

CHAPTER II

LITERATURE REVIEW

Among the constituents characteristic of industrial wastewater, heavy metal may cause adverse effects on the biological wastewater treatment process. The presence of heavy metals in wastewater results from wide usages in metal finishing industries with subsequent discharge of significant quantities of heavy metal. A tabulation of the diverse type of heavy metals utilized and discharged in industrial wastes is shown in Table 1.

This study deals only with the lead and zinc and the effects of these metals on the biological organisms present in wastewater treatment facilities that are responsible for the stabilization of biodegradable wastes.

LEAD

Lead, symbol Pb from the Latin name "plumbum", metallic element of atomic number 82, atomic weight 207.2, valences 2,4, is located in Group IV A. of the Periodic Table.

Physical Properties of Lead

The important physical properties of lead are listed in Table 2.

The physical properties of lead are not conducive to a widespread use of the metal for structural purposes, due to its low tensile strength and the tendency for the metal to flow under very low loads. It is generally conceded that it is unwise to subject lead to a continuous load of more than 200 psi. However, the tendency for lead to

TABLE 1
HEAVY METALS FOUND IN MAJOR INDUSTRIES
(Bagby, 1979)

| | Al | Ag | As | Cd | Cr | Cu | F | Fe | Hg | Mn | Pb | Ni | Sb | Sn | Zn |
|--|----|----|----|----|----|----|---|----|----|----|----|----|----|----|----|
| Pulp, paper mills | | | | | X | X | | | X | | X | X | | | X |
| Organic Chemicals, Petrochemicals | X | | X | X | X | | X | X | X | | X | | | X | X |
| Alkalis, Chlorine; Inorganic Chemicals | X | | X | X | X | | X | X | X | | X | | | X | X |
| Fertilizers | X | | X | X | X | X | X | X | X | X | X | X | | | X |
| Petroleum Refining | X | | X | X | X | X | X | X | | | X | X | | | X |
| Basic Steelworks | | | X | X | X | X | X | X | X | | X | X | X | X | X |
| Basic Non-Ferrous Metal Works | X | X | X | X | X | X | X | | X | | X | X | X | | X |
| Motor Vehicles, Aircraft-Plating, Finishing | X | X | | X | X | X | | | X | | | | | | |
| Flat glass, Cement, Asbestos Products | | | | | X | | | | | | | | | | |
| Textile Mills | | | | | X | | | | | | | | | | |
| Leather Tanning, Finishing | | | | | X | | | | | | | | | | |

TABLE 2
 PHYSICAL PROPERTIES OF LEAD
 (Hampel, 1968)

| | |
|--|---|
| Symbol | Pb |
| Atomic number | 82 |
| Atomic weight | 207.19 |
| Isotope, natural lead | 208(51.55%), 206(26.26%), 207(20.82%), 204(1.37%) |
| Density, 20°C | 11.34 g/cc |
| 400°C | 10.51 g/cc |
| Melting point | 327°C(621°F) |
| Boiling point | 1737°C(3159°F) |
| Latent heat of fusion | 5.89 cal/g |
| Latent heat of vaporization | 204.6 cal/g |
| Mean specific heat, 15°C to m.p. | 0.032 cal/g/°C |
| 400-500°C | 0.037 cal/g/°C |
| Vapor pressure, 987°C | 1 mm |
| 1167°C | 10 mm |
| 1417°C | 100 mm |
| 1508°C | 200 mm |
| 1611°C | 400 mm |
| Thermal conductivity, 18°C | 0.083 cal/cm ² /sec/cm/°C |
| 330°C | 0.039 " " " " " |
| 700°C | 0.036 " " " " " |
| Viscosity, 441°C | 2.116 centipoise |
| 551°C | 1.700 " |
| 703°C | 1.349 " |
| 844°C | 1.185 " |
| Surface tension, 350°C | 442 dyne/cm |
| 450°C | 438 " " |
| Thermal expansion coefficient | 29.1 x 10 ⁻⁶ /°C |
| Electrical resistivity, 20°C | 20.65 microhm-cm |
| 327°C(1) | 94.6 " |
| Electrochemical equivalent | 3.865 g/amp-hr |
| Thermal neutron absorption cross section | 0.17 barns |
| Crystal pattern | face-centered cubic |
| Brinell hardness number | 4.2 |
| Tensile strength | 2000 psi |
| Elongation, % in 2 in. | 64 |
| Young's modulus in tension | 2,560,000 psi |
| Color | bluish gray |
| Streak | gray |
| Fracture, cold | hackly |
| hot | columnar |
| Average pouring temperature | 382°C (720°F) |

flow even at room temperature makes it particularly easy to fabricate and very light mills are required for rolling lead sheet from large castings.

The ductility of the metal is shown by the ease with which it may be extruded under pressure through small die openings, exhibiting a high degree of fluid flow.

Since lead is very soft, the fatigue strength is naturally low. In construction, however, the metal is usually supported by other stiffer materials and its fatigue strength is seldom a limiting factor. When a higher fatigue strength is required, it is obtained by the use of alloying additions.

Another property of lead which permits many unique operations at room temperature, is its ready weldability under very moderate pressures. Advantage is taken of this in many extrusion processes, most notable of which is the widely used method of extruding lead sheathing around an insulated copper cable.

The low melting point of lead permits ready utilization of the metal by extremely simple and inexpensive handling techniques, particularly as a principal component in the majority of the low-temperature fusible alloys.

Considering the low melting point, the boiling point of the metal is surprisingly high. This fact permits certain unique uses for lead, particularly as a collector for gold and silver in assaying at elevated temperatures and as a liquid heating bath in drawing, or tempering steel.

Lead is by far the densest common metal and this has brought

the metal into almost universal use for weighing and ballast purposes. It is also a favored metal for shielding x-ray equipment, because of its ability to absorb gamma rays and is widely used for this purpose.

Chemical Properties of Lead

Lead is divalent and tetravalent with an atomic weight of 207.19. Lead is amphoteric.

It tarnishes rapidly in moist atmosphere, although its surface undergoes no change in perfectly dry air, or in water which is free from air. When melted in contact with air, the metal oxidizes and at dull red heat is converted into lead oxide, PbO . If the heating is continued at $430^{\circ}C$, the PbO gradually changes to the red oxide, Pb_3O_4 , which dissociates at $550^{\circ}C$ to PbO and oxygen. Other oxides of lead are the sesquioxide, Pb_2O_3 , and peroxide, PbO_2 , which also decompose at $630^{\circ}C$ to PbO and oxygen.

Lead combines directly with chlorine, fluorine and sulfur.

The solubility diagram of Lead-hydroxy complexes as a function of solution pH is shown in Figure 1.

The best solvent for lead is nitric acid, the very dilute acid acting more rapidly than the strong. Dilute hydrochloric and sulfuric acid have little effect on lead, as coatings of $PbCl_2$ and $PbSO_4$ protect the surface from further action. The metal is only slightly attacked by strong concentrations of these acids up to $200^{\circ}C$, a fact which gives the metal wide use for tank and chamber linings in chemical plants, such as for the manufacture of sulfuric acid. Above $200^{\circ}C$, the action becomes stronger and at $260^{\circ}C$, lead is completely dissolved.

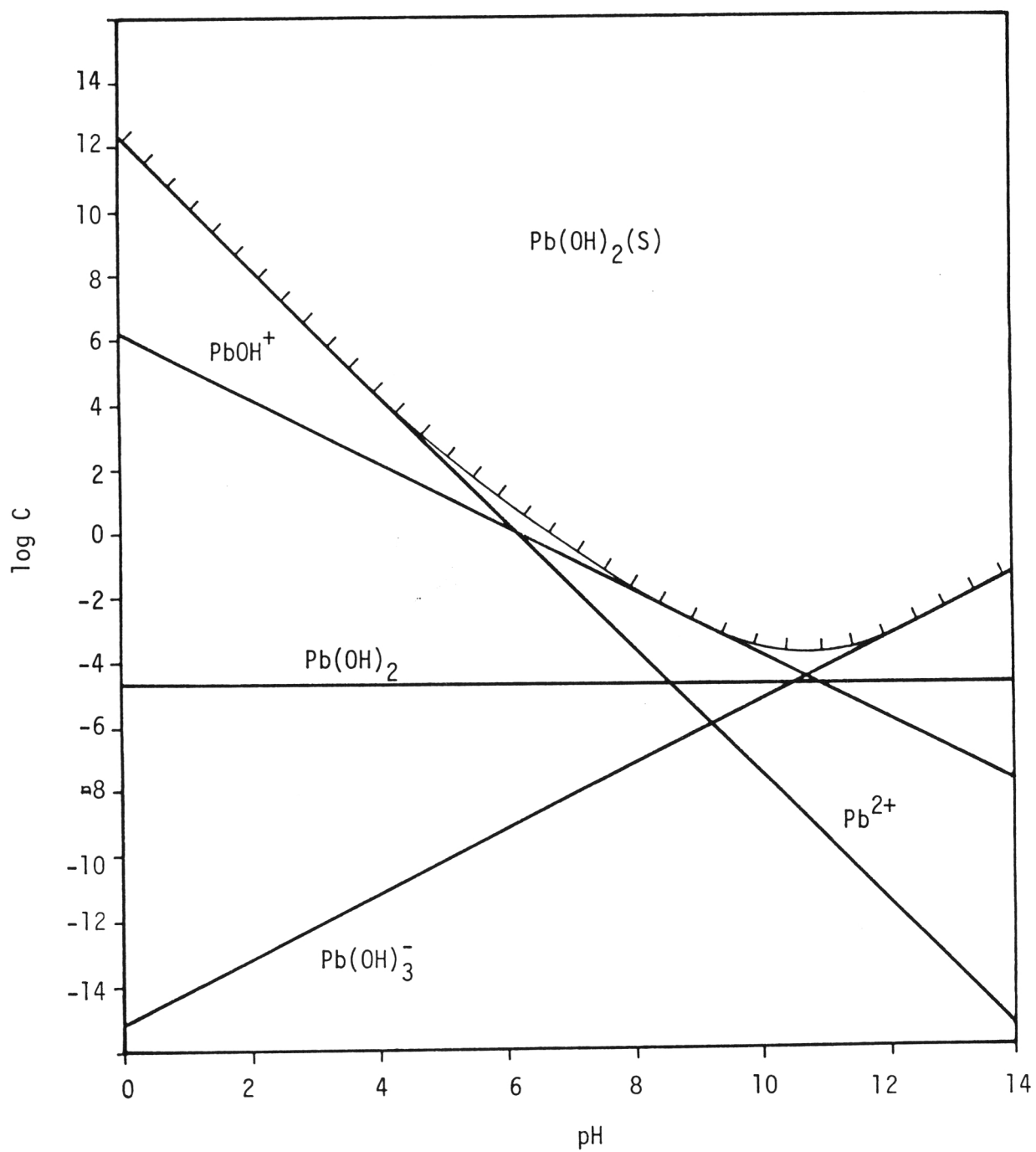


Figure 1. Theoretical Solubility Diagram for Lead Hydroxy as a Function of Solution pH.

Acetic, citric, tartaric and other organic acids, act slowly on lead in the presence of moist air. It is also attacked by sulfur dioxide between 550 and 850^oC and by hydrofluoric acid. The dissolution in hydrofluoric acid is quickly checked by the formation of PbF₂; hence the acid can be stored in lead vessels.

Uses of Lead

Lead is one of the major metals in use in industry and is outflanked by only a few other metals such as iron, aluminium, copper and zinc (Hampel, 1968). Lead is used extensively such as, storage batteries; tetraethyllead (gasoline additive); radiation shielding; cable covering; ammunition; chemical reaction equipment (piping, tank linings, etc.); solder and fusible alloys; type metal; vibration damping in heavy construction; foil; babbitt and other bearing alloys (Hawley, 1981).

ZINC

Zinc, atomic number 30, atomic weight 65.37, is located in Group II B of the Periodic Table.

Physical Properties of Zinc

Zinc is a bluish white metal. As cast it has a brittle, hexagonal crystal structure, but loses its brittleness at about 120^oC so that it can be rolled and drawn. Above 200^oC, it again becomes brittle. After being rolled or drawn in the range of 100-150^oC it is no longer brittle when cold.

Zinc crystals are highly anisotropic and some of its properties

are different for single crystals than they are for polycrystalline zinc. Further, small amounts of impurities change mechanical properties and increase the rate of solution in acids.

Physical properties of zinc are listed in Table 3.

Chemical Properties of Zinc

The outstanding property of zinc is its strong electropositive character, surpassed only by aluminum and magnesium. This property is used in galvanizing, where zinc in contact with iron or steel undergoes sacrificial corrosion.

Zinc exhibits divalency in all of its compounds.

Pure zinc is highly resistant to attack by dry air at normal ambient temperatures but the rate of attack increases rapidly above 225°C. In the presence of moist air, attack will occur at room temperature, and is accelerated by carbon dioxide and sulfur dioxide with a hydrated basic carbonate being the end product of normal atmospheric corrosion. Dry halogen gases will not attack zinc at ordinary temperatures but in the presence of moisture zinc foil will actually ignite. Steam begins to react on the metal at 350°C and reacts rapidly at red heat.

Zinc is attacked by mineral acids evincing the strongest reaction with sulfuric, then hydrochloric and nitric in descending order. Impurities in the metal expedite the attack. The reaction with nitric acid does not result in the evolution of hydrogen, as is the case with the other mineral acids, but rather the reduction in part of the pentavalent nitrogen to lower valences. This reaction shows the vigorous

TABLE 3
 PHYSICAL PROPERTIES OF ZINC
 (Hampel, 1968)

| | |
|---|----------------------------|
| Atomic number | 30 |
| Atomic weight | 65.37 |
| Isotopes, % natural abundance | |
| 64 | 48.86 |
| 66 | 27.62 |
| 67 | 4.12 |
| 68 | 18.71 |
| 70 | 0.69 |
| Electron configuration | 2-8-18-2 |
| Crystal structure | Hexagonal close-packed |
| $a = 2.664\text{\AA}$, $c = 4.9469\text{\AA}$, $c/a = 1.856$ | |
| Density, g/cc | |
| solid, 25°C | 7.133 |
| solid, 419.5°C | 6.83 |
| liquid, 419.5°C | 6.62 |
| liquid, 800°C | 6.25 |
| Melting point, °C | 419.5°C |
| Boiling point, °C | 907 |
| Heat of fusion, cal/g, 419.5°C | 24.4 |
| Heat of vaporization, cal/g, 907°C | 419.5 |
| Heat capacity, cal/mole | |
| solid, $C_p = 5.35 + 2.40 \times 10^{-3}T(298-693^\circ\text{K})$ | |
| liquid, $C_p = 7.50$ | |
| gas (monatomic), $C_p = 4.969$ | |
| Vapor pressure, mm Hg | |
| 487°C | 1 |
| 593°C | 10 |
| 736°C | 100 |
| 788°C | 200 |
| 844°C | 400 |
| Linear coefficient of thermal expansion, per °C | |
| polycrystalline, 20-250°C | 39.7×10^{-6} |
| a axis, 20-100°C | 14.3×10^{-6} |
| c axis, 20-100°C | 60.8×10^{-6} |
| Volume coefficient of thermal expansion, per °C, 20-400°C | 8.9×10^{-5} |
| Thermal conductivity, cal/sec/cm/°C | |
| solid, 18°C | 0.27 |
| liquid, 419.5°C | 0.415 |
| Modulus of elasticity, psi | 10 to 20 x 10 ⁶ |
| Surface tension, dynes/cm | |
| 510°C | 785 |
| 550°C | 778 |
| 600°C | 768 |
| 640°C | 761 |
| $\gamma = 758 - 0.09(t - 419.5^\circ\text{C})$ | |
| Viscosity, centipoise | |
| 450°C | 3.17 |
| 600°C | 2.24 |
| 700°C | 1.88 |
| Electrical resistivity, microhm-cm | |
| 419.5°C | 35.3 |
| 600°C | 35.0 |
| 800°C | 35.7 |
| polycrystalline, $t = 0-100^\circ\text{C}$ | |
| $R = 5.46(t + 0.0042t)$ microhm-cm | |
| Magnetic susceptibility (diamagnetic), 20°C, polycrystalline, cgs units | 0.139×10^{-6} |
| Thermal neutron absorption cross section, barns | 1.1 |

reducing power of zinc, which can be intensified by increasing the surface area exposed per unit weight.

Zinc also has an amphoteric property. The metal will dissolve in hot caustic solutions evolving hydrogen and forming zincates.

The solubility diagram of zinc-hydroxy complexes as a function of solution pH is shown in Figure 2.

Uses of Zinc

Zinc ranks fourth among metals of the world in annual consumption, being surpassed only iron, aluminium and copper (Nriagu, 1980). This metal is widely used in industry such as, alloys (brass, bronze and die-casting alloys); galvanizing iron and other metals; electroplating; metal spraying; automotive parts; electrical fuses; storage and dry cell batteries; fungicides; nutrition (essential growth element); roofing; gutters; engraver's plates; cable wrappings; organ pipes (Hawley, 1981).

LEAD AND ZINC IN WASTEWATER

Lead and zinc concentrations in wastewater are related to the kinds and amounts of industrial discharge entering a particular sewage treatment system. The composition of industrial wastes changes with consumer products, industrial processes and industrial activities. Because the principal source of lead and zinc in municipal refuse and wastewater is waste generated in plants that manufacture consumer and industrial products, the concentration of lead and zinc in wastewater depends on the uses of these metals. Table 4 summarize reported lead levels in industrial wastewater and Table 5 summarize values reported

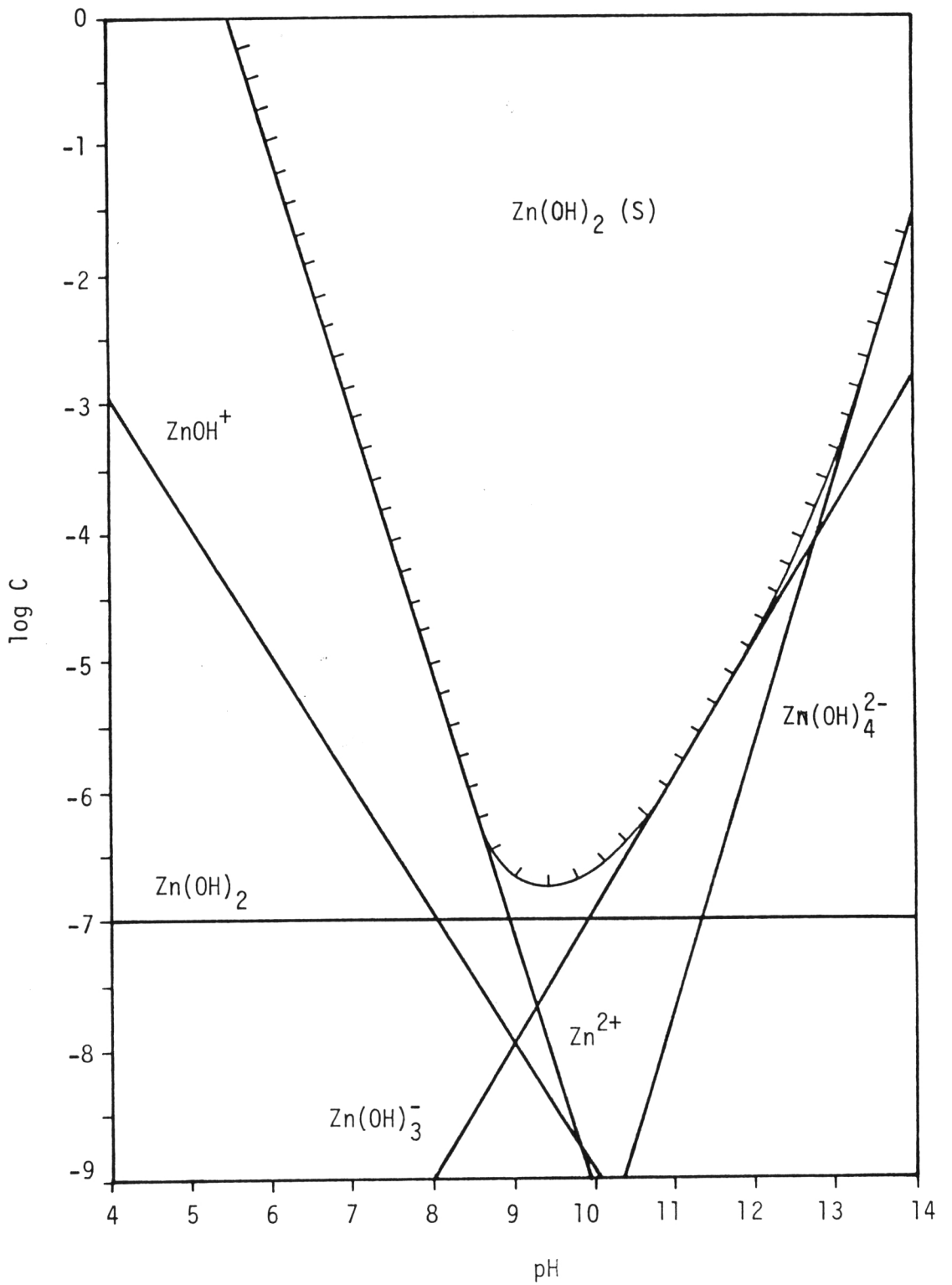


Figure 2. Theoretical Solubility Diagram for Zinc Hydroxy as a Function of Solution pH.
(Sawyer and McCarty, 1978)

TABLE 4
 REPORTED LEAD LEVELS IN INDUSTRIAL WASTEWATERS
 (Patterson, 1977)

| Industry | Lead (mg/l) |
|-----------------------------|----------------|
| Battery Manufacture | |
| Particulate | 5 - 48 |
| Soluble | 0.5 - 25 |
| Battery Manufacture | |
| Particulate | 0.4 - 66.5 |
| Soluble | 2.6 - 5.1 |
| Plating | 2 - 140 |
| Plating | 0 - 30 |
| Television Tube Manufacture | 400 |
| Mine Drainage | 0.02 - 2.5 |
| Mine Drainage | 0.04 - 0.5 |
| Mining Process Water | 0.018 - 0.098 |
| Lead Smelting | 0.07 - 0.16 |
| Ammunition Plant | 6.5 |
| Tetraethyl Lead Manufacture | |
| Organic | 126.7 - 144.8 |
| Inorganic | 66.1 - 84.9 |
| Tetraethyl Lead Manufacture | 45 |

008855

TABLE 5
 CONCENTRATIONS OF ZINC IN PROCESS WASTEWATER
 (Patterson, 1977)

| Industrial Process | Zinc Concentration (mg/l) | |
|----------------------------------|---------------------------|---------|
| | Range | Average |
| Metal Processing | | |
| Bright dip wastes | 0.2 - 37.0 | |
| Bright mill wastes | 40 - 1,463 | |
| Brass mill wastes | 8 - 10 | |
| Pickle bath | 4.3 - 41.4 | |
| Pickle bath | 0.5 - 37 | |
| Pickle bath | 20 - 35 | |
| Aqua fortis and CN dip | 10 - 15 | |
| Wire mill pickle | 36 - 374 | |
| Plating | | |
| General | 2.4 - 13.8 | 8.2 |
| General | 55 - 120 | |
| General | 15 - 20 | 15 |
| General | 5 - 10 | |
| Zinc | 20 - 30 | |
| Zinc | 70 - 150 | |
| Zinc | 70 - 350 | |
| Brass | 11 - 55 | |
| Brass | 10 - 60 | |
| General | 7.0 - 215 | 46.3 |
| Plating on Zinc Castings | 3 - 8 | |
| Galvanizing of cold rolled steel | 2 - 88 | |
| Silver Plating | | |
| Silver bearing wastes | 0 - 25 | 9 |
| Acid waste | 5 - 220 | 65 |
| Alkaline | 0.5 - 5.1 | 2.2 |
| Rayon Wastes | | |
| General | 250 - 1000 | |
| General | 20 ^a | |
| General | 20 - 120 | |
| Other | | |
| Vulcanized fiber | 100 - 300 | |
| Cooling tower blowdown | 6 | |

^aAfter process recovery of zinc by ion exchange.

for various zinc-bearing wastewaters.

THE EFFECTS OF HEAVY METALS ON ACTIVATED SLUDGE PROCESS

The most widely used type of secondary treatment is the activated sludge process. Due to the important role it plays in numerous municipal and industrial treatment facilities, many studies of the effects of heavy metals on the activated sludge wastewater sludge wastewater treatment process have been made. In this section previous investigations dealing with these topics are reviewed.

In a study of the effects of copper, chromium, nickel and zinc on the activated sludge process, Moore et al. (1961), McDermott et al. (1963), McDermott et al. (1965) and Barth et al. (1965) had concluded that an influent metal concentration of 10 mg/l, either singly or in combination, will result in a 5 percent reduction in overall plant efficiency when utilizing COD removal efficiency as the performance indicator. The results of this research indicated that the combined heavy metals studied did not act synergistically or antagonistically. The effects on the nitrification found that heavy metals inhibit nitrifying organisms. This was manifested by the decreased oxygen requirement of metal laden sludge and the presence of excess nitrogen, mainly in the form of ammonia, in the final effluent. There was no evidence of acclimation of the nitrifying organisms to metals.

Directo (1962) studied the influences of microorganism concentration and COD concentration on the toxicity of copper to the activated sludge process. The results indicated that, at constant copper concentration, an increase in microorganism concentration decreased the inhibitory effects of copper.

Barth et al. (1963) investigated the effects of a mixture of metals on the sewage treatment process. They found that copper, chromium, nickel and zinc combined, behaved independently in their distribution throughout the process. They concluded that there was no synergistic action at a total metal concentration of 8.9 mg/l.

Tomlinson et al. (1966) and Loveless and Painter (1968) investigated the inhibition of nitrification in the activated sludge process. The results indicated that the salts of heavy metals, such as nickel, chromium, and copper inhibited the growth of Nitrosomonas europaea and nitrifying activated sludge.

Neufeld (1970) studied activated sludge deflocculation caused by the presence of heavy metal in the process. Deflocculation occurred almost immediately upon receiving an influent containing mercury and indicated that in the operation of the activated sludge process receiving metal bearing wastewater, a potential problem may arise with regard to the possibility of substantial loss of biomass in the form of pinpoint discrete solids over the effluent weir of the secondary clarifier.

Ghosh and Zuger (1973) found that mercury at concentrations less than 2.5 mg/l as Hg^{2+} has little effect on activity of a mixed aerobic biomass. However at a dosage of 5.0 mg/l or higher, aerobic biological processes are definitely inhibited.

Oliver and Cosgrove (1974) studied the efficiency of heavy metal removal by a conventional activated sludge treatment plant. They have pointed out that the removal of heavy metals by the sludges occur in two stages. Firstly, by primary settling of insoluble metals or metal sorption to particulates. Secondly, by sorption of dissolved

metals or fine particulate metals to the biological floc in the aeration tanks with the subsequently settling out of the biological floc in the secondary clarifier.

Bonomo (1974) has shown that the toxic effects of zinc on the behaviour of activated sludge bacteria is less evident than that of other heavy metals.

Barth (1975) has reasoned that the aerobic treatment process can tolerate a wide range of heavy metal concentrations because of the high diversity of organisms present in the process. Heavy metals may adversely affect several organism species without significantly affecting total biological treatment efficiency.

Neufeld and Hermann (1975) investigated the heavy metal removal by acclimated activated sludge. The results indicated that mercury, cadmium, and zinc are rapidly removed from aqueous solutions by biological floc. Although eventual equilibrium was achieved after about 2 wk of contact, 3 hr of contact were sufficient to achieve an almost complete approach to that equilibrium. Their research indicated that the toxicity of zinc and cadmium is related to its accumulated concentration in the biomass. No effect was noticed until a threshold concentration of zinc and cadmium in sludge was reached, at which point the system began to be adversely affected. The overall affinity of biomass for heavy metals decreased in the order of $Pb > Cd > Hg > Cr > Zn > Ni$.

Cheng et al. (1975) investigated the mechanisms of heavy metal uptake in the activated sludge process. Results have indicated that the uptake of heavy metal by activated sludge can be characterized by short term, rapid metal uptake phase followed by a long term, slow

phase uptake. The uptake of heavy metal at low concentration is due to the formation of metallo-organic complexes. At high heavy metal concentrations, however, the metal ions precipitate from solution in addition to the uptake of heavy metal by the activated sludge. Metal uptake by biological solids depends on several factors including solubility of metal ions, metals concentration, pH, concentration of organic matter and amount of biomass present in the system. The order of metals uptaken by activated sludge was found to be in the sequence of lead>copper>cadmium>nickel.

WPCF and ASCE (1977) reported that the heavy metals, such as copper, zinc, nickel, lead, cadmium and chromium can react with the microbial enzymes to retard or completely inhibit metabolism. In general, the susceptibility of activated sludge to these heavy metal is related to the soluble, ionic concentration of the elements and the mass of sludge in the system. The recommendation of threshold concentrations of heavy metal inhibitory to the activated sludge process is depicted in Table 6.

Brown and Lester (1979) reported that several possible mechanisms of metal removal in activated sludge have been proposed. These mechanisms are :

- (i) physical trapping of precipitated metals in the sludge floc matrix;
- (ii) binding of soluble metal to extracellular polymers;
- (iii) accumulation of soluble metal by the cell;
- (iv) volatilisation of metal to the atmosphere.

The removal efficiencies of lead and zinc by activated sludge treatment plants, activated sludge pilot plants and laboratory scale activated

TABLE 6
 THRESHOLD CONCENTRATIONS OF HEAVY METAL INHIBITORY
 TO THE ACTIVATED SLUDGE PROCESS
 (WPCF and ASCE, 1977)

| Heavy Metal | Concentration (mg/l) | |
|-----------------------|----------------------|---------------|
| | Carbonaceous Removal | Nitrification |
| Aluminum | 15 to 26 | - |
| Cadmium | 10 to 100 | - |
| Chromium (hexavalent) | 1 to 10 | 0.25 |
| Chromium (trivalent) | 50 | - |
| Copper | 1.0 | 0.005 to 0.5 |
| Iron | 1,000 | - |
| Lead | 0.1 | 0.5 |
| Mercury | 0.1 to 5.0 | - |
| Nickel | 1.0 to 2.5 | 0.25 |
| Zinc | 0.08 to 10 | 0.08 to 0.5 |

sludge units, are summarised in Table 7 and 8, respectively. It appears from the results presented that the average removal efficiencies of lead and zinc are 64 and 69 percent, respectively.

Sherrard et al. (1979) concluded that combinations of Cd^{2+} and Ni^{2+} are much more toxic than the presence of each metal alone, hence, they act in a synergistic manner. COD removal efficiency was only marginally reduced, nitrification was severely inhibited, and that presence of heavy metals does markedly change biokinetic coefficients. Increasing the wastewater strength at a given influent metal concentration resulted in decreased toxic effects.

Trahern et al., (1980) concluded that the presence of nickel was found to be inhibitory to nitrification at a concentration of 1 mg/l but to have no effect at 0.5 mg/l. Biokinetic coefficients were altered in the presence of nickel. Nitrification was observed to occur at a pH as low as 4.9.

Sujarittanonta (1979), Sujarittanonta and Sherrard (1981) found that the influence of nickel on the activated sludge process depends on the organic substrate to nickel ratio, microorganism concentration to nickel ratio, and operating mean cell residence time. The near complete inhibition of nitrification while COD removal efficiency was affected only to a minor degree. COD removal efficiency was not significantly affected with influent nickel concentrations at high operating mean cell residence time.

Nriagu (1980) reported the effect of varying concentrations of zinc sulfate on the activated sludge process. No significant loss of treatment efficiency was observed with the 2.5 mg/l concentration of

TABLE 7
LEAD REMOVAL EFFICIENCIES IN ACTIVATED SLUDGE PROCESS
(Brown and Lester, 1979)

| Source of sample | Activated sludge lead influent (mg/l) | Range of removal efficiency (%) | Average removal efficiency (%) |
|------------------|---------------------------------------|---------------------------------|--------------------------------|
| ST | 0.02 - 0.06 | 83 - 95 | 89 |
| ST | 0.01 - 0.49 | 42 - 100 | 79 |
| ST | 0.02 - 0.06 | 43 - 63 | 73 |
| ST | 0.14 - 0.40 | 97 - 99 | 65 |
| ST | 0.16 | - | 43 |
| ST | 0.98 - 1.10 | - | 53 |
| PP | 0.055 | - | 60 |
| PP | 0.095 | - | 56 |
| LS | 2.10 - 25.5 | - | 98 |
| LS | 0.085 | - | 27 |
| AVERAGE | | | 64 |

ST = Activated Sludge Treatment Plants

PP = Activated Sludge Pilot Plants

LS = Laboratory Scale Activated Sludge Units

TABLE 8
 ZINC REMOVAL EFFICIENCIES IN ACTIVATED SLUDGE PROCESS
 (Brown and Lester, 1979)

| Source of sample | Activated sludge zinc influent (mg/l) | Range of removal efficiency (%) | Average removal efficiency (%) |
|------------------|---------------------------------------|---------------------------------|--------------------------------|
| ST | 0.18 - 0.51 | 91 - 97 | 93 |
| ST | 0.23 - 8.94 | 67 - 90 | 50 |
| ST | 0.31 - 0.60 | 44 - 75 | 78 |
| ST | 0.50 - 0.60 | 74 - 96 | 60 |
| ST | 0.35 | 78 - 100 | 48 |
| ST | 0.18 - 0.43 | - | 60 |
| PP | 0.527 | - | 57 |
| PP | 2.50 - 20.00 | - | 89 |
| PP | 9.00 | - | 89 |
| PP | 0.32 | - | 65 |
| LS | 7.50 - 15.00 | - | 89 |
| LS | 0.68 | - | 49 |
| AVERAGE | | | 69 |

ST = Activated Sludge Treatment Plants

PP = Activated Sludge Pilot Plants

LS = Laboratory Scale Activated Sludge Units

zinc sulfate. However, slight increases in all effluent parameters were observed with the 10 mg/l unit. Even at 20 mg/l the maximum biological oxygen demand (BOD) removal efficiency was reduced only 2%. The primary treatment is not very efficient in removing soluble zinc but the microbial floc in the activated sludge process is extremely efficient, resulting in overall process efficiencies of 74 and 95% of feed levels of 20 and 2.5 mg/l, respectively.

Jarusdumrongnit (1983) studied the effects of lead on the activated sludge process. The results indicated that the insignificant effects of lead on COD removal efficiency which obtained more than 90 percent. The degree of nitrification is not affected by lead concentration. However, nitrification is dependent on operating mean cell residence time. The values of maximum microorganism cell yield coefficient and endogenous respiration coefficient are decreased as the concentration of lead increased. Lead removal efficiency is higher than 80 percent throughout the study.