Waste Characteristics (chemical)

INTRODUCTION

Characterization of solid waste is often limited to material composition, which can be used to describe waste recycling and diversion efforts and estimate expected landfill behavior. As waste management practice evolves from conventional "dry-tomb" landfills to bioreactor landfills, a quantitative description of solid waste mechanical and biochemical characteristics is useful. A more thorough understanding of refuse as a composite material, and as individual constituent components, will aid in predicting the mechanical, hydological, chemical, and biological behavior of a landfill in response to liquid addition/leachate recirculation and gas production.

Chemical characteristics

Knowledge of the classification of chemical compounds and their characteristics is essential for the proper understanding of the behaviour of waste, as it moves through the waste management system. The products of decomposition and heating values are two examples of chemical characteristics. If solid wastes are to be used as fuel, or are used for any other purpose, we must know their chemical characteristics, including the following:

(i) **Lipids:** This class of compounds includes fats, oils and grease, and the principal sources of lipids are garbage, cooking oils and fats. Lipids have high heating values, about 38,000 kJ/kg (kilojoules per kilogram), which makes waste with high lipid content suitable for energy recovery. Since lipids become liquid at temperatures slightly above ambient, they add to the liquid content during waste decomposition. Though they are biodegradable, the rate of biodegradation is relatively slow because lipids have a low solubility in water.

(ii) **Carbohydrates:** These are found primarily in food and yard wastes, which encompass sugar and polymer of sugars (e.g., starch, cellulose, etc.) with general formula $(CH_2O)_x$. Carbohydrates are readily biodegraded to products such as carbon dioxide, water and methane. Decomposing carbohydrates attract flies and rats, and therefore, should not be left exposed for long duration.

(iii) **Proteins:** These are compounds containing carbon, hydrogen, oxygen and nitrogen, and consist of an organic acid with a substituted amine group

(NH_2). They are mainly found in food and garden wastes. The partial decomposition of these compounds can result in the production of amines that have unpleasant odours.

(iv) **Natural fibres:** These are found in paper products, food and yard wastes and include the natural compounds, cellulose and lignin, that are resistant to biodegradation. (Note that paper is almost 100% cellulose, cotton over 95% and wood products over 40%.) Because they are a highly combustible solid waste, having a high proportion of paper and wood products, they are suitable for incineration. Calorific values of oven-dried paper products are in the range of 12,000 -18,000 kJ/kg and of wood about 20,000 kJ/kg, i.e., about half that for fuel oil, which is 44,200 kJ/kg.

(v) **Synthetic organic material (Plastics):** Accounting for 1 – 10%, plastics have become a significant component of solid waste in recent years. They are highly resistant to biodegradation and, therefore, are objectionable and of special concern in SWM. Hence the increasing attention being paid to the recycling of plastics to reduce the proportion of this waste component at disposal sites. Plastics have a high heating value, about 32,000 kJ/kg, which makes them very suitable for incineration. But, you must note that polyvinyl chloride (PVC), when burnt, produces dioxin and acid gas. The latter increases corrosion in the combustion system and is responsible for acid rain.

(vi) **Non-combustibles:** This class includes glass, ceramics, metals, dust and ashes, and accounts for 12 – 25% of dry solids.

(vii) **Heating value:** An evaluation of the potential of waste material for use as fuel for incineration requires a determination of its heating value, expressed as kilojoules per kilogram (kJ/kg). The heating value is determined experimentally using the *Bomb calorimeter test*, in which the heat generated, at a constant temperature of 25°C from the combustion of a dry sample is measured. Since the test temperature is below the boiling point of water (100°C), the combustion water remains in the liquid state.

However, during combustion, the temperature of the combustion gases reaches above 100°C, and the resultant water is in the vapour form. Table 2.3 shows the typical inert residue and heating values for the components of municipal solid waste (Tchobanoglous, et al., 1977):

Table 2.3
Typical Heating and Inert Residue Values

Component	Inert Residue %		Heating Value (kJ/kg)	
	Range	Typical	Range	Typical
Food wastes	2-8	5	3500-7000	4500
Paper	4-8	6	11500-18500	16500
Cardboard	3-6	5	14000-17500	16000
Plastics	2-20	10	28000-37000	32500
Textiles	2-4	2.5	15000-20000	17500
Rubber	8-20	10	21000-28000	18500
Leather	8-20	10	15000-20000	17500
Garden trimmings	2-6	4.5	2300-18500	6500
Wood	0.6-2	1.5	17500-20000	18500
Glass	96-99	98	120-240	140
Tin cans	96-99	96	-	-
Nonferrous metals	90-99	96	240-1200	700
Ferrous metals	94-99	98	240-1200	700
Dirt, ash, bricks, etc.	60-80	70	2300-11500	7000
Municipal solid waste			9500-13000	10500

Note that while evaluating incineration as a means of disposal or energy recovery, we need to consider the heating values of respective constituents (see Table 2.3). For example:

- Organic material yields energy only when dry.
- The moisture content in the waste reduces the dry organic material per kilogram of waste and requires a significant amount of energy for drying.
- The ash content of the waste reduces the proportion of dry organic material per kilogram of waste and retains some heat when removed from the furnace.

(viii) **Ultimate analysis:** This refers to an analysis of waste to determine the proportion of carbon, hydrogen, oxygen, nitrogen and sulphur, and the analysis is done to make mass balance calculation for a chemical or thermal process. Besides, it is necessary to determine ash fraction because of its potentially harmful environmental effects, brought about by the presence of toxic metals such as cadmium, chromium, mercury, nickel, lead, tin and zinc. Note that other metals (e.g., iron, magnesium, etc.) may also be present but they are non-toxic. Table 2.4 shows the result of ultimate analysis of a typical municipal solid waste:

Table 2.4
Municipal Solid Waste: A Typical Ultimate Analysis

Element	**Range (%dry weight)**
Carbon	25-30
Hydrogen	2.5-6.0
Oxygen	15-30
Nitrogen	0.25-1.2
Sulphur	0.02-0.12
Ash	12-30

(ix) **Proximate analysis:** This is important in evaluating the combustion properties of wastes or a waste or refuse derived fuel. The fractions of interest are:

- moisture content, which adds weight to the waste without increasing its heating value, and the evaporation of water reduces the heat released from the fuel;
- ash, which adds weight without generating any heat during combustion;
- volatile matter, i.e., that portion of the waste that is converted to gases before and during combustion;
- fixed carbon, which represents the carbon remaining on the surface grates as charcoal. A waste or fuel with a high proportion of fixed carbon requires a longer retention time on the furnace grates to achieve complete combustion than a waste or fuel with a low proportion of fixed carbon.

PHYSICAL CHARACTERIZATION

Sample Processing

Solid waste samples were collected during construction of a field-scale lysimeter experiment at Deer Track Park Landfill in southeastern Wisconsin. Twelve samples, ranging from 48 to 94 kg each, were sorted to determine material composition. Each sample was initially screened on a 25-mm-screen. Material passing the screen (P25-mm) contained predominantly soil from daily cover, whereas material retained on the screen (R25-mm) contained visually identifiable waste components. The R25-mm fractions from each sample were separated by material groups, weighed, and allowed to air dry. Each P25-mm fraction was also allowed to air dry. The average wet weight water content for the composite refuse was 24±4%.

Material Composition

Material compositions for the twelve solid waste samples analyzed for this study and the average composition and range complied from the literature are presented in Fig. 1. The material groups selected for this study were chosen based on recommendations in ASTM D 5321 and Dixon and Langer (2006). These groups were common among reviewed literature for Fig. 1, with the following notable differences: 13 of 16 studies reported a single percent plastic composition, 10 of 16 studies reported a single organics composition in lieu of yard and food waste, and 5 of the 6 studies reported a percent finer fraction for a 20 mm. The average bulk plastics content was 11% and average organics content was 23% for the noted differences; otherwise, all individually reported material contents were used in Fig. 1.

The average contents of materials constituting solid waste for the twelve samples in this study are similar to the averages computed from literature (Fig. 1). A lower contribution of yard waste is expected as Wisconsin landfills have a yard waste ban, and a lower food waste contribution is expected as waste had already been in-place for approximately four months and some food waste undoubtedly decomposed. A large P25-mm fraction was anticipated for this study as soil used for daily cover was often left in-place when subsequent filling commenced. The material composition for the P25-mm fraction was determined for five subsamples (~5% by dry mass). This fraction consisted of 80% soil, gravel, and inert materials, 5% glass, 6% paper, and minor contributions of rigid plastic, wood, and food waste. Thus, adjusting material contributions in Fig. 1 with respect to the P25-mm composition primarily decreases the P25-mm contribution and increases gravel/inerts, glass, and paper.

Particle Size Distribution

Particle size distributions (PSD) for all materials comprising two R25-mm samples were determined by measuring the minimum and maximum dimensions and mass of each particle.

The P25-mm PSD was determined by combining materials from the five sorted subsamples used for material composition and mechanical sieving each material following ASTM D 422. The PSD on a dry mass basis for the two samples are shown in Fig. 2. The P25-mm data was added to the R25-mm by extrapolating the percent mass retained on each sieve to account for the total P25-mm dry mass.

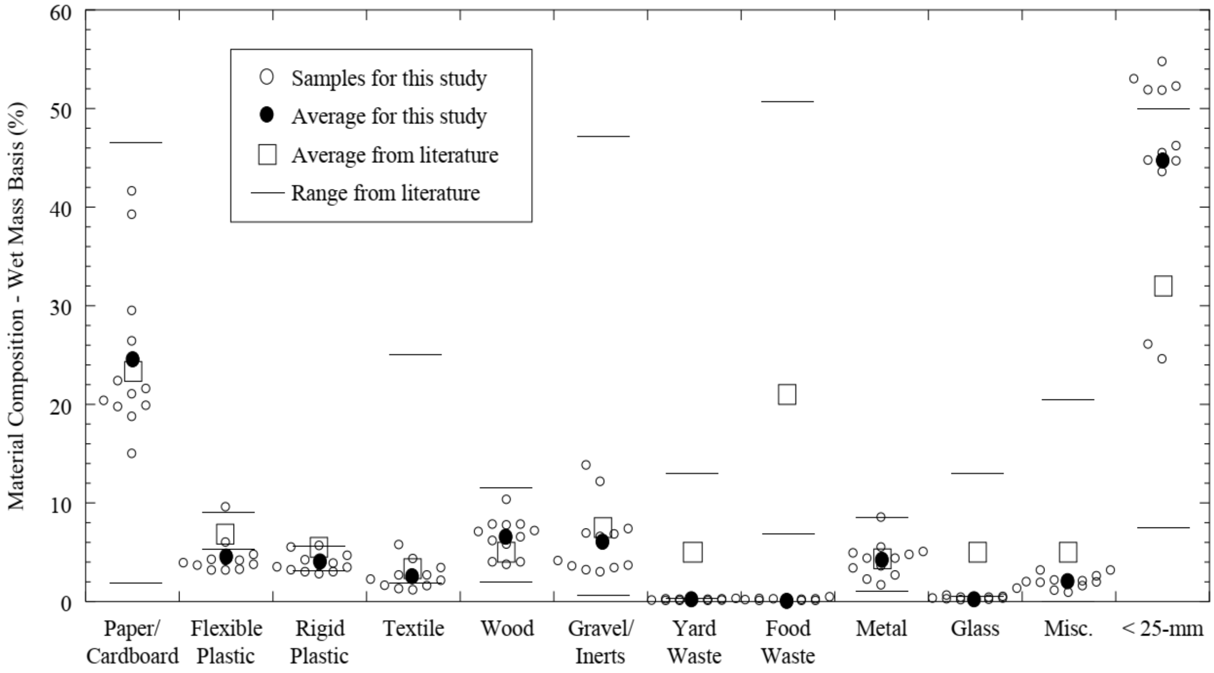

Fig. 1. Dot plot of the percent material composition on a wet mass basis for solid waste samples analyzed for this study, and the average and range (i.e., maximum and minimum) compiled from literature (Attal et al. 1992, Beaven and Powrie 1995, Gasparini et al. 1995, Sánchez-Alciturri et al. 1995, Landva et al. 2000, Yuen and Styles 2000, Vilar and Carvalho 2004, Hull et al. 2005, Dixon and Langer 2006, Francois et al. 2006, Mor et al. 2006, Sanphoti et al. 2006, USEPA 2008, Reddy et al. 2009, Staley and Barlaz 2009).

The PSDs in Fig. 2 are bimodal, with the mean particle size of approximately 20 mm. This suggests screening refuse excavated from a landfill on a 20 or 25-mm screen can separate the “soil-like” fraction from the bulky solid waste constituents. The distribution of the R25-mm fraction is similar to data presented in Dixon and Langer (2006), where particles ranging from 40-120 mm were dominant.

Particle Shape Evaluation

Relative contributions of shape-related subdivisions (reinforcing, compressible, and incompressible) were estimated for the average solid waste composition. Descriptions of these subdivisions and solid waste materials presented in Dixon et al. (2008) were used to identify subdivisions for this study. The contributions of reinforcing components are 34%, compressibles are 59%, and incompressibles are 8%, on a wet mass basis for waste composition (Fig. 1). These relative contributions of shape-related subdivisions are most similar to the synthetic waste sample in Dixon et al. (2008) that represents the composition of landfill refuse. A comparison of these wastes on a composition basis would suggest similar mechanical behavior.

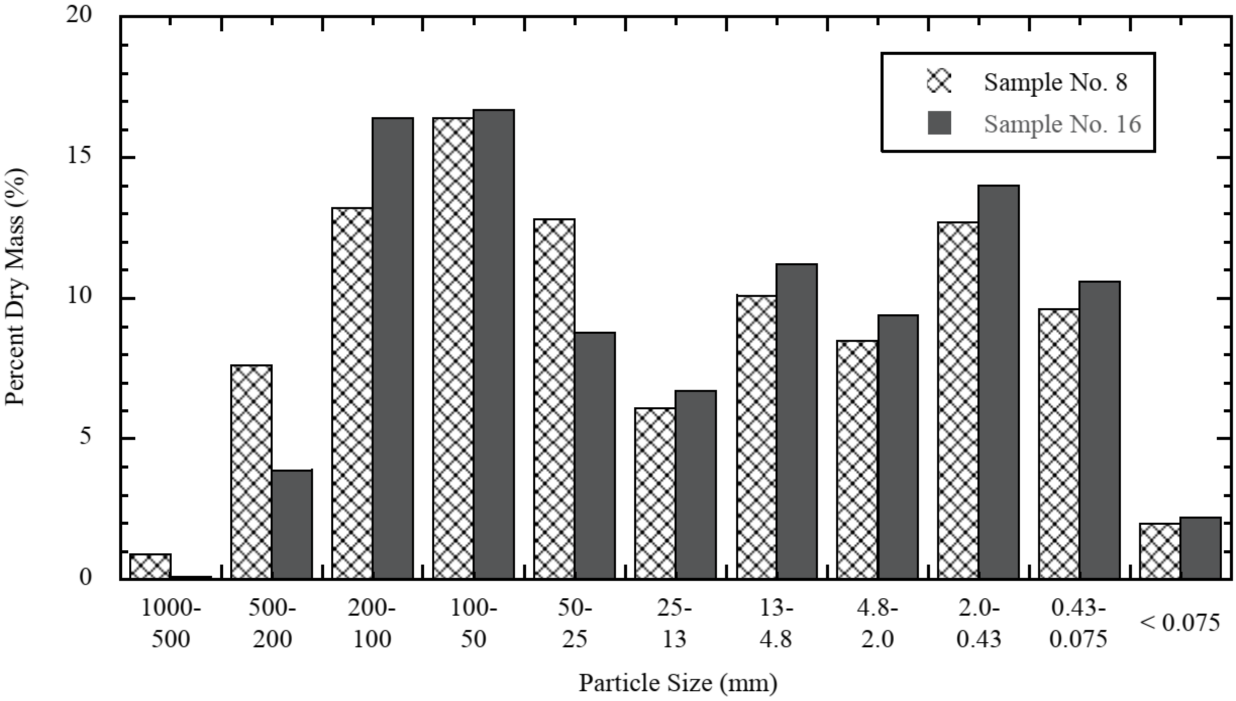

Fig. 2. Particle size distribution for two solid waste samples on dry mass basis.

DEGRADABILITILY ASSESSMENT

The degradability of excavated refuse and refuse degraded in laboratory reactors was assessed by measuring volatile solids (VS), biochemical methane potential (BMP), and cellulose (C), hemicellulose (H), and lignin (L) contents. The volatile solids content represents the mass loss on combustion at 550 °C for 2 hours. Biochemical methane potential was conducted following protocols described in Wang et al. (1994). Cellulose, hemicellulose, and lignin contents were conducted using procedures described in Petterson and Schwandt (1991). All tests were conducted on material ground to pass a 1-mm screen.

Solid waste with initial composition representing the average determined for this study (Fig. 1) was degraded to various states of decomposition in laboratory reactors. Each reactor contained approximately 150 kg of solid waste and was operated with leachate recirculation at mesophilic temperatures. Decomposition was evaluated by monitoring methane production, and reactor operation was terminated at selected times to obtain material at differents states of decomposition based on cumulative methane. Waste designated low degradation (LD) yielded

5.3 L-CH_4/kg-dry, medium degradation (MD) yielded 14.3 L-CH_4/kg-dry, and high degradation (HD) yielded 18.7 L-CH_4/kg-dry (1 L/kg = 1 mL/g).

The VS, BMP, C, H, and L contents, and degradability index for the bulk fresh solid waste, screened fractions, and degraded wastes from the laboratory reactors are summarized in Table 1. The cumulative methane yields from the three laboratory reactors were all less than 37% of the BMP of the initial refuse. This comparison emphasizes that the BMP represents an upper bound for methane generation, and to expect full realization of the BMP in laboratory reactors or in full-scale landfills is not appropriate. While BMP of the LD, MD, and HD samples (Table 1) relate to the varying degrees of decomposition (i.e., decreasing BMP with increasing degradation relative to fresh material), the VS, C, H, and (C+H)/L do not support the same conclusion. The C, H, and (C+H)/L of the LD, MD, and HD samples all decrease relative to the bulk fresh solid waste ; however, the C, H, and (C+H)/L support an opposite trend to what would be expected from the cumulative methane yield from the laboratory reactors (Table 1). The VS of the MD and HD samples are greater than the bulk fresh waste, which does not agree with previous reserach (Attal et al. 1992, Hull et al. 2005, Francois et al. 2006).

Table 1. Volatile solids (VS), biochemical methane potential (BMP), cellulose (C), hemicellulose (H), and lignin (L) contents, and degradability index for fresh bulk solid waste, screened fractions, and decomposed refuse samples.

Material	Bulk	P25-mm	R25-mm	LD	MD	HD
C (%)	19.6	4.8	22.5	4.4	10.1	12.5
H (%)	5.4	1.5	5.4	1.6	4.0	4.3
L (%)	28.8	6.6	28.6	43.5	30.6	33.1
(C+H)/L	0.87	0.95	0.98	0.14	0.46	0.51
VS (%)	52.9	16.5	66.4	25.6	56.7	53.8
BMP (mL-CH_4/g-dry)	51.4	12.0	43.8	12.4	12.0	9.3
BMP/VS (mL-CH_4/g-VS)	97.3	72.7	66.0	48.3	21.2	17.3
Degradability Index (%)	—	—	—	50.4	78.2	82.2
Reactor CH_4 Yield (L-CH4/kg-dry)	—	—	—	5.3	14.3	18.7

The BMP in Table 1 is also presented as normalized with respect to VS. The BMP/VS for the fresh bulk solid waste and degraded samples show a decreasing trend with increasing degradation, as expected from the reactor methane yields. This BMP/VS is used to compute the degradability index (DI) as follows:

$$\mathrm{DI} = \left(\frac{\mathrm{BMP/VS_i} - \mathrm{BMP/VS_f}}{\mathrm{BMP/VS_i}} \right) \times 100 \tag{1}$$

where the BMP/VS_i represents the initial/fresh state and BMP/VS_f represents the final/degraded state. For the degraded refuse samples, the DI increases with increasing degradation. The DI is proposed here as a metric for assessing the relative state of degradation. Applicability to various waste sources and relationships with watse behavior is currently in progress.

CONCLUSION AND RECOMMENDATIONS

The solid waste characterization framework outlined in Dixon and Langer (2006) provides a template for determining material composition, particle size distribution, particle shape descriptions, and degradability. The framework was evaluated for refuse samples collected from a full-scale landfill. Degradability was assessed by measuring the volatile solids (VS), biochemical methane potential (BMP), and cellulose (C), hemicellulose (H), and lignin (L) contents of the fresh refuse, screened fractions, and refuse samples degraded in laboratory reactors. A degradability index is proposed that is computed from BMP and VS measurements, and represents a relative percent degradation for a given waste. The following conclusions and recommendations were developed from this study:

- Material composition and shape-related subdivisions can be assessed by screening solid waste on a 25-mm-screen to separate the soil-like (P25-mm) and bulky (R25-mm) waste fractions, and sorting the R25-mm waste by material groups identified from mechanical properties.

- The particle size distribution of the R25-mm waste can be determined by manually measuring individual particle dimensions and mass, whereas mechanical sieve analysis can be used for the P25-mm fraction.

- Solid waste degradability can be quantified by measuring the VS and BMP and computing the BMP/VS, which was shown to decrease with increasing degradation.

- A degradability index (DI) is proposed as a universal metric to compare degradability. The DI is computed with respect to the BMP/VS of initial and degraded wastes, and increases with increasing degradation.

- Research is needed to determine the universal applicability of the DI and investigate relationships with mechanical, hydological, chemical, and biological behavior of landfills.

Fish production Waste Characteristics (Bio -chemical)

BIOLOGICAL FOOD CHAINS IN WASTE-FED PONDS

Food chain is the series of organisms existing in any natural community through which energy is being transferred. Each link in such a chain feeds on and obtains energy from the ones preceding it. In a pond ecosystem, there are generally three major groups of organisms present in the food chain, similar to the other marine and freshwater ecosystems. The three groups consist of: the primary producers; the primary, secondary and tertiary consumers; and the decomposer organisms (Figure 6.3).

At the beginning of the food chain, the primary producers (algae and aquatic plants) represent the first trophic or energy level. They synthesize organic materials (or cell biomass) through photosynthesis (e.g. Equation 2.6), utilizing the nutrients present in the water and light energy. Next is the primary consumer group, mainly zooplanktons and the herbivores, which consumes the primary producers, then they are preys for secondary consumers such as small fish and other plankton feeders. In this step, some fish consume benthic animals that grow at the pond bottom. Some herbivorous fish such as silver carp consumes phytoplankton directly and it can also take detritus. Tertiary consumers such as snakehead predate small fish. Depending on the type of fish stocked, they feed on phytoplankton or zooplankton and are primary consumers, secondary consumers or tertiary consumers.

The waste material produced by fish and decaying biomass will settle to the pond bottom and be decomposed by bacteria (the decomposers), resulting in the release of nutrients such as CO_2 and NH_3 (Equation 2.1) required for the primary production.

When comparing food chains in a normal fish pond and a waste-fed fish pond, there are no wide differences between them. However, to allow the herbivorous fish to grow effectively and maximizing the fish biomass production, carnivorous fish (tertiary consumers) are not normally stocked in the waste-fed fish ponds where herbivores are being reared. Additionally, in waste-fed fish ponds, there are more nutrients for primary producers due to the application of waste and its decomposition. Food chain depends on the primary productivity of the pond, which in turn depends on the nutrients and light.

Another important consideration related to food chain is the problems caused by biomagnification and bioaccumulation. Biomagnification may be defined as the accumulation of toxic materials such as pesticides or heavy metals in an organism in any particular trophic level at a concentration greater than that in its food or the preceding trophic level so that essentially animals at the top of food chain accumulate the largest residues (see Figure 6.3). Bioaccumulation is the phenomena where the toxic matter is in equilibrium at a higher concentration in tissues than that of the surrounding aquatic environment. This depends on the time of exposure, rate of uptake, metabolism within organism, rate of excretion, potential for storage in tissues and the physiological state of organism. Therefore the effect of both factors should be investigated especially when industrial or agricultural wastes containing high concentrations of heavy metals and/or toxic organic compounds are to be applied to fish ponds.

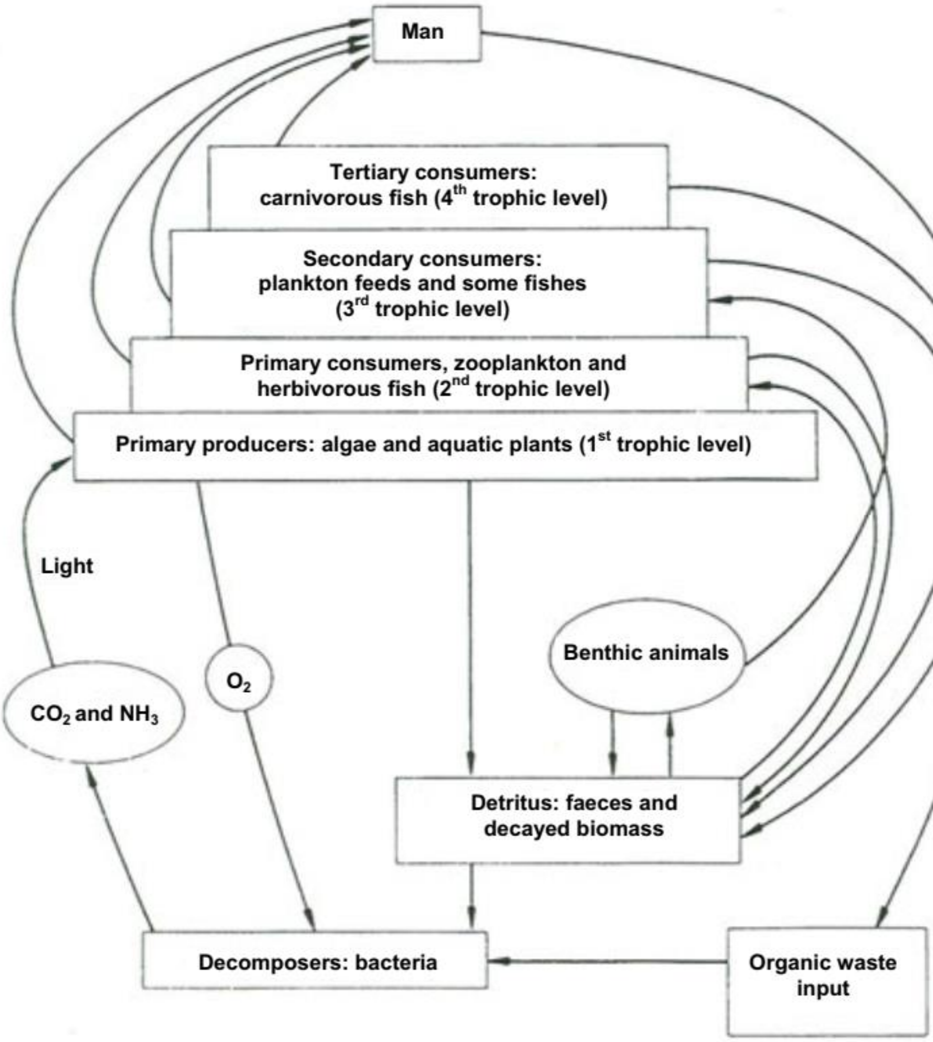

Figure 6.3 Food chain and other relationships in waste-fed ponds

A well-known example of bioaccumulation and biomagnifications involves the pesticide DDT, which is now banned in the United States (Campbell 1990). DDT concentration in a long Island Sound food chain was magnified by a factor of about 10 million, from just 0.000003 ppm as a pollutant in the seawater to a concentration of 25 ppm in a fish-eating bird, the osprey (see Figure 6.4).

BIOCHEMICAL REACTIONS IN WASTE-FED PONDS

In a waste-fed fish pond that is functioning well, algae, bacteria and fish are having symbiotic relationships. The oxygen and food for fish are to be produced by the algae, while bacteria decompose the waste. Figure 6.5 depicts the interactions among these organisms in a pond fed with wastewater or sludge.

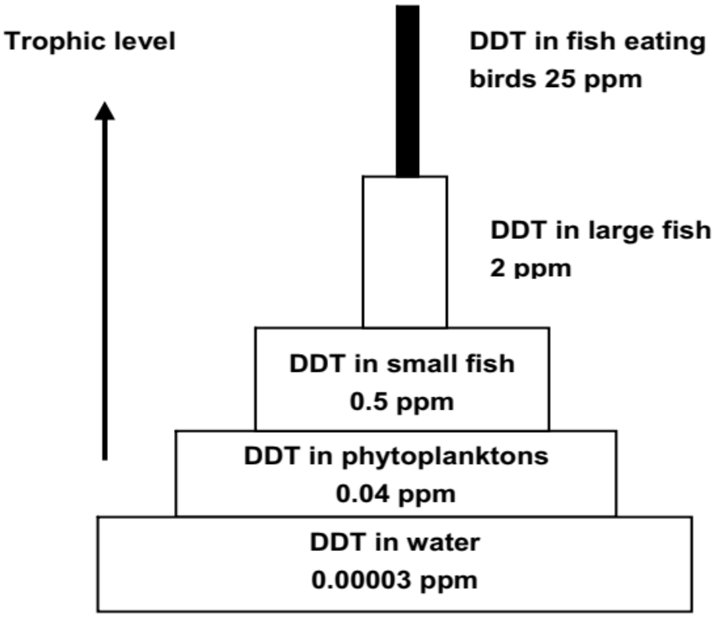

Figure 6.4 Bioaccumulation and biomagnifications of DDT in a food chain (adapted from Campbell 1990)

The biochemical reactions occurring in waste-fed fish ponds should be similar to those of facultative waste stabilization ponds in which the organic matter is decomposed by a combination of aerobic, facultative and anaerobic bacteria. Three zones exist in the ponds: the first is an aerobic zone where aerobic bacteria and algae exist in a symbiotic reaction, i.e. the oxygen supplied partly by natural surface re-aeration and from algal photosynthesis is used by the bacteria in the aerobic decomposition of the organic matter the nutrients and carbon dioxide released in this decomposition are, in turn, used by the algae The second is an intermediate (facultative) zone which is partly aerobic and partly anaerobic, in which waste stabilization is carried out by facultative bacteria; and the third, an anaerobic bottom zone in which the accumulated solids are decomposed by anaerobic bacteria. Fish normally live in the aerobic and facultative zones where oxygen and food (algae) are present.

When organic wastes are discharged into a pond, the soluble and colloidal compounds that remain in suspension will be decomposed by the aerobic and facultative bacteria. The settleable solids will settle down to the pond bottom and, together with other decayed biomass that settles there, forming a sludge layer. Anaerobic reactions occurring in the sludge layer zone are similar to those described in Chapter 4 in which there will be releases of soluble organic by-products (such as amino acids and volatile fatty acids, etc.) and gaseous by-products such as CH_4 and CO_2. Since the pond depth is usually about 1 m, these soluble by-products will dissolve in the water due to wind-induced mixing and fish movement, which will be further decomposed by the aerobic and facultative bacteria present in the above pond layers.

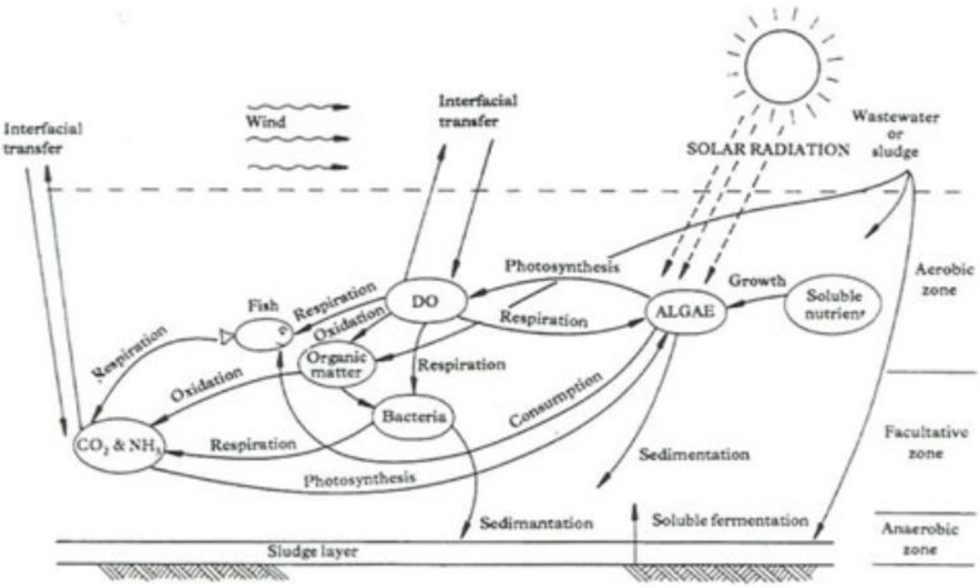

Figure 6.5 A simplified view of septage-fed fish pond dynamics (adapted from Bhattrai 1985)

Environmental requirements

To enhance the fish growth in waste-fed ponds, various environmental parameters should be properly maintained or acquired, as follows:

Light.

Light should be in sufficient intensity and with suitable duration during the daytime. It is the main factor in algal photosynthesis, which results in the production of fish feed (algal cells) and oxygen for fish respiration. Generally, this requirement is always met in tropical area where depth of fish ponds is maintained at about 1 m to allow for light penetration to the whole pond depth.

Temperature

Fish metabolic rate is directly correlated with water temperature. The temperature has a considerable influence on the principal and vital activities of fish, notably their breathing, growth and reproduction. Increased temperature will lower the DO in the water and also increase the metabolism of fish, which require more oxygen. The temperature tolerance limit within each species with individuals of different ages is the same, but the limit is different if they are acclimatized at different temperatures. Unfavourable temperatures at either end of the tolerance range produce a stress in which a prolonged exposure could result in lowered resistance and greater susceptibility to disease. Temperature does affect metabolism as well as food intake.

Dissolved oxygen (DO)

DO is an important factor in the growth of fish because all metabolic activities of fish are dependent on the oxygen consumed during respiration. DO in a waste-fed pond have diurnal variation. Factors affecting the variation of DO include organic loading, algal concentration, type of fish, fish stocking density, sludge accumulation, temperature and chloride concentration. Organic loading to a pond has influence on the bacterial activity in waste stabilization and, consequently, the oxygen utilization. Therefore, to design a waste-fed fish pond, organic loading and fish stocking density have to be properly selected so that the lowest DO to occur in the pond at dawn is within the tolerable range for fish.

Ammonia concentration

Un-ionized ammonia (NH3) is toxic to fish, but the ammonium ion (NH4+) is not. Many laboratory experiments of relatively short duration have demonstrated that the acute lethal concentrations of NH3 for a variety of fish species lie in the range 0.2-2.0 mg/L (Alabaster and Lloyd 1980). Un-ionized ammonia is more toxic when DO concentration is low. However, this effect is probably nullified in fish ponds since CO2 concentrations are usually high when DO levels are low and the toxicity of NH3 decreases with increasing CO2. The relationship between NH3 and NH4+ is pH-dependent, as follows:

$$NH_3 + H^+ \leftrightarrow NH_4^+ \tag{6.1}$$

Equation 6.1 indicates that NH_3 formation is favored under high pH or alkaline conditions as shown in Figure 6.8.

High concentrations of total ammonia (NH_3 + NH_4^+ or NH_3 -N) can occur following phytoplankton die-offs, but abundant CO_2 production associated with such events depresses pH and the proportion of the total ammonia present as NH_3 (Equation 6.1). NH_3 also increases the incidence of blue-sac disease in the fry of freshwater fish when the eggs were cultured in water with high NH_3 content (Wolf 1957). Considering some safety factor, the U.S. Committee on Water Quality Criteria (1972) has recommended that no more than 0.02 mg/L NH_3 be permitted in receiving waters. Sawyer *et al.* (2003) concluded that ammonia toxicity would not be a problem in receiving waters with pH below 8 and NH_3-N concentrations less than 1 mg/L.

pH

Huet and Timmermans (1971) stated that the best water for fish cultivation is that which is neutral or slightly alkaline, with a pH between 7.0 and 8.0. Reproduction diminishes at pH value below 6.5 and growth rate becomes lower at pH range of 4 to 6.5.

Carbon dioxide

The presence of free CO_2 may depress the affinity of fish blood for oxygen. Fish can sense small differences in free CO_2 concentration and apparently attempt to avoid area with high CO_2 levels. Nevertheless, 10 mg/L or more of CO_2 may be tolerable provided DO concentration is high. Water with less than 5 mg/L of CO_2 is preferable. The most detrimental effect of free CO_2 results during the period of critically low DO (Boyd 1979).

Stocking density

In addition to the limitations imposed by the available oxygen, the density of fish population can increase to the point of growth inhibition. Overcrowding can result in a reduction in growth rate due to stress and competition for food, oxygen and space, and in poor food utilization caused by wastage. It is generally known that there is a limit to the density at which fish can be stocked in ponds, for beyond a certain point, the advantage of growing a larger population of fish is cancelled by the slower growth of the fish, in spite of an excess of food.

Hydrogen sulfide (H_2S)

Un-ionized H_2S, mainly from anaerobic decomposition of bottom sludge, is extremely toxic to fish at concentrations that may occur in natural waters. Results from various bioassay studies suggest that any detectable concentration of H_2S should be considered detrimental to fish production (Boyd 1979).

Sulfide formation often occurs in anaerobic and facultative waste stabilization ponds due to the reduction of sulfate (SO_4^{2-}) under anaerobic conditions:

$$SO_4^{2-} + \text{organic matter} \xrightarrow[\text{bacteria}]{\text{Anaerobic}} S^{2-} + H_2O + CO_2 \qquad (6.2)$$

$$S^{2-} + 2H^+ \longrightarrow H_2S \qquad (6.3)$$

Heavy metals and pesticides

These compounds, either individually or in combination, can produce acute toxicity to fish at concentrations as low as a few µg/L, and the extent of toxic effects depends on several factors such as water quality; species, age and size of fishes; and antagonistic and synergistic reactions occurring in the pond water. Long-term effects of these compounds may include decline in growth rate and reproduction, and the enhancement of bioaccumulation and biomagnification in the food chains

Water supply

Water supply should be sufficient in quantity and of good quality since ponds fed with solid or semi-solid organic wastes e.g. animal manures or nightsoil, need a certain amount of water to compensate for losses through evaporation and seepage. Ponds fed with sewage or effluent of wastewater treatment plant sometimes needs dilution water. The quality of water should be in the permissible range for fish growth.

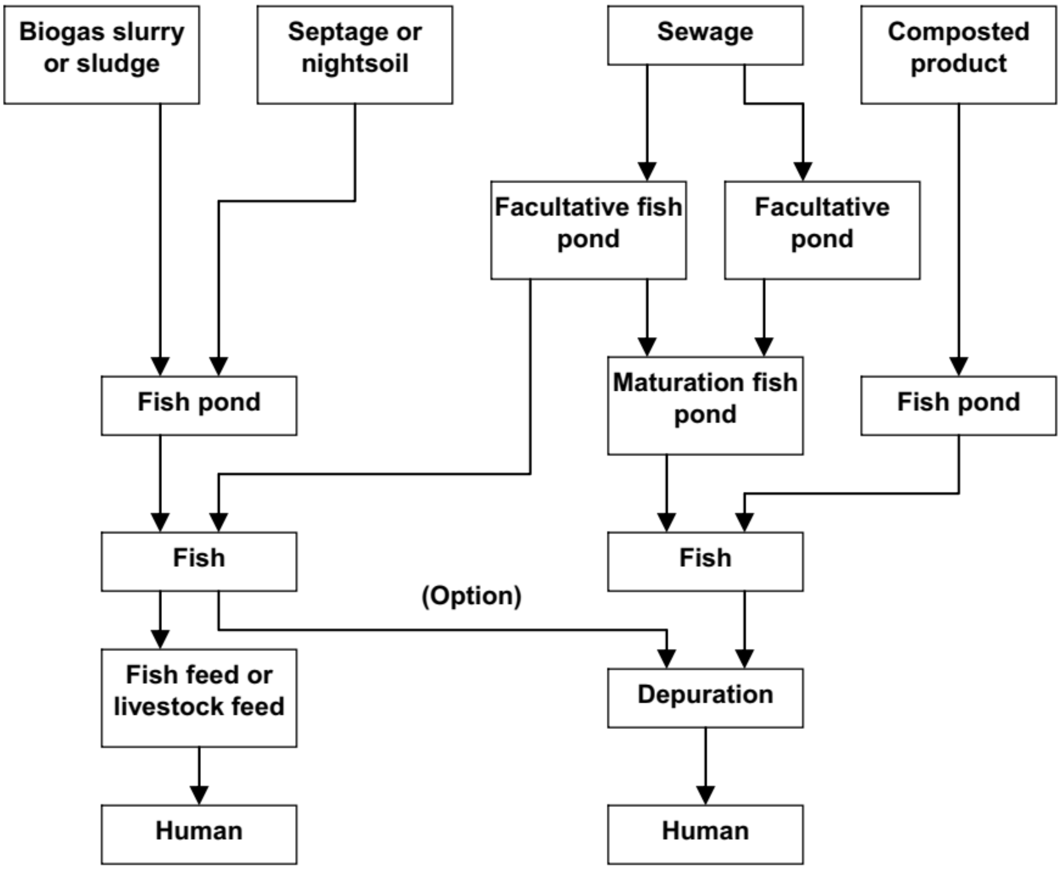

Figure 6.15 Some arrangements of waste-fed ponds

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