22.8	-	-	10.0
Textiles	55.0	6.6	31.2	4.6	0.15	2.5
Rubber	78.0	10.0	-	2.0	-	10.0
Leather	60.0	8.0	11.6	10.0	0.4	10.0
Garden trimmings	47.8	6.0	38.0	3.4	0.3	4.5
Timber	49.5	6.0	42.7	0.2	0.1	1.5
Mixture of organic materials	48.5	6.5	37.5	2.2	0.3	5.0
Dirt, ash, bricks etc. …	26.3	3.0	2.0	0.5	0.2	68.0

Example (2.3)

Find approximate chemical formula of the organic component of the sample composition of a solid waste as set out in the following table. Use chemical composition obtained to estimate energy content of this solid waste.

Component	Percent by mass
Garden trimmings	10
Food waste	25
Timber	4
Paper	38
Cardboard	13
Rubber	4
Tin cans	6
Total sum	100

Solution

1) Given: sample composition.
2) Form the following table using typical moisture values.

Composition (1)	Percent by Mass (2)	Moisture content (M), % (from table) (3)	Dry mass (M_d), kg (4)
Garden trimmings	10	60	$\frac{10-W_d}{10}=\frac{60}{100}, Wd=4$
Food waste	25	75	$\frac{25-W_d}{25}=\frac{75}{100}, Wd=6.25$
Timber	4	20	$\frac{4-W_d}{4}=\frac{20}{100}, Wd=3.2$
Paper	38	6	$\frac{38-W_d}{38}=\frac{6}{100}, Wd=35.72$
Cardboard	13	5	$\frac{13-W_d}{13}=\frac{5}{100}, Wd=12.35$
Rubber	4	2	$\frac{4-W_d}{4}=\frac{2}{100}, Wd=3.92$
Tin cans	6	3	$\frac{6-W_d}{6}=\frac{3}{100}, Wd=5.82$

3) Determine dry mass of mixture without tin cans = 4+6.25+3.2+35.72+12.35+3.92+5.82 = 65.44
4) Determine Moisture content of mixture = 94 -65.44 =28.56 %

Table (b)

Component	Mass, kg
Carbon	33.73
Hydrogen	4.52
Oxygen	26.53
Nitrogen	0.61
Sulfur	310.
Ash	4.08

5) Change moisture content (H_2O) in previous step to hydrogen and oxygen

   Hydrogen = $\frac{2}{18} \times 28.56 = 3.17\ kg$

   Thus hydrogen = 4.52 + 3.17 = 7.69 kg

   Oxygen = $\frac{16}{18} \times 28.56 = 25.39\ kg$

   Thus oxygen = 26.53 + 25.39=61.2333

6) Repeat summary of rate in table (c) using additions of hydrogen and oxygen as presented in table (d).

Table (d).

Component	Mass, kg
Carbon	33.73
Hydrogen	7.69
Oxygen	51.92
Nitrogen	0.61
Sulfur	310.
Ash	4.08
Total	98.16

Component	Mass, kg	Percent (by mass)
Carbon	33.73	33.73/98.16= 34.36%
Hydrogen	7.69	7.83%
Oxygen	51.92	52.89%
Nitrogen	0.61	0.62%
Sulfur	0.13	0.13%
Ash	4.08	4.16%
Total	98.16	100

7) Find energy value for waste from Dulong formula

$$\frac{KJ}{kg} = 337C + 1428\left(H - \frac{O}{8}\right) + 9S$$

$$\frac{KJ}{kg} = 337 \times 34.36 + 1428\left(7.83 - \frac{52.893}{8}\right) + 9 \times 0.13 = 13320.9$$

Element	Mass, kg	Atomic weight	Number of moles
Carbon	33.73	12	2.81
Hydrogen	7.69	1	7.69
Oxygen	51.92	16	3.25
Nitrogen	0.61	14	0.044
Sulfur	0.13	32	0.004

8) Approximate chemical formula with sulfur

	Mole normality	Mole normality
Element	Sulfur = 1	Nitrogen = 1
Carbon	4702.5	63.86
Hydrogen	1922.5	174.77
Oxygen	812.5	73.86
Nitrogen	11	1
Sulfur	1	0

Chemical formula with sulfur is: $C_{702.5}H_{1922.5}O_{812.5}N_{11}S$

Chemical formula without sulfur is: $C_{63.86}H_{174.8}O_{73.9}N$

Example (2.4)

A processed refuse-derived fuel has the following composition. Estimate its heat value.

Component	Fraction by weight, dry basis
Paper	0.3
Food waste	0.1
Plastics	0.2
Glass	0.2
Wood	0.1
Cardboard	0.1

Solution

1) Given: Refuse composition.
2) Form the following table.

Component	Fraction by weight, dry basis	Heat value
Paper	0.3	7200
Food waste	0.1	2000
Plastics	0.2	14000
Glass	0.2	60
Wood	0.1	8000
Cardboard	0.1	7000

3) Estimate the heat value based on the typical values in table = 0.3x7200 + 0.1x2000 + 0.2x14000 + 0.2x60 + 0.1x8000 + 0.1x7200 = 6672 Btu/Lb.

Exercise (2.1)

1) What is the benefit of properties of solid waste in management systems and related engineering topics?
2) How can you estimate the amount of solid waste in an area?
3) What are the related effects to physical properties of solid waste and garbage?
4) What is the benefit to know the angle of stability in a landfill?
5) Write briefly about **THREE** of the following:
   a. Current classification of solid waste in KSA.
   b. The challenge for society is to minimize how much waste is generated and to convert waste into a resource (Essence of the zero waste concept).
   c. Potential problems of solid waste, garbage and sweeping.
   d. Factors that affect quality and quantity of solid waste produced from a particular locality.
   e. Most important properties of solid waste and their significance.
6) Attempt writing briefly about **ANY THREE** questions of the following:
   i. “The challenge for society is to minimize how much waste is generated and to convert waste into a resource”. Discuss this statement.
   ii. Municipal solid waste may be defined as a “heterogeneous mass of throwaways from the urban community, as well as the more homogeneous accumulations of agricultural, industrial and mineral wastes”. Based on this definition, how can you classify urban municipal solid waste? State your reasons.
   iii. “Waste and garbage disposal is a big responsibility for the government. If the authority did not have good management for its disposal, it exposes itself to political and social problems.” Explain why?
   iv. “It is difficult to determine relevance of diseases with waste and garbage. Nonetheless, about 50% of various diseases are transferred by flies, mosquitoes and rodents proliferating in the waste.” To take caution, what procedures would you advocate to be followed by concerned authorities?
   v. There are many sources of solid waste, garbage and sweeping which include: agriculture, mining, building and construction, industry, housing, homes, offices, open markets, restaurants, hospitals, shops, educational institutions, hazardous ... etc. Outline major types of hazardous solid waste. Which type would expect to be found in KSA? Why?
   vi. Write briefly about most important properties of solid waste and associated benefits.
7) Indicate importance of moisture content measurements for a sample of municipal solid waste.
8) List a method of conducting an experiment to estimate the moisture content of a household solid waste.
9) Why do newspapers contain higher moisture content compared to plastic materials in a domestic dustbin?
10) What is the benefit to know the size of grains of a solid waste?
11) How bulk density of trade solid waste is determined?
12) How can you estimate the chemical composition of garbage?
13) What is the benefit of estimating the calorific value of a solid waste?

14) What is the purpose of measuring heat values of refuse?

Exercise (2.2)

1) A residential waste has the following components:

Aluminum cans	10%
Paper	35%
Glass	15%
Food	30%
Plastic	10%

Estimate its moisture concentration using the typical values in table of moisture content.

2) Household garbage contains the following components

Tin cans	10%
Paper	30%
Leather	10%
Food waste	30%
Cardboard	20%

Estimate moisture content using the typical values in a table.

3) A residential waste has the components presented in the table. Estimate its moisture concentration using the typical values.

Paper	40%
Steel cans	10%
Food	30%
Garden trimmings	10%
Leather	10%

4) For illustrative purposes only, assume that refuse has the following components and bulk densities

Component	Percentage(by weight)	Uncompacted bulk density
Miscellaneous paper	50	3.81 (lb/ft^3)
Cardboard	10	1161(lb/yd^3)
Garden waste	20	4.45 (lb/ft^3)
Glass	20	18.45(lb/ft^3)

Assume that the compaction in the landfill is 1300 lb/yd^3.

a) Estimate the percent volume reduction achieved during compaction of the waste using the following equation:

$$F = \frac{\rho_o}{\rho_c}$$

b) Estimate the overall uncompacted bulk density if the miscellaneous paper is removed. Estimate the percent volume reduction achieved.

c) Comment on your results

5) Assume that a certain refuse has the following components and bulk densities

Component	Percentage (by weight)	Apparent density before compaction (g/cm^3)
Aluminum	20	0.038
Glass	10	0.295
Various paper	30	0.061
Food waste	40	0.368

i. Assuming compaction of landfill 700 kg/m^3, find percent volume reduction achieved when compacting this solid waste.
ii. Compute total apparent density before compaction by removing various paper component. Estimate the percent volume reduction achieved.
iii. Comment on your results

6) Estimate the overall moisture content of a sample of as collected residential municipal solid waste with the typical composition given in table (1). (UoD, B.Sc. 2012)

Table (1): Typical physical composition of residential municipal solid waste

	Percent by weight	
Component	Range	Typical
Organic		
Food wastes	6 – 18	9.0
Paper	25 – 40	34.0
Cardboard	3 – 10	6.0
Plastics	4 – 10	7.0
Textiles	0 – 4	2.0
Rubber	0 – 2	0.5
Leather	0 – 2	0.5
Yard wastes	5 – 20	18.5
Wood	1 – 4	2.0
Miscellaneous organics	-	-
Inorganic		
Glass	4 – 12	8.0
Tin cans	2 – 8	6.0
Aluminum	0 – 1	0.5
Other metal	1 – 4	3.0
Dirt, ash, etc.	0 - 6	3.0
Total		100

7) A certain solid waste have the following composition and apparent density:

Component	Percentage (by weight)	Apparent density before compaction (gm/cm^3)
Aluminum	10	0.038
Glass	10	0.295
Various paper	40	0.061
Food waste	40	0.368

Assuming compaction of landfill 700 kg/m^3, find percent volume reduction achieved when compacting this solid waste. Compute total apparent density before compaction by removing various paper components.

8) The following table shows the components and bulk density of a certain solid waste and garbage.

Component	Percent (by weight)	Apparent density before compaction, g/cm^3
Yard waste	20	0.071
Plastics	10	0.037
Newspaper	20	0.099
Glass	10	0.295
Food waste	30	0.368
Corrugated cardboard	10	0.03

Assuming compaction in a landfill for the production of apparent density in the field of 700 kg/m^3, find size reduction due to compaction of the solid waste. Find apparent density before compaction assuming total separation of glass and newspapers.

9) Find approximate chemical formula of the organic component of the sample composition of a solid waste as set out in the following table. Use chemical composition obtained to estimate energy content of this solid waste.

Component	Percent by mass
Garden trimmings	10
Food waste	20
Timber	5
Paper	35
Cardboard	15
Rubber	10
Tin cans	5
Total sum	100

Assume total organic composition of the solid waste assuming a mass of 100 kg of the sample as shown in table (b).

Component	Mass, kg
Carbon	35
Hydrogen	5
Oxygen	28
Nitrogen	0.5
Sulfur	0.1
Ash	5

10) Find the approximate chemical formula for the organic component for a sample of solid waste of the composition set out in the following tables. Use the chemical composition to estimate gross energy content of this solid waste.

Component	Percent by mass
Garden trimmings	10
Food waste	25
Wood	5
Paper	35
cardboard	10
Plastics	10
Glass	5
Grand Total	100

Component	Mass, kg
Carbon	31
Hydrogen	4.5
Oxygen	26
Nitrogen	0.6
Sulfur	0.1
Ash	4

11) Determine the energy value of a typical residential MSW with the average composition shown in the table[5].

Table (1): Typical physical composition of residential municipal solid waste

	Percent by weight	
Component	Range	Typical
Organic		
Food wastes	6 – 18	9.0
Paper	25 – 40	34.0
Cardboard	3 – 10	6.0
Plastics	4 – 10	7.0
Textiles	0 – 4	2.0
Rubber	0 – 2	0.5
Leather	0 – 2	0.5
Yard wastes	5 – 20	18.5
Wood	1 – 4	2.0
Miscellaneous organics	-	-
Inorganic		
Glass	4 – 12	8.0
Tin cans	2 – 8	6.0
Aluminum	0 – 1	0.5
Other metal	1 – 4	3.0
Dirt, ash, etc.	0 - 6	3.0
Total		100

[5] This problem has been adopted from Tichobanoglous, et al (39)..

Table (2): Typical values for energy content of residential municipal solid waste

	Energy[6], Btu/lb	
Component	Range	Typical
Organic		
Food wastes	1500 - 3000	2000
Paper	5000 - 8000	7200
Cardboard	6000 - 7500	7000
Plastics	12000 - 16000	14000
Textiles	6500 - 8000	7500
Rubber	9000 - 12000	10000
Leather	6500 - 8500	7500
Yard wastes	1000 – 8000	2800
Wood	7500 - 8500	8000
Miscellaneous organics	-	-
Inorganic		
Glass	50 - 100[7]	60
Tin cans	100 - 500[(1)]	300
Aluminum	-	-
Other metal	100 - 500[(1)]	300
Dirt, ash, etc.	1000 – 5000	3000
Municipal solid wastes	4000 – 6000	5000

12) Given that the chemical composition of a residential municipal solid waste including sulfur and water is:

$C_{760}H_{1980}O_{874.7}N_{12.7}S$

Determine the total energy content using the modified Dulong formula:

$$\frac{BTU}{lb} = 145C + 610\left(H2 - \frac{O2}{8}\right) + 40S + 10N$$

Where:

C = Carbon, percent by weight.

H_2 = Hydrogen, percent by weight.

O_2 = Oxygen, percent by weight.

S = Sulfur, percent by weight.

N = Nitrogen, percent by weight.

[6] As discarded basis.

[7] Energy content is from coatings, labels, and attached materials.

13) Determine the chemical composition of the organic fraction, without and with sulfur and without and with water, of a residential MSW with the typical composition shown in the table[8].

Typical data on the ultimate analysis of the combustible componentsin residential MSW

Component	Percent by weight (dry basis)					
	Carbon	Hydrogen	Oxygen	Nitrogen	Sulphur	Ash
Organic						
Food wastes	48.0	6.4	37.6	2.6	0.4	5.0
Ppaer	43.5	6.0	44.0	0.3	0.2	6.0
Cardboard	44.0	5.9	44.6	0.3	0.2	5.0
Plastics	60.0	7.2	22.8	-	-	10.0
Textiles	55.0	6.6	31.2	4.6	0.15	2.5
Rubber	78.0	10.0	-	2.0	-	10.0
Leather	60.0	8.0	11.6	10.0	0.4	10.0
Yard wastes	47.8	6.0	38.0	3.4	0.3	4.5
Wood	49.5	6.0	42.7	0.2	0.1	1.5
Inorganic						
Glass	0.5	0.1	0.4	<0.1	-	98.9
Metals	4.5	0.6	4.3	<0.1	-	90.5
Dirt, ash, etc.	26.3	3.0	2.0	0.5	0.2	68.0

14) For a sample of a solid food waste the composition presented in table (a) was detected. Assuming total organic composition of the solid waste and for a mass of 100 kg of the sample as shown in table (b),

- Find moisture content of the mixture.
- Determine approximate chemical formula of the organic component of the sample.
- Use chemical composition obtained to estimate energy content of this waste.

Table (a) Waste composition.

Component	Percent by mass
Yard waste	10
Food waste	28
Timber	4
Paper	40
Cardboard	10
Leather	4
Aluminum cans	4
Total sum	100

[8] This problem has been adopted from Tichobanoglous, et al (39).

Table (b) Organic composition of sample

Component	Mass, kg
Carbon	30.87
Hydrogen	4.26
Oxygen	21.44
Nitrogen	0.58
Sulfur	0.15
Ash	5.12

Comment on your answers.

15) Define the terms and show how to use the following equations for determining moisture content and energy values of a sample of municipal solid waste.

$$M = \frac{W_w - W_d}{w_w} \times 100 \qquad \frac{KJ}{kg} = 337C + 1428\left(H - \frac{O}{8}\right) + 9S$$

For a sample of a solid food waste the composition presented in table (a) was detected. Assuming total organic composition of the solid waste and for a mass of 100 kg of the sample as shown in table (b),

- Find moisture content of the mixture.
- Determine approximate chemical formula of the organic component of the sample.
- Use chemical composition obtained to estimate energy content of this waste.

Table (a) Waste composition.

Component	Percent by mass
Yard waste	12
Food waste	20
Timber	6
Paper	40
Cardboard	10
Rubber	8
Tin cans	4
Total sum	100

Table (b) Organic composition of sample.

Component	Mass, kg
Carbon	31
Hydrogen	4.3
Oxygen	21.5
Nitrogen	0.5
Sulfur	0.15
Ash	5.1

Comment on your answers.

16) A processed refuse-derived fuel has the following composition.

Component	Fraction by weight, dry basis
Paper	0.3
Food waste	0.3
Plastics	0.2
Glass	0.2

Estimate its heat value.

17) A sample of refuse is analyzed and found to contain 15% water (measured as weight loss on evaporation). The Btu of the entire mixture is measured in a calorimeter and is found to be 5000 Btu/lb. A 1.0 g sample is placed in the calorimeter, and 0.3 g ash remains in the sample cup after combustion. What is the comparable, moisture free Btu and the moisture- and ash-free heat value?
18) A benzoic acid pellet weighing 6.54 g is placed in a bomb calorimeter along with 0.35 g fuse wire. The benzoic acid is ignited, and the temperature rise is 3.6^{o}C. What is the heat capacity of this calorimeter?
19) A 15 g sample of a refuse-derived fuel (RDF) is combusted in a calorimeter that has a heat capacity of 8900 cal/^{0}C. The detected temperature rise is 3.5^{o}C. What is the heat value of this sample?

Chapter Three
Solid waste collection

Municipal solid waste collection systems are customarily person/truck systems. MSW collectors traverse a generation sites and source production in trucks to transport collected refuse to a site at which the truck is emptied. This process may be an intermediate stopover where the refuse is transferred from a small truck into trailers, larger vans, barges, or railway cars for long-distance transport or a selected final site such as the landfill, compost site, or materials recovery facility. During this cycle some of the useful MSW may be isolated, sorted out or segregated for reuse or recycling or conversion into other useful products.

The process of refuse collection is a multiphase process, and it can be divided in separate phases namely: House to can (transferring MSW from home to dust pin inside or outside the house), can to truck (for movement of MSW from dust bin to MSW and garbage car by MSW workers or owner of housing), truck from house to house (Collection phase of MSW from different sources by best and efficient ways and its transfer to collection areas and to areas of intermediate or final disposal), truck routing (Stage of path of truck through the city's road network) and truck to disposal (stage of final disposal or recovery of materials).

Example (3.1)

A family of six people generates solid waste at a rate of 2.5 lb./cap/day and the bulk density of refuse in a typical garbage can is about 230 lb./yd^3. If collection is once a week, how many 30-gallon garbage cans will they need, or the alternative, how many compacted 20-lb blocks would the family produce if they had a home compactor? How many cans would they need in that case?

Solution

1) Given: P = 6, generated waste = 2.5 lb./cap/day, ρ = 230 lb./yd^3.
2) Weight of SW generated = 2.5 lb./cap/day x 6 persons x 7 days/week = 105 Lb.
3) Volume of SW = Weight/density = 105 lb./230 lb./yd^3 = 0.457 yd^3
   Volume (convert to gallons) = 0.457 yd^3 x 202 gal/yd^3 = 92.3 gal
   They will require four 30-gallon cans.
4) If the refuse is compacted into 20-lb blocks, they would need to produce such compacted blocks to take care of the week's refuse
   If each block of compacted refuse is 1400 lb./yd^3, the necessary volume is 105 lb./1400 lb./yd^3) x 202 gal/yd^3 = 15.15 gal
   They would need only one 30-gal can.

Number of collection vehicles needed for a community may be determined from equation 3.1.

$$N = \frac{S*F}{X*W} \tag{3.1}$$

Where:
N = Number of collection vehicles needed.
S = Total number of customers serviced.

F = Collection frequency, number of collections per week.
X = Number of customers a single truck can service per day.
W = Number of workdays per week.

Example (3.2)

1) Use the equation for estimating number of MSW collection vehicles needed for a certain community

$$N = \frac{S\ F}{X\ W}$$

Calculate the number of collection vehicles a community would need if it has a total of 4000 services (customers) that are to be collected once per week during working days in a city in KSA. (Realistically, most trucks can service only about 200 to 300 customers before the truck is full and a trip to the landfill is necessary).
Solution

Solution

1) Given:
   N = Number of collection vehicles needed
   S = Total number of customers serviced = 4000
   F = Collection frequency, number of collections per week = 1
   X = Number of customers a single truck can service per day (A single truck can service 300 customers in a single day and still have time to take the full loads to the landfill) = 300.
2) W = Number of workdays per week (The town wants to collect on Saturday, Sunday, Monday, and Tuesdays leaving Wednesdays for special projects and truck maintenance) = 4 days.
3) Thus: N = SF/XW = (4000 * 1)/(300 * 4) = 3.3
4) The community will need four trucks.

Exercise (3.1)

1) Write briefly about the following agenda concerning solid waste as related to your research project:
   - Process of collection.
   - Sorting of SW components from each other.
   - Responsible personnel for collection and sorting of SW.
   - Preferred method to transport in your city. Give reasons for your answer.
   - Objectives of SW collection.
   - Stages of SW collection.
   - Difference between collection of SW in both rural and urban areas.
   - Appropriate routes for car collecting SW between neighborhoods in the city.
   - Disadvantages and advantages of transfer stations.
   - Transfer station location, divisions available and methods to unload SW trucks.
   - Difference between re-use and recycling.
   - Methods of collecting recyclable materials.

- Methods of storage of SW in house, apartment, and office. Harmful effects for keeping SW for a long time.
- Kinds of baskets preferred for storage until transferred.
- Anti-breeding of trash flies used risks resulting from breeding of blow flies.
- Appropriate hours of collection of SW and related reasons
- Obstacles to collect SW in your area. Give most appropriate solutions to improve the situation.

2) Write briefly about oobjectives of municipal solid waste, MSW, collection in Al-Danaha municipality.
3) Write briefly about mmajor factors affecting cost of municipal solid waste, MSW, collection.
4) Write briefly about stages of municipal solid waste, MSW, process collection in an urban area.
5) What innovative methods to finance and fund programs for collection and disposal of municipal solid waste, MSW, would you propose to be adopted in KSA. Outline your reasons for your proposal?
6) Write briefly about role of a transfer station in municipal solid waste, MSW, collection. Indicate when it is preferred to rely on transfer stations.
7) Write briefly about municipal solid waste, MSW, recycling and reuse.
8) Write briefly about objectives of municipal solid waste, MSW, collection.
9) Write briefly about refuse collection phases**.**

Exercise (3.2)

1) A family of four people generates MSW at a rate of 2.5 lb/cap/day and the bulk density of refuse in a typical garbage can is about 250 lb/yd^3. If collection is once a week, how many 30-gallon garbage cans will they need, or the alternative, how many compacted 20-lb blocks would the family produce if they had a home compactor? How many cans would they need in that case?
2) A family of five people generates solid waste at a rate of 2 lb./cap/day. Collection is once a week. How many customers can a 20-yd^3 truck that compacts the refuse to 500 lb/yd^3 collect before it has to make a trip to the landfill? (UoD, B.Sc. 2012).
3) A family of five people generates solid waste at a rate of 2 lb./cap/day and the bulk density of refuse in a typical garbage can is about 200 lb./yd3. If collection is once a week, how many 30-gallon garbage cans will they need? Or the alternative, how many compacted 20-lb blocks would the family produce if they had a home compactor? How many cans would they need in that case? Assume that the bulk density of the compacted refuse is about 1400 lb/yd^3 (830 kg/m^3).
4) Assume each household produces 50 lb of refuse per week (as in problem 2). How many customers can a 20-yd^3 truck that compacts the refuse to 600 lb/yd^3 collect before it has to make a trip to the landfill?
5) Assume each household produces 60 lb of refuse per week. How many customers can a 20-yd^3 truck that compacts the refuse to 550 lb/yd^3 collect before it has to make a trip to the landfill?
6) Suppose a crew of two people requires 2 minutes per stop, at which they can service four customers. If each customer generates 50 lb of refuse per week, how many customers can they service if they did not have to go to the landfill?

7) Suppose a crew of two people requires 3 minutes per stop, at which they can service four customers. If each customer generates 50 lb of refuse per week, how many customers can they service if they did not have to go to the landfill?
8) Suppose a crew of two people requires 2 minutes per stop, at which they can service five customers. Assume that a working day is 8 hours. How many customers can they service if they did not have to go to the landfill?
9) A community of 1200 homes cannot pay for the initial and operating costs of the recycling collection vehicles that were to be used. Instead, residents are to haul recycling containers to a drop-off center operated by the community. Calculate the number of vehicles from which recyclable materials must be unloaded per hour at the recycling drop-off center. Assume the center is open for eight hours per day, two days per week, and that 40 percent of the residents will deliver recycling containers. Also assume that 75 percent of the participants will take their separated materials to the drop-off center once per week and that the remaining 25 percent of the participants will bring their separated materials to the drop-off center once every two weeks.
10) A truck is found to be able to service customers at a rate of 2 customers per minute. If they find that the actual time they spend on collection is 5 hours, how many customers can be served per day?
11) A truck is found to be able to service customers at a rate of 1.5 customers per minute. If they find that the actual time they spend on collection is 5 hours, how many customers can be served per day?
12) Calculate the number of collection vehicles a community would need if it has a total of 4000 services (customers) that are to be collected once per week.
13) Calculate the number of collection vehicles a community would need if it has a total of 6000 services (customers) that are to be collected once per week.
14) The number of collection vehicles a community would need for solid waste collection in a certain municipality is 6 trucks. Find total number of services (customers) that are to be collected once per week during working days in a Al-Doha in KSA. (Realistically, most trucks can service only about 200 to 300 customers before the truck is full and a trip to the landfill is necessary).
15) Define the terms contained in the equation used to determine maximum volume that can be squeezed by a crushing cylinder (roll) C = k.v.D.L.s.r
    Find capacity in (tons / hour) of a crushing cylinder noting that speed of cylinder is 60 cycles per minute, cylinder diameter of 20 cm, its length 0.35 meters, and taking density of material of 2.6 g/cm3 and distance between discs of 5 mm. Assume crushing roll constant = 60 when taking units and dimensions described in this equation. (UoD, B.Sc. 2012).

Chapter four
Processing solid waste and material separation

MSW refuse is a heterogeneous material with unpredictable and time-variable characteristics and amounts. These conditions interfere negatively with design MSW processing and materials recovery facilities, MRFs, when attempting to utilize the material in producing a desirable product. Some types of MSW refuse are easily processed, yet certain other types are difficult and/or dangerous to handle. MSW processing operations incorporate many interlinked factors at operational, organizational and safety levels. Therefore, the material ought to be designed for extraordinary contingencies. Such a requirement often results in overdesign and underutilization of resources when processing all of the feed material.

Primary treatment operations to prepare MSW and garbage in a sustainable management system format target increasing efficiency of operation, extracting useful materials and resources and restoring products and energy. This could be achieved through: size reduction by mechanical means (e.g. compaction or fragmentation) or chemical means (e.g. incineration and burning); or by automatic and mechanical separation of components; or extraction of moisture content and drying.

Basic types of conveyors used primarily to move MSW and refuse include: rubber-belted conveyors, live bottom feeders and pneumatic conveyors. Other conveyors used to feed or meter refuse to a load-sensitive device (such as a combustor) incorporate: vibratory feeders, screw feeders and drag chains.

Power requirements of belt conveyors can be estimated by a number of empirical equations. Equation 4.1 represent the power necessary to move a load horizontally and vertically together with power loss due to friction.

$$\text{Horsepower} = \frac{LSF}{1000} + \frac{LTC}{990} + \frac{TH}{990} + P \qquad (4.1)$$

Where
L = Length of conveyor belt, ft
S = Speed of belt, ft/min
F = Speed factor, dimensionless
T = Capacity, tons/h
C = Idle resistance factor, dimensionless
H = Lift, ft
P = Pulley friction, horsepower

Screw conveyors are used to meter shredded refuse into a furnace. The volume of material moved by a screw conveyor in a flooded condition can be estimated by equation 4.2.

$$Q = CNRV \qquad (42)$$

Where
Q = Delivery of refuse, m^3/min.
C = Efficiency factor.
N = Number of conveyor leads or number of blades that are wrapped around the conveyor hub.
R = Rotational speed of screw, rpm.
V = Volume of refuse between each pitch, m^3

Crushing devices or rolls break fragile materials such as glass, while unfolding rout iron such as iron cans, which would facilitate separation by sieving. Crushing rolls strongly hold the raw material entering between two rollers operating in opposite directions. The maximum volume that can be squeezed by crushing cylinders can be estimated by equation 4.3.

$$C = k.v.D.L.s.\rho \qquad (4.3)$$

Where:
C = Capacity, tons/hour.
k = Constant, dimensionless = 60 When taking units and dimensions described in this equation.
v = Speed of cylinders, rpm.
D = Cylinder diameter, m.
L = Length of cylinder, m.
s = Distance of separation between cylinders (discs), m.
ρ = Density of the material, g/cm^3.

Example (4.1)

Find capacity of a crushing cylinder noting that speed of cylinder is 4200 cycles per hour, cylinder diameter of 250 mm, its length 45 cm, and taking density of material of 2500 kg/m^3 and distance between discs of 5 mm.

Solution

1) Given: v = 4200 cycles/hr = 4200/60 cycles/min, D = 250 mm = 20 cm, L = 0.45 meters, ρ = 2500/1000 = 2.5 g/cm^3, s = 5 mm.
2) Then, capacity, C = k.v.D.L.s.r
   C = k.v.D.L.s.r = 60 x (4200/60) rpm x 0.25 m x 0.45 m x 0.005 m x 2.5 (g/cm^3) = 7.1 tones/hr.

In separating various pure materials from a mixture, the separation can be either binary (two output streams) or polynary (more than two output streams). A binary separator is designed to extract one type of material from a waste stream (e.g. magnet drawing off ferrous materials as the desired output or product or extract). A polynary separator separates components from each other through multiple paths (e.g. screen with a series of different sized holes, producing several products).

Suppose in a binary separator the input stream is composed of a mixture of x and y to be separated. The mass per time (e.g., tons/hour) of x and y fed to the separator is x_0 and y_0, respectively. The mass per time of x and y exiting in the first output stream is x_1 and y_1, and the second output stream is x_2 and y_2. The device separates the x into the first output stream and y into the second. The effectiveness of the separation then can be expressed in terms of recovery.

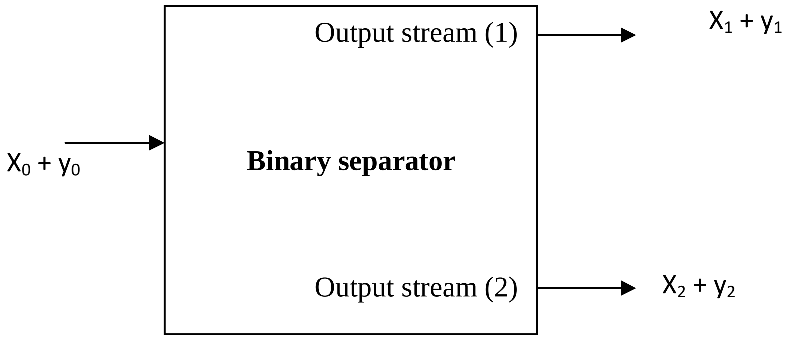


Figure 4.1: Binary separator.

The recovery of component x in the first output stream is Rx1, defined as shown in equation 4.4.

$$R_{x_1} = \frac{x_1}{x_o} \times 100 \qquad (4.4)$$

Where:

R_{x1} = Recovery of component x in the first output stream (1).
x_1 = First component emerging of the first output stream (1), mass/time.
x_o = x component entering to the binary separator, mass/time.

Similarly, the recovery of y in the second output stream may be found from equation 4.5.

$$R_{y2} = \frac{y_2}{y_o} \times 100 \qquad (4.5)$$

Purity of output can be determined from equation 4.6.

$$P_{x_1} = \frac{x_1}{(x_1 + x_2)} \times 100 \qquad (4.6)$$

Where:

P_{x1} = Purity of the first output stream in terms of x, which is expressed as a percentage.

Similarly, the purity of the second output stream in terms of y is as presented in equation 4.7.

$$P_{y_2} = \frac{y_2}{(x_2 + y_2)} \times 100 \qquad (4.7)$$

Overall recovery is useful only for process design, such as sizing conveyor belts. Nevertheless, it is not a measure of separation effectiveness. It should not be used in describing the operation of materials separation. Overall recovery may be defined as in equation 4.8.

$$OR_{x,y} = \left(\frac{x_1 + y_1}{x_o + y_o} \right) \times 100 \qquad (4.8)$$

Where:
$OR_{x,y}$ = Overall recovery for components x and y.

Rietema separation effectiveness measure for a binary separation with input of x_0 and y_0 yields equation 4.9.

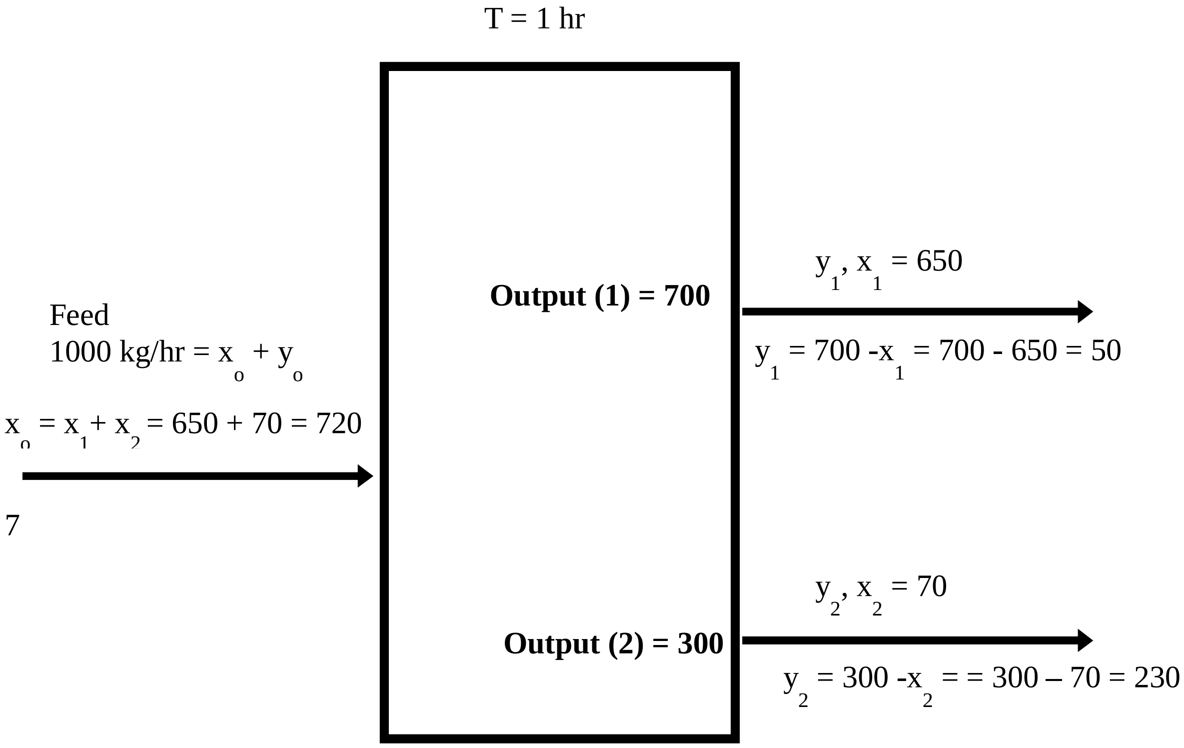
$$E_{x,y} = 100\left|\frac{x_1}{x_o} - \frac{y_1}{y_o}\right| = 100\left|\frac{x_2}{x_o} - \frac{y_2}{y_o}\right| \qquad (4.9)$$

Worrell and Stessel equation for finding the separation performance of a binary separator is reflected in equation 4.10.

$$E_{x,y} = \left|\frac{x_1}{x_o}\ \frac{y_2}{y_o}\right|^{1/2} \times 100 \qquad (4.10)$$

Example (4.2)

A binary separator has a feed rate of 1 ton/h. It is operated so that during any 1 hour, 700 kilograms reports as output (1) and 300 kg as output (2). Of the 700 kg the x constituent is 650 kg, while 70 kg of x ends up in output 2. Find the recoveries and the effectiveness of separation using different methods.



Solution

1) Given: Data: x_1 = 650 kg, $x_o + y_o$ = 1000 kg (1 ton), x_2 = 70 kg. (See figure).
2) From data find $x_o = x_1 + x_2$ = 650 + 70 = 720 kg,

3) Then, find y_o = total value - x_o = 1000 - 720 = 280 kg.
4) From track (1) the value of $y_1 = 700 - x_1 = 700 - 650 = 50$ kg.
5) From track (2) the value of $y_2 = 300 - x_2 = 300 - 70 = 230$ kg.
6) Find the recovery of x in the first output from equation

$$R_{x_1} = \frac{x_1}{x_0} \times 100 = \tfrac{650}{720} \times 100 = 90$$

7) Find purity of this output stream from equation :

$$P_{x_1} = \frac{x_1}{x_1 + y_1} \times 100 = \frac{650}{650 + 50} \times 100 = 90$$

8) Using Rietema's definition of effectiveness

$$E_{x,y} = 100 \left| \frac{x_1}{x_o} - \frac{y_1}{y_o} \right| = 100 \left| \frac{650}{720} - \frac{50}{280} \right| = 72$$

9) and according to Worrell-Stessel effectiveness equation,

$$E_{x,y} = \sqrt{\left| \frac{x_1}{x_o} \frac{y_2}{y_o} \right|} \times 100 = \sqrt{\left| \frac{650}{720} \frac{230}{280} \right|} \times 100 = 86$$

Exercise (4.1)

1) Write briefly about primary treatment systems to prepare municipal solid waste, MSW.

Exercise (4.2)

1) Find capacity of a crushing cylinder noting that speed of cylinder is 50 cycles per minute, cylinder diameter of 20 cm, its length 0.6 meters, and taking density of material of 2.3 g/cm^3 and distance between discs of 5 mm.
2) Find capacity of a crushing cylinder noting that speed of cylinder is 60 cycles per minute, cylinder diameter of 30 cm, its length 0.5 meters, and taking density of material of 2.5 g/cm^3 and distance between discs of 5 mm.
3) A binary separator has a feed rate of 1 tonne/h. It is operated so that during any 1 hour, 800 kg reports as output 1 and 200 kg as output 2. Of the 800 kg, the x constituent is 750 kg, while 90 kg of x ends up in output 2. Calculate the recoveries and the effectiveness of the separation using different methods.

Chapter five
Sanitary landfill

A sanitary landfill is an engineered method for land disposal of solid or hazardous wastes in a manner that protects the environment. Within the landfill biological, chemical, and physical processes occur biodegrading wastes and resulting in the production of leachate and gaseous substances. Leachate production and quantity can be estimated using empirical data or a water balance technique.
Water balance System in the landfill facilitates estimating amount of percolating water production by establishing a mass balance among precipitation, evapotranspiration, surface runoff, and soil moisture storage as presented in equation 5.1.

$$C = P\,(1 - r) - S - E \tag{5.1}$$

Where:
C = Total amount percolating within the top layer of soil, mm/year.
P = Precipitation, mm/year.
r = Coefficient of runoff (can be estimated for different types of soil).
S = Storage in the soil or solid waste, mm/year.
E = Evapotranspiration, mm/year.

Gas production over time may be estimated from the EPA LandGEM model[9] based on equation 5.2.

$$Q_T = \sum_{i=1}^{n} 2k\; L_o M_i e^{-kt_i} \tag{5.2}$$

Where:
Q_T = Total gas emission rate from a landfill, volume/time.
n = Total time periods of waste placement.
k = Landfill gas emission constant, time^{-1}.
L_o = Methane generation potential, volume/mass of waste.
t_i = Age of the ith section of waste, time.
M_i = Mass of wet waste, placed at time i.

Example (5.1)

A landfill cell is open for four years, receiving 90,000 tons of waste per year (recall that 1 ton = 1000 kilograms). Find the peak gas production for the first year if the landfill gas emission constant is 0.03 per year, and the methane generation potential is 140 m^3/ton.

[9] This model can be downloaded at http://www.epa.gov/ttn/catc/products.html#software.

Solution

1) Given: Mi =90000 t/yr, k = 0.03, Lo = 140, ti = 1

$$Q_T = \sum_{i=1}^{n} 2k\ L_o M_i\ e^{-kti}$$

2) For the first year,

Q_T = 2 (0.03) (140) (90000)($e^{-0.0307(1)}$) = 733657 m^3

Depth of leachate in the lining can be estimated using Darcy's law and continuity equation, depending on: rates of filtration, permeability of drainage materials, distance from discharge tube, slope of drainage system. Equation 5.3 illustrates depth of leachate estimates.

$$Y_{max} = \frac{P}{2}\left(\frac{q}{k}\right)\left[\frac{k.\tan^2\alpha}{q} + 1 - \frac{k.\tan\alpha}{q}\left(\tan^2\alpha + \frac{q}{k}\right)^{\frac{1}{2}}\right] \qquad (5.3)$$

Where:
Y_{max} = Maximum saturated depth over the liner, ft
P = Distance between collection pipes, ft
q = Vertical inflow (infiltration), defined in this equation as from a 25-year, 24-hour storm, ft/day
α = Inclination of liner from horizontal, degrees
K = Hydraulic conductivity of the drainage layer, ft/day

Needed land area can be found from estimates of required volume from equation 5.4.

$$V = \frac{W}{\rho}\left(1 - \frac{x}{100}\right) + v_r \qquad (5.4)$$

Where:
V = Volume of sanitary landfill area.
W = Weight of SW to be buried.
ρ = Average density of SW and garbage.
x = Percentage of compressed SW volume,%
Vr = Volume of a layer of coverage required (thickness of 15 to 30 cm for medium layers, temporary edge and front and overhead slope, and at least 60 cm in the final layer) and that this volume ranges between 17% of volume of SW for deep burial to 33% for surface burial and in average 25 per cent.

Average sanitary landfill volume can be estimated as shown in equation 5.5.

$$V = 1.25\,\frac{W}{\rho}\left(1 - \frac{x}{100}\right) \qquad (5.5)$$

Exercise (5)

1) Find the percolation of water through a sanitary landfill assuming the amount of rainfall is 1200 mm per year, and transpiration 480 mm/year. Assuming a runoff coefficient of 0.14.

2) Estimate the percolation of water through a landfill 15 m deep, with a 1.2 m cover of sandy loam soil. Use the following data:
   - P = 1000 mm/yr
   - R = 0.12
   - E = 600 mm/yr
   - Soil field capacity, F_s = 200 mm/m
   - Refuse field capacity, F_r = 300 mm/m, as packed.
3) Find the percolation of water through a sanitary landfill assuming the amount of rainfall is 1500 mm per year, and transpiration 600 mm/year. Assuming a runoff coefficient of 0.13.
4) A landfill cell is open for three years, receiving 180,000 tonnes[10] of waste per year. Calculate the peak gas production in the first year if the landfill-gas emission constant is 0.03 yr^{-1} and the methane generation potential is 150 m^3/tonne.
5) Find maximum design depth above lining noting that distance between leachate collection tubes is 12 meters. Using a coarse discharge material and assuming that rain water from 25 years and a storm entering the leachate drainage system of a 24-hour, design storm (vertical flow) = 0.018 cm/min, and hydraulic conductivity 0.015 cm/s, and slope of discharge 1.5 percent.
6) Determine the spacing between pipes in a leachate collection system using granular drainage material and the following properties. Assume that in the most conservative design all stormwater from a 25-year, 24-hour storm enters the leachate collection system.
   - Design storm (25 years, 24 hours) = 8.2 in = 0.015 cm/min
   - Hydraulic conductivity = 0.01 cm/s
   - Drainage slope = 2%
   - Maximum design depth on liner = 16 cm.

[10] 1 tonne = 1000 kg

Chapter 6
Biochemical processes, combustion and energy recovery

Municipal solid waste, MSW, components reliable for bioconversion processes are: garbage (food waste), paper products, and yard wastes for their cellulose content. All methods of biochemical conversion (anaerobic digestion, composting) use the organic fraction of refuse. Decay of organic matter under anaerobic conditions produces end-products that include gases such as: methane (CH_4), carbon dioxide (CO_2), small amounts of hydrogen sulfide (H_2S), ammonia (NH_3), and a few others

Ideally, production of methane and carbon dioxide can be calculated using equation 6.1 if chemical composition of a material is known.

$$C_a H_b O_c N_d + \left(\frac{4a-b-2c+3d}{4}\right) H_2O \rightarrow \left(\frac{4a+b-2c-3d}{8}\right) CH_4 + \left(\frac{4a-b+2c+3d}{8}\right) CO_2 + dNH_3 \qquad (6.1)$$

Example (6.1)

Estimate the production of CO_2 and CH_4 during the anaerobic decomposition of Acetic acid, CH_3COOH.

Solution

1) Given: Reactants and products.
2) The formula for acetic acid is CH_3COOH

$$C_a H_b O_c N_d + \left(\frac{4a-b-2c+3d}{4}\right) H_2O \rightarrow \left(\frac{4a+b-2c-3d}{8}\right) CH_4 + \left(\frac{4a-b+2c+3d}{8}\right) CO_2 + dNH_3$$

3) The formula for acetic acid is CH_3COOH, hence by above equation
   A = 2, b = 4, c = 2 and d =0
   $CH_3COOH + \{(8-4-4+0)/4\}H_2O = \{(8+4-4-0)/8\}\ CH_4 + \{8-4+4+0)/8\}\ CO_2$
   $CH_3COOH = CH_4 + CO_2$
4) Note that the equation balances.
5) The molecular weight are 58 = 1(16) + 1(44). Hence, I kg of acetic acid produces 0.27 kg CH_4 and 0.73 kg CO_2.
6) Recalling that 1 gm. Molecular weight of a gas at standard temperature and pressure occupies 22.4 liters, the production of CO_2 and CH_4 from one kg of acetic acid is liters each of methane and carbon dioxide.

In the beginning of composting process, mesophilic[11] microorganisms are frequent with most of occurring biochemical reactions being attributed to them. The increase in these organisms, after about a week, increases the temperature of compost which limits growth of these organisms to be replaced by thermophilic[12] organisms. When the temperature drops, it usually means that the

[11] Mesophiles live in medium temperature ranging from 25 to 45oC.
[12] Thermophiles are microorganisms that live at high temperatures, above 45oC.

compost needs to be aerated, or watered, or that composting is complete. It is desirable to work at a temperature between 60 to 75° C for complete digestion.

A critical variable in composting is the moisture content. If the mixture is too dry, the microorganisms cannot survive, and composting stops. If there is too much water, the oxygen from the air is not able to penetrate to where the microorganisms are, and the mixture becomes anaerobic. The right amount of moisture, whether wastewater sludge or other sources of water, that needs to be added to the solids to achieve just the right moisture content can be calculated from a simple mass balance as presented in equation 6.2.

$$M_P = \frac{M_a\, x_a + 100\, x_s}{x_s + x_a} \qquad (6.2)$$

Where:

M_p = Moisture in mixed pile (heap) ready to begin process of composting, %.

M_a = Moisture in solids as in shredded and screened refuse, %.

x_a = Mass of solids, wet tons.

x_s = Mass of sludge or other source of water, ton. (This assumes that the solids content of the sludge is very low, a good assumption if waste activated sludge is used, which is commonly less than 1 percent solids).

Example (6.2)

A mixture of paper, newspapers and potentially composted materials of mass 6 tons, amount of moisture content in it is 5 percent. It is required to make a mixture for the process of composting of moisture content of 50 percent moisture. Find amount of water or wastewater sludge to be added to the solids of this MSW to obtain desired concentration of moisture content of the heap to start the process of composting.

Solution

1) Given: Data: xa = 6 tons, Ma = 5%, MP = 50%.
2) Use equation to find amount of water needed xs from wastewater:

$$M_P = \frac{M_a\, x_a + 100\, x_s}{x_s + x_a}$$

$$50 = \frac{(5 \times 6) + 100\, x_s}{x_s + 6}$$

Then, xs = 5.4 tons from water or from wastewater sludge.

Estimation of carbon and nitrogen levels and the C/N ratio is based on mass balances. If two materials such as shredded refuse and sewage sludge are mixed, the carbon of the mixture is calculated as shown in equation 6.3.

$$C_p = \frac{c_r\, x_r + c_s\, x_s}{x_r + x_s} \qquad (6.3)$$

Where

C_p = Carbon concentration in the mixture prior to composting, as percent of total wet mass of mixture.

C_r = Carbon concentration in the refuse, as percent of total wet refuse mass.

C_s = Carbon concentration in the sludge, as percent of total wet sludge mass.

X_s = Total mass of sludge, wet tons per day.

X_r = Total mass of refuse, wet tons per day.

MSW and refuse can be burned as is, or it can be processed to improve its heat value and to make it easier to handle in a combustor. Processed refuse also can be combined with other fuels (such as coal) and co-fired in a heat recovery combustor or can be used to provide electrical power for the community. Amount of oxygen necessary to oxidize some hydrocarbon is known as stoichiometric oxygen. Usually, refuse is not burned using air as the source of oxygen. Since air contains 23.15% oxygen by weight, then stoichiometric air required can be determined from equation 6.4.

Stoichiometric air = stoichiometric oxygen/ 0.2315 (6.4)

Example (6.3)

Calculate the stoichiometric oxygen and stoichiometric air required for the combustion of methane gas.

Solution

1) The equation for combustion of methane is
   $CH_4 + 2O_2 = CO_2 + 2H_2O$
2) That is, it takes 16 grams of methane (12 + 4) to react with 2x2x16 = 64 moles of oxygen. Thus, stoichiometric oxygen required for combustion of methane is 64/16 = 4 g O_2/g CH_4
3) Stoichiometric air requirement = 4/0.2315 = 17.3 g air/g methane.

In a power plant, water is heated to steam in a boiler. Steam is used to turn a turbine, which drives a generator. This process can be simplified to a simple energy balance where energy in has to equal energy out (energy wasted in the conversion + useful energy) plus energy accumulated in box (energy changed in form) as presented in equation 6.5.

[Rate of energy accumulated] = [Rate of energy in] - [Rate of energy out] + [[Rate of energy produced] – [Rate of energy consumed] (6.5)

Energy systems in steady state are defined as no change occurring over time. As such, there cannot be a continuous accumulation of energy, or if some of the energy out is useful and the rest is wasted and the equation 6.5 becomes 6.6.

[Rate of energy in] = [Rate of energy out] (6.6)

[Rate of energy IN] = [Rate of energy used] + [Rate of energy wasted] (6.7)

Efficiency (E %) of process can be calculated as indicted in equation 6.8.

$$E = \frac{\text{Energy used}}{\text{Energy in}} x100 \qquad (6.8)$$

A thermal balance on a large combustion unit is difficult because much of the heat cannot be accurately measured. Assuming recovery of heat as steam in a combustor, input heat to a black box (see figure 6.1) is from heat value in the fuel and heat in the water entering the water-wall pipes. The output is the sensible heat in the stack gases, the latent heat of water, the heat in the ashes, the heat in the steam, and the heat lost due to radiation. If the process is in a steady state, the equation of thermal balance can be as indicated in equation 6.9.

[Rate of heat accumulated] = [Rate of heat in the fuel] + [Rate of heat in the water] -[Rate of heat out in the stack gases] - [Rate of heat out in the stem] - [Rate of heat out as latent heat of vaporization] – [Rate of heat out in the ash] - [Rate of heat loss due to radiation] (6.9)

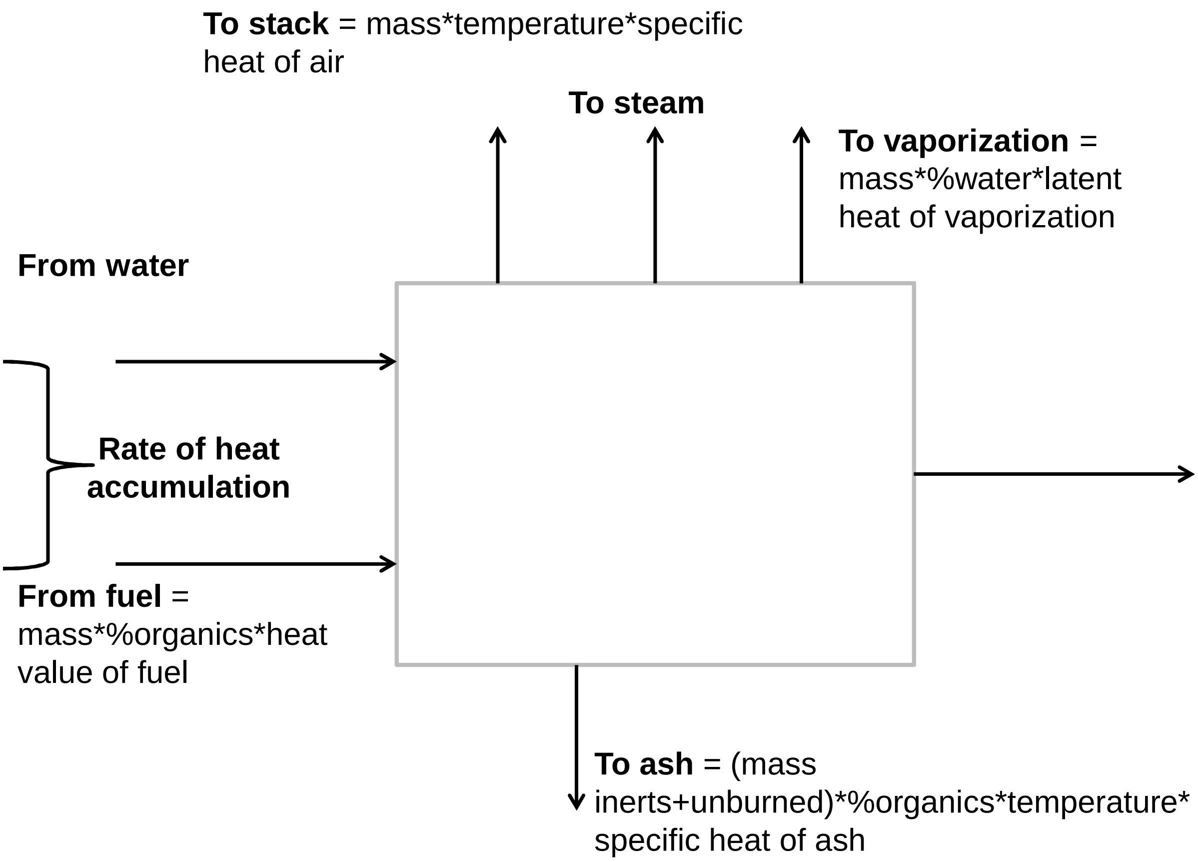


Figure 6.1: Energy flow in a combustor.

Example (6.4)

A refractory combustion unit lined with no water wall and no heat recovery is burning refuse-derived fuel (RDF) consisting of 80% organics, 12% water, and 8% inorganics or inerts at a rate of 19,920 kg/d. Determine the temperature of the stack gases, assuming the following:

- Heat value of the fuel = 19,000 kJ/kg on a moisture-free basis.
- Air flow = 8,300 kg/h and that the under- and over fire air contributes negligible heat.
- 7% of the heat input is lost due to radiation.
- 15% of the fuel remains un-combusted in the ash.
- ash exits the combustion chamber at a temperature = 750^{o}C.
- Specific heat of ash = 0.837 kJ/kg/^{o}C..
- Specific heat of air is 1.0 kJ/kg/^{o}C.
- Latent heat of vaporization = 2575 kJ/kg.

Solution

1) Given: RDF 80% organics, 12% water, 8% inorganics or inerts , RDF rate = 19,920 kg/d = 19920/24 = 830 kg/hr, Heat value of the fuel = 19,000 kJ/kg, Air flow = 8,300 kg/hr, Heat input is lost due to radiation = 7%, Fuel remaining uncombusted in the ash = 15%, Ash temperature = 750^{o}C, Specific heat of ash = 0.837 kJ/kg/^{o}C, Specific heat of air is 1.0 kJ/kg/^{o}C, Latent heat of vaporization = 2575 kJ/kg.
2) Draw balance box as follows:

To stack = mass*temperature*specific heat of

To stack = heat of combustion – heat losses

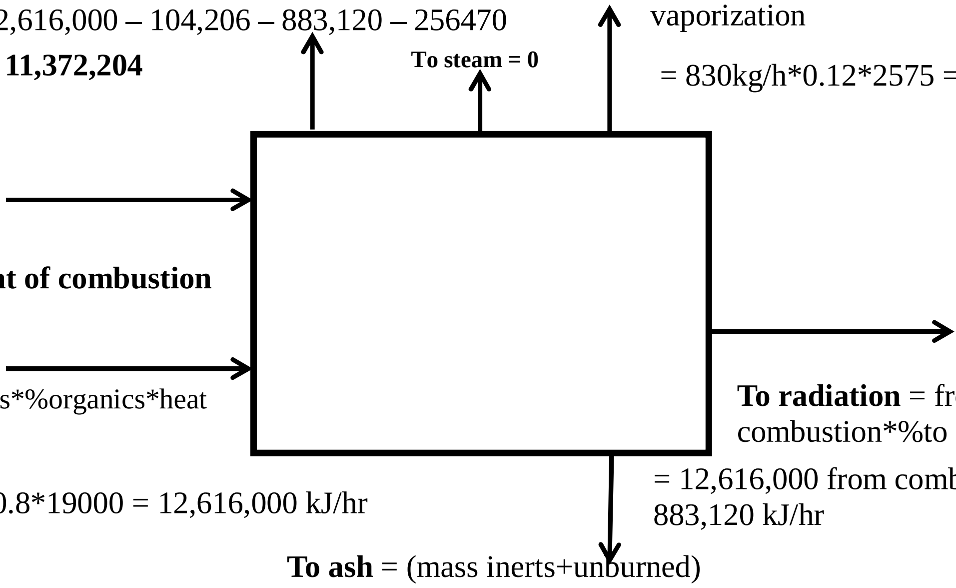
= 12,616,000 – 104,206 – 883,120 – 256470

= 11,372,204

To steam = 0

To vaporization = mass*%water*latent heat of vaporization

= 830kg/h*0.12*2575 = 256,470 kJ/hr



Heat of combustion

From fuel = mass*%organics*heat value of fuel

830 kg/hr *0.8*19000 = 12,616,000 kJ/hr

To radiation = from combustion*%to radiation

= 12,616,000 from combustion*0.07 = 883,120 kJ/hr

To ash = (mass inerts+unburned) *%organics*temperature*specific heat of

= (830*0.08 inerts + 830*0.8 organics *0.15uncombusted)*750*0.837 = 104,206.5 kJ/hr

Energy flow in a combustor

Heat to stack = mass*temperature*specific heat of = 8300 kg/hr*T*1kJ/kg^{o}C = 11372204

Temperature of stack gases = 1370 ^oC = (1370*9/5) +32 = 2499 ^oF

Exercise (6.1)

1) The three components of MSW of greatest interest in the bioconversion processes are: garbage (food waste), paper products, and yard wastes. What are the main factors that affect variation of garbage fraction of refuse?
2) Theoretically, the combustion of refuse produced by a community is sufficient to provide about 20% of the electrical power needs for that community. Discuss this statement.

Exercise (6.2)

1) Write down a balanced equation for the anaerobic decomposition of glucose. Estimate amount and volume produced (at STP)[13] of CO_2 and CH_4 during the anaerobic decomposition of glucose.
2) Estimate production of CO_2 and CH_4 during the anaerobic decomposition of municipal solid waste, MSW using the chemical composition approximation of organic fraction of refuse as described by $C_{99}H_{149}O_{59}N$.
3) 12 tons of a mixture of paper and other compostable materials has a moisture content of 8%. The intent is to make a mixture for composting of 60% moisture. How many tons of water or sludge must be added to the solids to achieve this moisture concentration in the compost pile?
4) Methane and carbon dioxide generation by anaerobic digestion can be calculated using the following equation:

$$C_aH_bO_cN_d + \left(\frac{4a-b-2c+3d}{4}\right)H_2O \rightarrow \left(\frac{4a+b-2c-3d}{8}\right)CH_4 + \left(\frac{4a-b+2c+3d}{8}\right)CO_2 + dNH_3$$

   Given the chemical composition of ethanol C_2H_5OH, propionic acid CH_3CH_2COOH and butyric acid $C_4H_8O_2$
   a) Write down the chemical reaction equations for the production of CO_2 and CH_4 during any anaerobic decomposition of the stated compounds.
   b) Compute amount of methane and carbon dioxide to be produced from anaerobic digestion of one kilogram of each compound.
   c) Determine total volume, in liters, of gases produced.
5) A coal-fired power plant uses 800 Mg[14] of coal per day. The energy value of the coal is 28,000 kJ/kg (kiloJoules/kilogram). The plant produces 3.2×10^6 kWh[15] of electricity each day. What is the efficiency of the power plant?
6) A combustion unit is burning refuse-derived fuel (RDF) consisting of 75% organics, 15% water, and 10% inorganics (inerts) at a rate of 1000 kg/h. Compute the temperature of the stack gases assuming the following:
   a) Heat value of the fuel = 15,000 kJ/kg on a moisture-free basis.

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[13] STP is used for expression of the properties and processes of ideal gases. The standard temperature is the freezing point of water and the standard pressure is one standard atmosphere. Standard temperature: 0°C = 273.15 K; Standard pressure = 1 atmosphere = 760 mmHg = 101.3 kPa ; Standard volume of 1 mole of an ideal gas at STP: 22.4 liters

[14] Megagrams, or 1000 kg, commonly called a metric tonne.

[15] 1 kWh = 3.6×10^6 Joule

b) Unit is refractory lined with no water wall and no heat recovery andd under- and overfire air contributes negligible heat.
c) Air flow = 8,000 kg/h.
d) 8% of the heat input is lost due to radiation
e) 10% of the fuel remains uncombusted in the ash,
f) Ash exits the combustion chamber at a temperature of 600^{o}C.
g) specific heat of ash is 0.837 kJ/kg/^{o}C,
h) Specific heat of air is 1.0 kJ/kg/^{o}C.
i) Latent heat of vaporization = 2258 kJ/kg.

7) A refractory combustion unit lined with no water wall and no heat recovery is burning refuse-derived fuel (RDF) consisting of 85% organics, 10% water, & 5% inorganics or inerts at a rate of 950 kg/hr. Determine the temperature, T, at which ash exits the combustion chamber (in both ^{o}C and ^{o}F), assuming the following:
   Heat value of the fuel = 19,000 kJ/kg on a moisture-free basis.
   Air flow = 9,500 kg/h & that the under- & overfire air contributes negligible heat.
   5% of the heat input is lost due to radiation
   15% of the fuel remains uncombusted in the ash
   Specific heat of ash = 0.837 kJ/kg/^{o}C,
   Specific heat of air is 1.0 kJ/kg/^{o}C.
   Latent heat of vaporization = 2575 kJ/kg.
   Temperature of the stack gases = 1500^{o}C

Chapter Seven
Financing solid waste facilities

Solid waste may be defined as garbage, refuse and other solid material derived from any agricultural, commercial, consumer or industrial operation or activity if it is both: used material or residual material, and reasonably expected to be introduced into a qualified[16] solid waste disposal process within a reasonable time after such purchase or acquisition.

Solid waste financing or funding concerns revenues and costs which vary with specifics of the solid waste system, ownership and contractual arrangements and complexity of financial system. Revenue and profit for solid waste operations may be received from: sale of services and goods, garbage bill paid by home or business, tipping fees at disposal site, sale of recyclables and sale of products such as landfill gas or electricity from waste-to-energy plant. The initial cost of the facility (or its capital cost) is an important one-time investment that may be paid from budget of the municipality or agency, or proceeds of bank loans, or general obligation bonds, or revenue bonds etc...

Capital cost and capital recovery factor

The capital costs of competing facilities can be projected by determining the cost that the municipality or agency would incur if it were to pay interest on a loan of that amount and value. Computing the annual cost of a capital investment resembles computing the annual cost of a loan or mortgage on a building or land. The municipality or agency borrows the money from a moneylender or a financier or bank and then has to pay it back in a number of equal installments. If the municipality borrows (X) dollars and aims to pay back the loan in (n) number of installments at an interest rate of (i), each installment can be found as presented in equation 7.1.

$$Y = \left[\frac{i(1+i)^n}{(1+i)^n - 1}\right] X \tag{7.1}$$

Where

Y = Installment cost.

i = Annual interest rate (enter interest (i) in decimal form i.e. as a fraction).

[16] A qualified solid waste disposal process may employ any biological, engineering, industrial or technological method. Eligible types of solid waste disposal processes include a final disposal process, an energy conversion process and a recycling process. A final disposal process is either the placement of solid waste in a landfill, the incineration of solid waste without capturing any useful energy, or the containment of solid waste with a reasonable expectation that the containment will continue indefinitely and that the solid waste has no current or future beneficial use. Energy conversion process encompasses a thermal, chemical or other process that is applied to solid waste to create and capture synthesis gas, heat, hot water, steam or other useful energy. The energy conversion process ends before any transfer or distribution of synthesis gas, heat, hot water, steam or other useful energy. Recycling process regards a process reconstituting, transforming or otherwise processing solid waste into a useful product (http://www.squiresanders.com/tax_exempt_financing_of_solid_waste_disposal_facilities/).

n = Number of installments.
X = Amount borrowed.

A capital recovery factor, CRF, is defined as shown in equation 7.2

$$CRF = \left[\frac{i(1+i)^n}{(1+i)^n - 1}\right] \qquad (7.2)$$

Equations 7.1 and 7.2 can be combined as revealed in equation 7.3.

$$Y = CRF*X \qquad (7.3)$$

Example

A municipality decides to purchase a refuse collection truck that has an expected life of 10 years for SAR[17]590,000. Cost of the truck is to be borrowed from the local bank and to be paid back in 10 annual payments. Determine the annual installments on this capital expense if the interest rate is 6.125%

Solution

1. Given: t = 10 yr., cost of truck, X = SAR 590,000, payments = 10, i = 6.125%.
2. From Table (7.2), the capital recovery factor, CRF for n years = 10 is 0.13667. or:

$$\left[CRF = \frac{i(1+i)^n}{(1+i)^n - 1} = \right] = \left[\frac{0.06125(1+0.06125)^{10}}{(1+0.06125)^{10} - 1}\right] = 0.136674$$

3. The annual cost to the municipality would then be, Y = CRF * X = 0.13667 * 590,000 or Y = SAR 80,636.
4. That is, the municipality would have to pay SAR 80,636 each year for 10 years to pay back the bank loan on this truck.
5. It is to be noted that this truck does not cost 10 * 80,636 = SAR 800,636, because the Saudi riyals for each year are different and cannot be augmented and added.

Present worth value and present worth factor

The actual cost of a capital investment also may be estimated by evaluating the present worth value or the value on a given date of a payment made at other times. This concerns finding amount to be invested at the moment (present), (Y) dollars, at a certain interest rate (i) to have available (X) dollars every year for (n) number of years. The relationship can be figures as presented in equation 7.4.

$$Y = \left[\frac{(1+i)^n - 1}{i(1+i)^n}\right]X \qquad (7.4)$$

Where

[17] 1 United States dollar, US$ ≈ 3.8 Saudi Arabia Riyal, SAR.

Y = Amount that has to be invested.
i = Annual interest rate.
n = Number of years.
X = Amount available every year.

A present worth factor, PWF can be introduced as shown in equation 7.5

$$PWF = \left[\frac{(1+i)^n - 1}{i(1+i)^n}\right] \qquad (7.5)$$

Then, by combining equations 7.4 and 7.5, equation 7.6 is obtained.

$$Y = PWF*X \qquad (7.6)$$

Example

A town wants to invest money in a bank account drawing an interest rate of 6.125% so that it can withdraw SAR 80,636 every year for the next 10 years. Compute the amount that must be invested?

Solution

1. Given: i = 6.125%, withdraw, X = SAR 80,636, n = 10 yr.
2. From Table (7.2), the present worth factor (PWF) for n = 10 is 7.316.
3. Thus, the money required, Y = PWF*X = 7.316 x SAR 80,636 or Y = SAR 590,000.

Sinking fund and sinking fund factor

Sinking fund may be defined as a fund established by a municipality or government agency or business for the purpose of reducing debt by repaying or purchasing outstanding loans and securities held against the entity. This indicates that a sinking fund would be a sum of money set up to collect a certain amount of money to pay for purchasing a certain commodity or paying the bill of a major work. This means that the municipality or agency is saving money by investing it so that at some later date it would have available some specified sum. An example of such a fund in solid waste engineering is for the case of landfill entity investing money during the active life of the landfill so that, when the landfill is full, sufficient funds would be available to place the required final landfill cover.
Equation 7.7 illustrates how to determine the funds (Y) necessary to be invested in an account that draws (i) percent interest so that at the end of (n) years the fund has (X) value in it.

$$Y = \left[\frac{i}{(1+i)^n - 1}\right] X \qquad (7.7)$$

A sinking fund factor, SFF may be introduced as shown in equation 7.8.

$$SFF = \left[\frac{i}{(1+i)^n - 1}\right] \qquad (7.8)$$

Example

A local solid waste enterprise aspires to have SAR 2 million available at the end of a 10 year period by investing annually into an account that gives an interest of 6.125%. Find the amount the enterprise has to invest annually?

Solution

1. Given: X = SAR 2,000,000, t = 10 yr., i = 6.125%
2. From Table (7.2), the sinking fund factor (SFF) at 10 years is 0.07452.
3. The required annual investment is therefore Y = SFF*X = 0.07452 x SAR 2,000,000 or Y = SAR 149,040.
4. Note that the value of money of 10*149,040 = SAR 1,490,040 is significantly less than SAR 2,000,000. This is because the investments during the early years are drawing interest and adding to the sum available.

Table (7.1) gives a general summary of selected compounding factors.

Table (7.1) Summary of selected compounding factors.

Factor	Abbreviation	Equation	Use	Examples
Compound amount	CA	$\left[(1+i)^n\right]$		
Capital recovery factor	CRF	$\left[\frac{i(1+i)^n}{(1+i)^n - 1}\right]$	Pay loan back in a number of equal installments. Converts a present value into a stream of equal annual payments over a specified time.	
Present worth factor	PWF	$\left[\frac{(1+i)^n - 1}{i(1+i)^n}\right]$	how much to be invested right now	
sinking fund factor	SFF	$\left[\frac{i}{(1+i)^n - 1}\right]$	saving money by investing it so that at some later date some specified sum would be available	When landfill owner must invest money during active life of landfill so that, when landfill is full, there are sufficient funds to place final cover.

The capital recovery factor, present worth factor and sinking fund factors need not be computed, since they can be found in interest tables or are programmed into hand-held calculators or computer software. Table (7.2) shows these capital recovery factors for an interest rate of 6.125%.

Table (7.2) Capital recovery factors for an interest rate of 6.125%

Year	CRF	PWF	SFF
1	1.06125	0.942285041	1
2	0.546392511	1.83018614	0.485142511
3	0.374975336	2.666842064	0.313725336
4	0.289417974	3.455210425	0.228167974
5	0.238204237	4.198078139	0.176954237
6	0.204161994	4.898071274	0.142911994
7	0.179931702	5.557664333	0.118681702
8	0.161833535	6.179189007	0.100583535
9	0.147823104	6.764842409	0.086573104
10	0.136673733	7.31669485	0.075423733
11	0.127604778	7.836697149	0.066354778
12	0.120095776	8.326687537	0.058845776
13	0.113786379	8.788398151	0.052536379
14	0.10841917	9.223461155	0.04716917
15	0.103805354	9.633414516	0.042555354
16	0.099803313	10.01970744	0.038553313
17	0.096304735	10.38370548	0.035054735
18	0.093225356	10.72669538	0.031975356
19	0.090498641	11.04988964	0.029248641
20	0.088071346	11.35443076	0.026821346

Key:

CRF = Capital Recovery Factor = $\left[\dfrac{i(1+i)^n}{(1+i)^n - 1}\right]$

PWF = Present Worth Factor $= \left[\dfrac{(1+i)^n - 1}{i(1+i)^n}\right]$

SFF = Sinking Fund Factor $= \left[\dfrac{i}{(1+i)^n - 1}\right]$

Total cost

Total cost to the community is the sum of the annual payback of the capital costs (fixed costs) of the investments and the labor and raw materials costs and operating and maintenance costs (variable costs).

Example

A municipality wants to purchase a refuse collection truck that has an expected life of 10 years and costs SAR 590,000. The municipality preferred to pay back the loan in 10 annual installments at an interest rate of 6.125%. The annual operation cost of the truck (gas, oil, service and regular maintenance) amounts to SAR 80,000. How much will this truck cost the municipality every year?

Solution

1. Given: n = 10 years, X = SAR 590,000, i = 6.125%. truck operating cost = SAR 80,000/yr
2. From Table, the capital recovery factor for n = 10 is 0.13667
3. so the annual cost of the capital investment is y = CRF*X = 0.13667 x SAR 590,000 or Y = SAR 80,636.
4. Total annual cost to the community = operating cost + annual investment = SAR 80,636 + SAR 80,000 or Total cost = SAR 160,,636.

Exercise (7)

1. A municipality decides to purchase a refuse collection truck that has an expected life of 15 years for SAR 700,000. Cost of the truck is to be borrowed from the local bank and to be paid back in 15 annual payments. Determine the annual installments on this capital expense if the interest rate is 6.125%
2. A municipality decides to purchase a refuse collection truck that has an expected life of 20 years for SAR 980,000. Cost of the truck is to be borrowed from the local bank and to be paid back in 20 annual payments. Determine the annual installments on this capital expense if the interest rate is 6.125%
3. A municipality chooses to purchase a refuse collection truck that has an expected life of 15 years for the value of SAR 650,000. The cost of the truck is to be borrowed from the local bank and to be paid back in 10 annual payments. Given that the annual installments on this capital expense is SAR 67,500. Find the rate of interest.
4. A town wants to invest money in a bank account drawing an interest rate of 6.125% so that it can withdraw SAR 90,500 every year for the next 10 years. Compute the amount that must be invested?
5. A local solid waste enterprise aspires to have SAR 1.8 million available at the end of a 10 year period by investing annually into an account that gives an interest of 6.125%. Find the amount the enterprise has to invest annually?
6. A municipality wants to purchase a refuse collection truck that has an expected life of 15 years and costs SAR 700,000. The municipality preferred to pay back the loan in 15 annual installments at an interest rate of 6.125%. The annual operation cost of the truck (gas, oil, service and regular maintenance) amounts to SAR 72,000. How much will this truck cost the municipality every year?

References

1) Abdel-Magid, I. M., Hago, A. and Rowe, D. R., Modeling methods for environmental engineers, CRC Press/ Lewis Publishers, Boca Raton FL, 1995.
2) Abdel-Magid, I.M, Solid waste engineering and management, Sudan Academy Distributing and Publishing House, Scientific Books Series No. 1, Sudan Academy for Sciences, Khartoum, 2006 (In Arabic).
3) Anschutz, J., Ijgosse, J., and Scheinberg, A., Putting integrated sustainable waste management into practice. Using the ISWM assessment methodology, WASTE, Gouda, The Netherlands, 2004.
4) Blackman, W. C., Basic hazardous waste management, Lewis Publishers CRC Press LLC, Boca Raton, 2001.
5) Brown, R. P., Greenwood, J. H., Practical Guide to the Assessment of the Useful Life of Plastics, ERA Technology Ltd., Shropshire, SY, 2002.
6) de Bertoldi, M., Science of composting, Springer; 1996,
7) Chandler, A. J., Eighmy, T. T., Hartlen, J., Hjelmar, O., Kosson, D. S., Sawell, S. E., Vehlow, J., Municipal solid waste incinerator residues, the international ash working group, Studies in Environmental Science 67, Elsevier, Amsterdam, 1997.
8) Cheremisinoff, N. P., handbook of solid waste management and Waste minimization technologies, Burlington, MA, Elsevier Science, 2003.
9) Cheremisinoff, N. P., Consulting engineer handbook of solid waste management and waste minimization technologies, Butterworth-Heinemann.
10) CEHA, Solid waste management in some countries of the Eastern Mediterranean region, WHO, Eastern Mediterranean Regional Office, Regional Centre for Environmental Health Activities, Amman, Jordan, CEHA Document No. , Special studies, ss-4, 1995.
11) Davis, M. L. and Cornwell, D. A., Introduction to environmental engineering, McGraw-Hill Science, New York, 2006.
12) Dulac, N., The organic waste flow in integrated sustainable waste management, Waste, Gouda, The Netherlands, 2001.
13) Envirodyne, E., Beveridge and Diamond, P. C., Municipal solid waste management options Vol. 1-4, Illinois Department of Energy and Natural Resources, Office of Solid Waste and Renewable Resources, Spring field, IL, ILENR/RR- 89/06, 1989.
14) Franchetti, M. J., Solid waste analysis and minimization: a systems approach: The systems approach, McGraw-Hill Companies, Inc., New York, 2009.
15) Gören, S., Sanitary Landfill, Fatih University, Istanbul, 2004Henry, J. G. and Heinke, G. W., Environmental science and engineering, Prentice Hall, Englewood Cliffs. N. J., 1989.
16) Hibrawi, K., Engineering encyclopedia environmental treatment of solid waste, Saudi Aramco DeskTop Standards.
17) Hoornweg. D., Thomas, L. and Otten, L., Composting and its applicability in developing countries, Working Paper Series, 8, Published for the Urban Development Division, The World Bank, Washington, DC., 1999.
18) Johannessen, L. M. and Boyer, G., Observations of solid waste landfills in developing countries, Africa, Asia and Latin America, Urban Development Division, Waste Management Anchor Team, The World Bank, Washington, DC., 1999.
19) Kindlein, J., Dinkler, D. and Ahrens, H., Verification and application of coupled models for transport and reaction process in sanitary landfills, Proceedings Sardinia, Ninth

International Waste Management and Landfill Symposium, S. Marghorita di Pula, Cagliari, Italy, 6 – 10 October 2003.
20) Kumar, E. S., Waste management, Intech, Olajnica, India, 2010.
21) Maczulak, A. E., Cleaning up the environment: hazardous waste technology, Anne Maczulak, New York NY, 2009.
22) McDougall, F.R., White, P.R., Franke, M. and Hindle, P., Integrated solid waste management: a life cycle inventory, Blackwell Science Ltd, Oxford, 2009.
23) Ojovan, M. I., Edi., Handbook of advanced radioactive waste conditioning technologies, Woodhead Publishing Ltd., 2011
24) Peavy, H. S., Rowe, D. R., Tchobanglous, G., Environmental engineering, McGraw-Hill Book Co., New York, 1985.
25) Perry, R. H., Green, D. W. and Maloney, J. O., Edi., Perry's Chemical Engineers' Handbook, McGraw-Hill Professional; 8 edition, 2007.
26) Popel, J. H., Storage, collection and transportation of domestic refuse, Delft University of Technology. Delft, 1971.
27) Proceedings Sardinia, Ninth International Waste Management and Landfill Symposium, S. Marghorita di Pula, Cagliari, Italy, 745 scientific papers, 6 – 10 October 2003
28) Rodic-wiersma, L., Introduction to solid waste management and engineering, Refresher course on solid waste management and engineering, organized by UNESCO-IHE Institute for water education, Delft, The Netherlands, 16 – 22 October 2005, Mombasa, Kenya.
29) Rietema, K., On the efficiency in separating mixtures of two components, Chemical Engineering Science, 7, 89, 1957.
30) Rood, M. J., Technological and economic evaluation of municipal solid waste incineration, OTT-2, Sept. 1988, University of Illinois Center for Solid Waste Management and Research office of Technology Transfer, Chicago, IL, 1988.
31) Salvato, J. A., Environmental Engineering and Sanitation, A Wiley-Interscience Publication, New York, 1982.
32) Schubeler, P., Wehrle, K. and Christen, J., Conceptual framework for municipal solid waste management in low-income countries, Urban Management and Infrastructure, UNDP, UNCHS (Habitat), World Bank, SDC Collaborative Program on Municipal Solid Waste Management in Low-Income Countries, August 1996, Working Paper No. 9, SKAT (Swiss Centre for Development Cooperation in Technology and Management), Gallen, Switzerland, 1996.
33) Senate, E., Galtier, L., Bekaert, C., Lambolez-Michel, L. and Budka, A., Odor management at MSW landfill sites: odor sources, odorous compounds and control measures, Proceedings Sardinia, Ninth International Waste Management and Landfill Symposium, S. Marghorita di Pula, Cagliari, Italy, 6 – 10 October 2003.
34) Shah, K. L., Basics of solid and hazardous waste management technology, Prentice Hall; 1999.
35) Sonnemann, G., Castells, F., Schuhmacher, M., Integrated life-cycle and risk assessment for industrial processes, Lewis Publishers CRC Press Co., Boca Raton, 2004.
36) Stokoe J. and Teague, E., Integrated solid waste, USDA Rural Utilities Service, Washington, D.C., 1995.

37) Suess, M. J. ed., Solid waste management: Selected topics, WHO, Regional Office for Europe, Copenhagen, 1985.
38) Tchobanoglous, G., Theisen, H., and Eliassen, R., Solid waste engineering principles and management issues, McGraw-Hill Kogakusha, Ltd, Tokyo, 1977.
39) Tchobanoglous, G., Theisen H. and Vigil S., Integrated solid waste management: Engineering principles and management issues, Mc-Graw-Hill International Editions, New York, 1993
40) Tchobanoglous, G. and Kreith, F., Handbook of solid waste management, McGraw-Hill Professional; 2002.
41) Tedder, D. W., Pohland, F. G., Emerging technologies in hazardous waste management 8, Kluwer Academic Publishers, New York, 2002.
42) Twardowska, E., Edi., Solid waste: assessment, monitoring and remediation, Waste Management Series, Volume 4, ELSEVIER B.V., Amsterdam, 2004.
43) Vesilind, P. A., Worrell, W. A. and Reinhart, D. R., Solid waste engineering, Brooks/Cole, Thomson Learning, Bill Stenquist Pub., Pacific Grove, CA, 2002.
44) Van de Klundert, A. and Anschutz, J., Integrated sustainable waste management – The concept, WASTE, Gouda, The Netherlands, 2001.
45) Walsh, P. and O'Leary, P., Implementing municipal solid waste to energy systems, University of Wisconsin – Extension for Great Lakes Regional Biogas Energy Program, 1986.
46) Worrell, W. A. and Vesilind, P. A., Solid waste engineering, CL-Engineering Pub., 2012.

Appendixes

Appendix (1): Typical specific weight and moisture content data for residential, commercial, industrial, and agricultural wastes [2,4,6,8,10,23-25,46].

	Specific weight, lb/yd^3		Moisture content, % by weight	
Type of waste	Range	Typical	Range	Typical
Residential (Compacted)				
Food wastes (mixed)	220 - 810	490	50 - 80	70
Paper	70 - 220	150	4 - 10	6
Cardboard	70 - 135	85	4 - 8	5
Plastics	70 - 220	110	1 - 4	2
Textiles	70 - 170	110	6 - 15	10
Rubber	170 - 340	220	1 - 4	2
Leather	170 - 440	270	8 - 12	10
Yard wastes	100 - 380	170	30 - 80	60
Wood	220 - 540	400	15 - 40	20
Glass	270 - 810	330	1 - 4	2
Tin cans	85 - 270	150	2 - 4	3
Aluminum	110 - 405	270	2 - 4	2
Other metal	220 - 1940	540	2 - 4	3
Dirt, ash, etc.	540 - 1685	810	6 - 12	8
Ashes	1095 - 1400	1255	6 - 12	6
Rubbish	150 - 305	220	5 - 20	15
Residential yard wastes				
Leaves (loose and dry)	50 - 250	100	20 - 40	30
Green grass (loose and moist)	350 - 500	400	40 - 80	60
Green grass (wet and compacted)	1000 - 1400	1000	50 - 90	80
Yard waste (shredded)	450 - 600	500	20 - 70	50
Yard waste (composted)	450 - 650	550	40 - 60	50
Municipal				
In compactor truck	300 - 760	500	15 - 40	20
In landfill				
Normally compacted	610 - 840	760	15 - 40	25
Well compacted	995 - 1250	1010	15 - 40	25
Commercial				
Food wastes (wet)	800 - 1600	910	50 - 80	70
Appliances	250 - 340	305	0 - 2	1
Wooden crates	185 - 270	185	10 - 30	20
Tree trimmings	170 - 305	250	20 - 80	5
Rubbish (combustible)	85 - 305	200	10 - 30	15
Rubbish (noncombustible)	305 - 610	505	5 - 15	10
Rubbish (mixed)	235-305	270	10-25	15
Construction and demolition				
Mixed demolition (noncombustible)	1685 -2695	2395	2-10	4
Mixed demolition (combustible)	505 -675	605	4-15	8
Mixed construction (combustible)	305 -605	440	4-15	8
Broken concrete	2020 -3035	2595	0- 5	-
Industrial				
Chemical sludges (wet)	1350 - 1855	1685	75 - 99	80
Fly ash	1180 - 1515	1350	2 - 10	4
Leather scraps	170 - 420	270	6 - 15	10
Metal scrap (heavy)	2530 - 3370	3000	0 - 5	-
Metal scrap (light)	840 - 1515	1245	0 - 5	-
Metal scrap (mixed)	1180 - 2530	1515	0 - 5	-
Oils, tars, asphalts	1350 - 1685	1600	0 - 5	2
Sawdust	170 - 590	490	10 - 40	20
Textile wastes	170 - 370	305	6 - 15	10
Wood (mixed)	675 - 1140	840	30 - 60	25
Agricultural				
Agricultural (mixed)	675 - 1265	945	40 - 80	50
Dead animals	340 - 840	605	-	-
Fruit wastes (mixed)	420 - 1265	605	60 - 90	75
Manure (wet)	1515 - 1770	1685	75 - 96	94
Vegetable wastes (mixed)	340 - 1180	605	60 - 90	75

IA	IIA	IIIB	IVB	VB	VIB	VIIB	VIIIB	VIIIB	VIIIB	IB	IIB	IIIA	IVA	VA	VIA	VIIA	VIIIA
1 **H** 1.00794																1 **H** 1.00794	2 **He** 4.002602
3 **Li** 6.941	4 **Be** 9.012182											5 **B** 10.811	6 **C** 12.0107	7 **N** 14.00674	8 **O** 15.9994	9 **F** 18.9984032	10 **Ne** 20.1797
11 **Na** 22.989770	12 **Mg** 24.3050											13 **Al** 26.981538	14 **Si** 28.0855	15 **P** 30.973761	16 **S** 32.066	17 **Cl** 35.4527	18 **Ar** 39.948
19 **K** 39.0983	20 **Ca** 40.078	21 **Sc** 44.955910	22 **Ti** 47.867	23 **V** 50.9415	24 **Cr** 51.9961	25 **Mn** 54.938049	26 **Fe** 55.845	27 **Co** 58.933200	28 **Ni** 58.6934	29 **Cu** 63.546	30 **Zn** 65.39	31 **Ga** 69.723	32 **Ge** 72.61	33 **As** 74.92160	34 **Se** 78.96	35 **Br** 79.904	36 **Kr** 83.80
37 **Rb** 85.4678	38 **Sr** 87.62	39 **Y** 88.90585	40 **Zr** 91.224	41 **Nb** 92.90638	42 **Mo** 95.94	43 **Tc** (98)	44 **Ru** 101.07	45 **Rh** 102.90550	46 **Pd** 106.42	47 **Ag** 107.8682	48 **Cd** 112.411	49 **In** 114.818	50 **Sn** 118.710	51 **Sb** 121.760	52 **Te** 127.60	53 **I** 126.90447	54 **Xe** 131.29
55 **Cs** 132.90545	56 **Ba** 137.327	57 **La*** 138.9055	72 **Hf** 178.49	73 **Ta** 180.9479	74 **W** 183.84	75 **Re** 186.207	76 **Os** 190.23	77 **Ir** 192.217	78 **Pt** 195.078	79 **Au** 196.96655	80 **Hg** 200.59	81 **Tl** 204.3833	82 **Pb** 207.2	83 **Bi** 208.98038	84 **Po** (209)	85 **At** (210)	86 **Rn** (222)
87 **Fr** (223)	88 **Ra** (226)	89 **Ac**** (227)	104 **Rf** (261)	105 **Db** (262)	106 **Sg** (265)	107 **Bh** (262)	108 **Hs** (265)	109 **Mt** (266)	110 **Ds** (269)	111 **Uuu** (272)	112 **Uub** (277)		114 **Uug** (289) (287)		116 **Uuh** (289)		118 **Uuo** (293)

* Lanthanide series	58 **Ce** 140.116	59 **Pr** 140.90765	60 **Nd** 144.24	61 **Pm** (145)	62 **Sm** 150.36	63 **Eu** 151.964	64 **Gd** 157.25	65 **Tb** 158.92534	66 **Dy** 162.50	67 **Ho** 164.93032	68 **Er** 167.26	69 **Tm** 168.93421	70 **Yb** 173.04	71 **Lu** 174.967
** Actinide series	90 **Th** 232.0381	91 **Pa** 231.03588	92 **U** 238.0289	93 **Np** (237)	94 **Pu** (244)	95 **Am** (243)	96 **Cm** (247)	97 **Bk** (247)	98 **Cf** (251)	99 **Es** (252)	100 **Fm** (257)	101 **Md** (258)	102 **No** (259)	103 **Lr** (262)

Appendix (2): Periodic Table of Elements.

Answers to practical exercises

Chapter one: Exercise (1.2)

1) 32%, 9%

Chapter two: Exercise (2.2)

1) 69.5%
2) 25.1 %
3) 30.8 %
4) 143 lb/yd^3, 0.11; 232 lb/yd^3, 0.18
5) 86 kg/m^3, 0.12; 11 kg/m^3, 0.15
6) 21 %
7) 95 kg/m^3, 0.14; 250 kg/m^3, 0.36
8) 24 kg/m^3, 0.03; 18 kg/m^3, 0.03
9) Chemical formula with sulfur $C_{934.4}H_{2489.6}O_{1004.8}N_{11.5}S$; Chemical formula without sulfur: $C_{81.1}H_{216.1}O_{87.2}N$; 14125 Btu/lb
10) Chemical formula with sulfur is: $C_{860}H_{2513.3}O_{1050}N_{14.3}S$; Chemical formula without sulfur is: $C_{60}H_{175.3}O_{73.86}N$; 1162 Btu/lb
11) 5065 Btu/lb = 11782 kJ/kg
12) 5772 Btu/lb
13) Chemical formulas without sulfur:
    1. without water $C_{60}H_{94.3}O_{37.8}N$
    2. with water $C_{60}H_{156.3}O_{69.1}N$

    Chemical formulas with sulfur:
    1. without water $C_{760}H_{1194.7}O_{478.7}N_{12.7}S$
    2. with water $C_{760}H_{1980}O_{874.7}N_{12.7}S$
14) 30%, Chemical formula with sulfur is: $C_{548.8}H_{1612.8}O_{637.9}N_{8.83}S$, Chemical formula without sulfur is: $C_{62.1}H_{182.5}O_{72.2}N$, 1749 Btu/lb
15) 25.5%; chemical formula with sulfur is: $C_{551.1}H_{1521.1}O_{588.4}N_{7.6}S$; Chemical formula without sulfur is: $C_{72.3}H_{199.6}O_{77.2}N$; 14487 kJ/kg
16) 5172 Btu/lb
17) 9091 Btu/lb
18) 171 cal/^{o}C
19) 10471 Btu/lb

Chapter three: Exercise (3.2)

1) 2, one 30-gal can
2) 143 customer
3) three 30-gallon cans, four 20-lb blocks, one 30-gal can
4) 240 customer
5) 184 customer

6) 720 customer
7) 480 customer
8) 900 customer
9) 27 cars/hr
10) 600 customers/d
11) 450 customers/d
12) 4 vehicles
13) 5 vehicles
14) 3.3 tones/hr

Chapter four: Exercise (4.2)

1) 4.14 tones/hr
2) 6.75 tones/hr
3) 89%, 94%, 58% 78%

Chapter five: Exercise (5)

1) 552 mm/yr
2) 280 mm/y
3) 705 mm/yr
4) 1572122 m^3
5) 11 cm
6) 15 m

Chapter six: Exercise (6.2)

1) $C_6 H_{12} O_6 = 3CH_4 + 3CO_2$; 0.27 kg CH_4 and 0.73 kg CO_2, 67.2 liters
2) 0.37 kg CH_4; 0.88 kg CO_2
3) 16.5 tonnes of water or sludge to be added
4) $C_2H_5OH = 1.5CH_4 + 0.5CO_2$ or $2C_2H_5OH = 3CH_4 + CO_2$
   $CH_3CH_2COOH + 0.5H_2O = 1.75CH_4 + 1.25CO_2$ or $4CH_3CH_2COOH + 2H_2O = 7CH_4 + 5CO_2$
   $C_4H_8O_2 + H_2O = 2.5CH_4 + 1.5CO_2$ or $2C_4H_8O_2 + 2H_2O = 5CH_4 + 3CO_2$; 1.2, 1.8 kg; 201, 336 litres
5) 41%
6) 1238 ^oC, 2260 ^oF
7) 572 ^oC, 1062 ^oF

Chapter seven: Exercise (7)

1) SAR 72,664
2) SAR 86,310
3) 6.131%
4) SAR 662,098
5) SAR 134,136
6) SAR 72,664

7)

The author at a glance

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