CHAPTER 3

INDUSTRIAL POLLUTION PREVENTION

Chapter Outline

3.1 DEFINITION OF INDUSTRIAL WASTE

All materials produced in large amount, which is not utilizable, by any means is called a waste. The definition of waste can be very subjective. What represents waste to one person may represent a valuable resource to another. It must have a strict, clear and legal definition to comply with the law.

There are different types of wastes produced by the industries. The wastes are associated not only with the production of raw materials and their formation to the site of utilization but also during production, processing, packing and also utilization (Figure 3.1).

Figure 3.1. View of the sky across the West Coast Highway in Singapore.

To elaborate the pollution caused by raw material and its procurement can be shown by taking a simple example of the corn food industry, which requires growing and harvesting corn in a field and its transportation to a plant for producing food items like corn flour, corn oil, carboxymethylcellulose, glucose. The huge amount of waste is also produced in the form of waste water and corn cobs. The waste-water and corn cobs can be used in land irrigation and cattle farming respectively. If these cannot be utilized properly for certain reasons, then they become wastes.

Increasing regulation of the waste management industry leads to an accurate definition of the different types of waste required for licensing of waste management facilities. In general, the nature of waste is a heterogeneous material and difficult to describe, define and classify.

3.2 TYPES OF INDUSTRIAL WASTES

There are hundreds and thousands of factories in the world, which are polluting the atmosphere, water streams and land by releasing toxic chemicals, metals, gases, particulate matter and liquid. These toxic chemicals are released from petrochemical refineries, chemicals, metal processing, refining, finishing, pharmaceutical, paint, pesticides, fertilizers, cement, glass, explosives and plastic producing plants. The examples of these chemicals are given in the following table (Table 3.1) (Figure 3.2) [1].

Courtesy USGS

Figure 3.2. Sulphur dioxide and nitrogen oxide are responsible for acid rain problems.

Table 3.1 List of prescribed substances and major substances requiring control-
Environmental Protection (Prescribed Processes and Substances) Regulations

Prescribed substances

Release to air: prescribed substances

Oxides of sulfur and other sulfur compounds
Oxides of nitrogen and other nitrogen compounds
Oxides of carbon
Organic compounds and partial oxidation products
Metals, metalloids and their compounds
Asbestos (suspended particulate matter and fibers) glass fibers and mineral fibers
Halogens and their compounds Phosphorus and its compounds, and particulate matter

Release to water: prescribed substances

Mercury and its compounds
Cadmium and its compounds
All isomers of hexachlorocyclohexane
All isomers of DDT
Pentachlorophenol and its derivatives
Hexachlorobenzene
Hexachlorobutadiene
Aldrin
Dieldrin
Endrin
Polychlorinated biphenyls
Dichlorvos
1,2-Dichloroethane
All isomers of trichlorobenzene
Atrazine
Simazine
Tributyltin compounds
Triphenyltin compounds
Triflualin
Fenitrothion
Azinphos-methyl
Malathion
Endosulfan

Release to land: prescribed substances

Organic solvents
Azides
Halogens and their covalent compounds
Metal carbonyls
Organometallic compounds
Oxidizing agents
Polychlorinated dibenzofuran
Polychlorinated dibenzo-p-dioxin
Polyhalogenated biphenyls, terphenyls and naphthalenes
Phosphorus
Pesticides
Alkali metals and their oxides and alkaline earth metals and their oxides

Table 3.1 (cont….)

Major substances requiring control
In addition to the prevention or minimization of the release of the prescribed substances, the following substances should be considered in each application and authorization:
Particulate matter
Carbon monoxide
Hydrogen chloride
Sulfur dioxide
Oxides of nitrogen
Lead and its compounds
Cadmium and its compounds
Mercury and its compounds
Organic chemicals (trace amounts)
Dioxins Furans

3.2.1 Classification of Industrial Waste

The waste is not only classified according to the type of industry producing it but also on the type of waste itself. The broad spectrum term of waste includes the following categories [2]:

1. Inactive
2. Low activity
3. Biodegradable
4. Scrap
5. Contaminated general waste
6. Healthcare waste
7. Asbestos
8. Oily waste
9. Solvents and CFCs
10. Generic types of inorganic chemical waste
11. Waste organic chemical
12. Radioactive waste
13. Explosives
14. Dust

Pollution is the most current environmental concern in waste management. The environment has been considered as a sink of all wastes. Materials have been released into the atmosphere or watercourses, or dumped into landfills which are further diluted or dispersed by natural weathering decay. Natural, biological and geochemical processes are able to deal with such flows at low level without resulting in changes in the environment. However, as the levels of emissions have increased with the rises in human activity or industrial progress, natural processes do not have sufficient turnover to prevent these changes. In some extreme cases, the overloading of the natural process of replenishment may breakdown completely affecting seriously the environment.

Environmental pollution produced by human activity has also an effect on the society through the deterioration in the quality of the environment.

3.3 PUBLIC CONCERN OVER POLLUTION

Industrial pollution has affected not only the environment but also the human community at large. Pollution has its effect on the air quality (Figure 3.3). The discharge of toxic gases, chemicals and particulate matters has created problems for the people living in the cities and in the suburbs of the plants. These discharges may cause nausea, allergies, irritation to eyes, sino splash, cystic fibrosis and other diseases. The damage done by these pollutants appears through the depletion of ozone layer and the increase of the level of CO_2, which has led to a global warming.

On the 24 March 1986, at 6.30 a.m., the bungalow at 51 Clarke Avenue, Loscoe, in Derbyshire, was completely destroyed by an explosion of methane landfill gas and the three occupants of the bungalow were injured. The bungalow was situated only 70 m from the Loscoe landfill site. In fact, the site was surrounded by housing. The Loscoe landfill was an old quarry, which had been worked for clay, stone and coal since before 1879. Infilling of the quarry with waste materials commenced in 1973 and by 1979, 100 tones/day of domestic waste was being deposited in the quarry. Disposal of waste ceased in 1982 and the site was covered with a light covering of low permeable material in 1984, followed by a more extensive covering in 1986.

The identification of landfill gas as the cause of the explosion was from the gas composition evidence of 60% methane and 40% carbon dioxide, which is characteristic of landfill gas. In addition, prior to the explosion there had been evidence of localized damage to vegetation, which was later ascribed to landfill gas. Examination of the geological characteristics of the rocks underlying the Loscoe site showed that they consisted of permeable sandstones and coal seams, allowing gas migration. In addition, blasting during quarrying operations and excavated wells may also have formed migration pathways for landfill gas. The figure shows a geological cross-section through the Loscoe site. Landfill gas from the landfill site migrated through the permeable sandstone beds, resulting in a build-up of gas to form an explosive mixture with air. These and many other incidents occurred due to air pollution which resulted in damaging not only the property but also human lives as well. For examples, the very famous Bhopal incident at Union Carbide Plant at Pune India, which took more than 2000 lives resulted from a leak of isocyanate from a storage tank [3].

Liquid waste, which is discharged by the metal refining industries, has polluted the natural water resources that are essential for the human being. For example, the discharge from chromium and cadmium processing industries has polluted the nearby water sources and the human consumption of this water has resulted in defective bone fermentation, liver failure, blindness and defective birth.

Solid waste has created more problems than the liquid wastes generated by the industries. This solid waste may come from municipal or industrial sources. The disposal of this solid waste represents a serious problem. It can be dumped as landfill or may be used as a composite. It can also be recycled into pure metals or used in the production of other useful items.   In addition, the solid waste that contains no inflammable materials can be incinerated and the resulting energy can be used in the power generation and in the steam production for heating purposes.

The pollutants stored in the landfill can be leached down causing pollution in the pollution of the ground water sources.

Waste prevention and management are the ways to tackle all these problems at the waste source either during its production or at the end-pipe treatment. By practicing prevention, industry can help in achieving good environmental protection and at same time increasing its profitability and production. The industry needs to modify the methods of production in order to reduce the waste generation at sources.

Figure 3.3. Haze over Cairo

3.4 LEGISLATION TO WASTE MANAGEMENT

There are two waste disposal incidents, which influenced waste management and its legislation in the UK and the US.

At Nuneaton, Coventry, Warwickshire, a series of toxic waste dumping episodes occurred in the early months of 1972; the most serious of which was the dumping of 36 drums of sodium cyanide in disused brickworks at Nuneaton, on the outskirts of Coventry. The site was in constant use as a play area by local children. The drums were heavily corroded and contained a total of one and a half tones of cyanide, enough, police reported, to wipe out millions of people. Over the following weeks and months further incidents of toxic waste dumping were reported extensively in the press. Drums of hazardous waste were found in numerous unauthorized sites including a woodland area and a disused caravan site. The episodes generated outrage in the population, and emergency legislation was rushed through Parliament in a matter of weeks in the form of The Deposit of Poisonous Waste Act, 1972. The new act introduced penalties of 5 years imprisonment and unlimited fines for the illegal dumping of waste, in solid or liquid form, which is poisonous, noxious or polluting. The basis of the legislation was the placing of responsibility for the disposal of waste on industry. Further legislation on waste treatment and disposal followed in 1974 with the Control of Pollution Act [4].

The other incident happened in the US. Love Canal, Niagara City in New York State. This site was an unfinished canal excavated for a projected hydro-electricity project. The abandoned site was used as a dump for toxic chemical waste and more than 20,000 tones of waste containing over 248 different identified chemicals were deposited in the site between 1930 and 1952. Following the sale of the plot in 1953, a housing estate and school were built on the site. In 1977, foul smelling liquids and sludge seeped into the basements of houses built on the site. The dump was found to be leaking and tests revealed that the air, soil and water around the site were contaminated with a wide range of toxic chemicals, including benzene, toluene, chloroform and trichloroethylene. Several hundred houses were evacuated and the site was declared a Federal Disaster Area. There were also later reports of ill health, low growth rates for children and birth defects amongst the residents. As the actual and projected clean-up costs of the site became known, Congress introduced legislation in the form of the Comprehensive Environmental Response, Compensation and Liabilities Act, 1980. This legislation placed the responsibility and cost of clean-up of contaminated waste sites back to the producers of the waste [5].

3.5 INDUSTRIAL POLLUTION PREVENTION

In fact, good industrial pollution prevention is definitely better than its cure. The first objective must be the reduction in the amount of waste produced if it cannot be avoided. The second objective is to manage the waste in a suitable way while minimizing the overall burden associated with the waste management system [6].

In order to reduce the waste production, the potential of the waste production in an industry should be properly assessed. This step should start with the procurement of the raw materials taking into consideration their type and nature, their conversion processing into products, their packing process and their recycling and reuse if possible.

Pollution prevention can ameliorate the environmental conditions by reducing the generation of waste. This can also address the serious problems of global warming caused by ozone depletion.

Figure 3.4. Development of alternative energies (such as wind power) will decrease air pollution

In addition, pollution control prevention has also economic benefits. Although waste management and recycling in most cases increases the production cost, it pays back the initial investment at the long term. Economic benefits include the amount of reduction of waste produced/treated and disposal and also in reduction of raw material.

The second thing is the modification of the production process, which includes the replacement of the raw material containing hazardous causalities, the optimization of the process, and the type of the raw material use. Also, the determination of the sources of leaks and spills in the process, the separation of hazardous from non-hazardous and recyclable waste should be also considered. The third part is the management of waste including its recycling and reuse.

The modification of the plant should take into consideration the minimum or no production of the waste by installing new equipment to control the pollution. It is also possible to enhance the recovery or recycling options in the plants.

3.6 ASSESSMENT OF INDUSTRIAL POLLUTION PREVENTION

In order to explore all waste reduction opportunities in any process, it is desirable to have a systematic approach to consider all important factors. These factors include the location of waste water sources, the facility available to reduce this waste and the determination of its economical feasibility. This requires a team of experts from management, plant operators, engineers, analysts, environmentalists and economists etc., who have the following clear goals:

1) Assessment of source
2) Reclamation of waste generated
3) Economic feasibility of reclamation procedure
4) Implementation by the organization

3.6.1 Assessment of Waste Generation

The assessment of waste generation should start with the collection information about the plant's waste stream process and operation. The thorough understanding of the waste generating process and streams is considered the best option for the reduction of this waste.

The information regarding the facility waste's streams can be collected from various sources like environmental bulletins, hazardous waste manifests, waste assays, and permissible limit. The amount of waste generating streams and their mass balances should be made available in order to have a good understanding of their quantity and processing. This information gives a clear picture about the type, the nature and the amount of each waste, its frequency of discharge and its management cost.

After the collection of this information, priorities should be given to the hazardous waste sources by keeping in view the compliance with the current environmental regulations. This should take into consideration the hazardous nature of waste, the potential of the waste minimization, the disposal cost and its volume, the facility available for the disposal and the allocated budget.

The next step is to search for the possible ways to reduce wastes. The new potential option should have its merits over the other possible options available. The available options are the published literature, conference's procedures, equipment vendors, state environmental agencies and consultants. There may be many proposals for waste minimization.

These merits are low capital cost requirement, operating cost reduction, reduction of waste hazards, short recovery period, ease of implementation and overall economical burden.

3.6.2 Feasibility of the Industrial Pollution Prevention

The feasibility of the selected options is evaluated on the basis of three aspects. The first one is the technical evaluation, the second one is on the economical basis and the third one is on the implementation basis.

The technical evaluation is done to assess the efficiency of this process. The new process should be compatible with the current one with a similar application and performance. It should reduce both the environmental and toxic wastes.

The economic evaluation is carried out taking into consideration the profitability and the pay back for the installation of new waste mining unit. Economic evaluation is of two types that include the capital cost and the operation running cost.

In designing, purchasing and installing new units, the capital cost is involved. While in running the process on a one-year basis, the operating cost is involved. For economic feasibility of a process, both capital and operating cost should show a money back period and profitability from the operation of the new unit in improving the product quality, in reducing waste generation and waste dumping cost.

The profitability of a waste minimization assessment program is important in deciding the ways to comply with the environmental regulations. Violation may ultimately result in shutting down a facility.

3.6.3 Feasibility Implementation

After considering all pros and cons of the waste minimization program, the option should be qualified to be implemented. After implementation of the proposed option, the process should be monitored carefully and evaluated on a regular basis to determine its efficiency. Otherwise, modification is required to make it beneficial [7]. A successful waste minimization assessment approach has the following stages (Fig. 3.5).

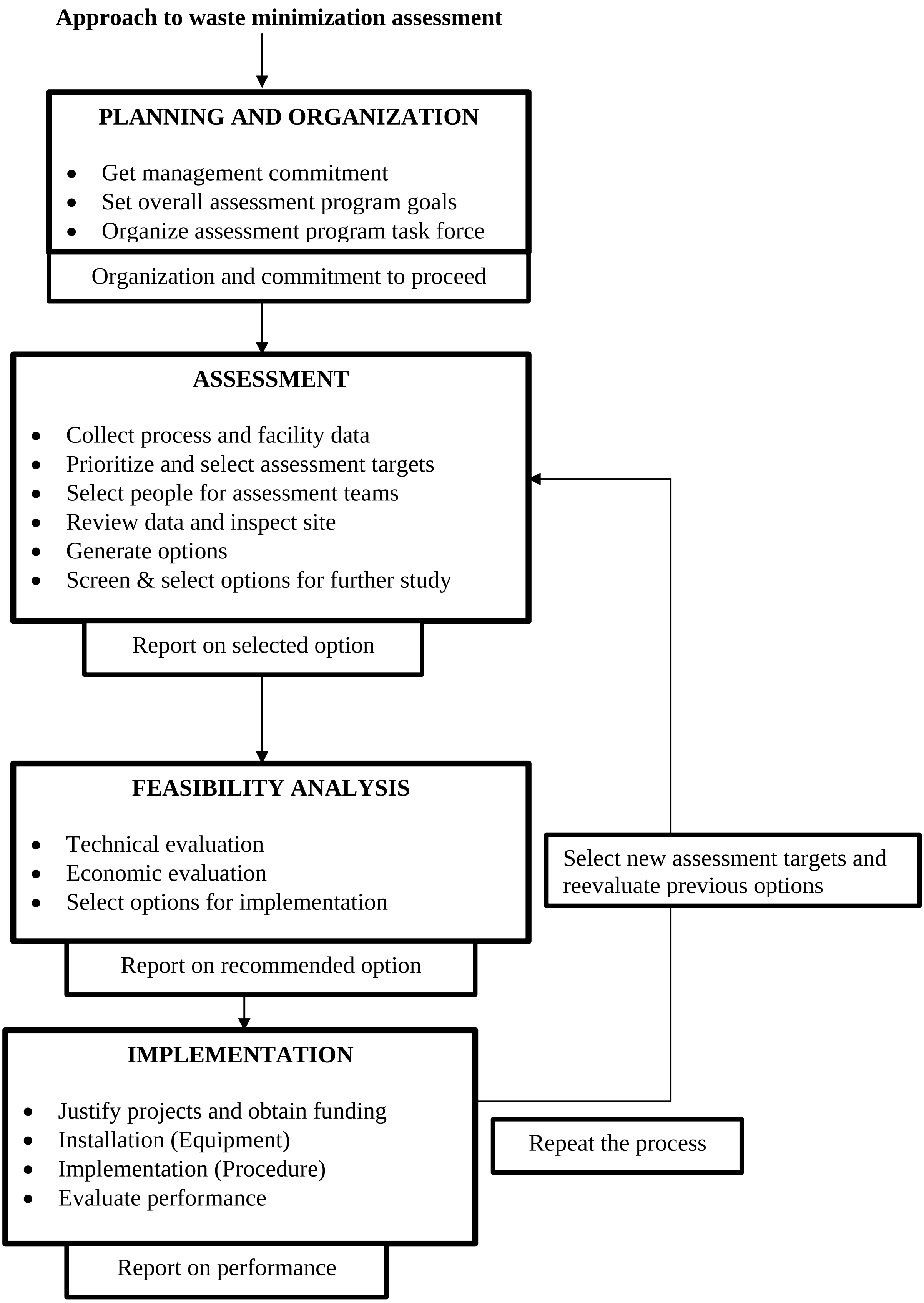


Figure 3.5 Waste minimization assessment approach

3.7 WASTE MANAGEMENT

Once the pollution prevention assessment program has identified the opportunities for the waste reduction, the waste management program can be implemented at that facility. This program starts with the source reduction technique, which involves the reduction of pollutant wastes at their source within the process. This technique is the most desired option in the pollution prevention hierarchy. By avoiding waste generation at its source, it is possible to eliminate the problem of waste handling and disposal. A wide variety of procedural options are available to minimize the waste generation.

Most of the source reduction options involve a change in procedural or organizational activities. For this reason, these options demand no large capital and time investment. There are two types of product changes: procedural and technology.

3.7.1 Procedural Change

This change involves the management, organizational, and personal functions of production. The reevaluation of the plant procedures can often reveal some reduction opportunities that are relatively inexpensive and easy to implement. Many of these measures, which are used in industry mostly to improve the waste reduction, can be implemented as well in all areas of a plant. They often require little capital cost and results in a high return on investment. Procedural changes can include:

1) Good housekeeping
2) Loss prevention
3) Material handling
4) Joint personnel practices

Good housekeeping involves the transport and the storage of the incoming raw material carefully with minimum spill during handling. This can be achieved by using leak proof transport vehicles with automatic loading and unloading facilities, use of conveyor belts, and sealed storage tanks for the raw material.

Loss prevention minimizes wastes by avoiding spills and leaks from equipment during the process. The most effective way to reduce the amount of waste generated by spills is to make precautionary modification, practices, training, and regular inspection of equipment, ensuring that spill never occurs in the first place. Cleaning of chemical spills with a typical adsorbent, results in the generation of additional waste. Several procedures can be adopted into plant design and operations to reduce the likelihood of spills, which include;

1) Controlled and supervised loading, unloading and transfer of all hazardous substances.
2) Properly designed storage tanks and containers.
3) Good physical integrity of tanks and containers.
4) Installation of overflow arms and automatic pumps shutoffs.
5) Training employees for careful handling and operation of the raw material and the process.

Material handling and inventory practices include programs to reduce loss of input resulting from mishandling, expired shelf life and improper storage conditions. The proper handling and transfer of the stored materials reduces the chances of a spill. The proper training of the employees working in the processes and the transfer of materials for an adequate spacing for stored containers and a proper labeling are efficient ways to ensure the reduction of waste production.

A poor inventory control can result in the overstocking or disposal of expired material. The economic loss due to this malpractice can be avoided by computerizing the inventory control where one can monitor shipping, storing, raw material requests and material tracking.

Wastes are mainly divided into two types: hazardous and non-hazardous. A proper segregation reduces the volume of hazardous waste by preventing the mixing of hazardous and non-hazardous wastes. The separation of hazardous waste from a non-hazardous one can significantly reduce the quantity of one kind of waste, which in turn reduces the treatment/disposal cost. Moreover, this waste can be reduced or sent for onsite or offsite treatment plant for recovery.

The reduction of the waste production can also be achieved by keeping the waste streams of wastewater separated from contaminated water or by keeping separate the stream of solvents from the hazardous materials. Cleaning solvents and wastewater can be recovered and reused, which can reduce the operational cost.

Concerning the joint personnel practices, all employees should be aware of the waste management procedures so that they can adhere efficiently to the waste reduction. Moreover, the implementation of ISO's can help them in the awareness and training program, which ultimately help in reducing the waste production. This option can be achieved by proper training and by giving incentives and bonuses and other programs to encourage employee to strive for pollution prevention.

3.7.2 Technology Change

The technology change includes the process and equipment modifications to reduce waste. This option may include inexpensive minor changes of reusing raw materials to major changes involving replacement of processes at a very high cost. After evaluating all possible procedural changes, technology changes can be opted as a last option to reduce waste, since it usually requires high capital cost. The innovations are carried out to improve product and reduce the raw material input and waste generation. Some steps involving technology change are as follows:

1) Process change
2) Equipment, piping or layout changes
3) Changes to operation settings
4) Additional alteration

Research and development is constantly being upgraded paving the ways for new improved processes with less raw material and energy inputs and also reducing the waste production. The development of activities should encompass a pollution prevention program with a new process resulting in a reduced volume of waste generation.

Process changes can include alteration of an existing process by addition of new unit operations or changing to a new technology to replace an out of date operation.

The inefficient equipment can be replaced to reduce waste generation. The required capital for new equipment can be justified by the higher productivity, the reduction of raw material costs, and the reduction of waste generation and its management. Many equipment changes are inexpensive and simple which makes their use imperative considering the cost of the reduced waste material.

The optimization of the operational settings is another way to reduce waste generation. This includes the adjustment of the process conditions, e.g., temperature, pressure, flow rate, residence time, aeration rate, raw material input rate etc. These changes often represent the easiest and the least expensive ways to reduce waste generation. If a process operates at its optimum parameter, it produces less waste material. Every reaction is accompanied by other side reactions, which produce waste in a process. When a process runs optimally, the conversion rate increases which results in a decrease of the waste material. Trial runs can be used to determine the actual optimum settings. For example, chromium coating thickness on aluminum utensils, making them corrosion proof, can be kept uniform by optimizing the time of dipping in the chromium solution, leading to a reduction of the waste production.

Additional controls can result in improved monitoring and adjustment of the operating parameters to ensure the greatest level of efficiency. Automation can reduce the human errors resulting in spills and costly down time. The resulting increase in efficiency owing to automation can increase the product yields.

3.7.3 Input Material Change

Pollution prevention can also be achieved by input material change. It actually reduces or eliminates the waste material that first enters the process. Material changes can also be done to reduce the waste generation within a production process. This can be achieved by material substitution or by material purification/concentration. The new substituted material is either very pure or has a reduced amount of hazardous constituent in it, which produces less pollutants, or has a lower waste generation and also satisfies end-product specification. The best candidate for substitution is non-toxic and non-hazardous materials in nature.

3.7.4 Product Change

The pharmaceutical industry is always challenged towards the development of new and improved medicines that have fewer side effects. The challenge for producing new products is also true for other industries. Producers are constantly seeking ways for introducing new products with the intent of reducing the resulting waste. For example, non palladium-containing paints have replaced the paints containing Pd. The organic solvents used in polishes have been replaced by water based polishes in order to reduce hazardous/toxic volatile organic emissions into the atmosphere.

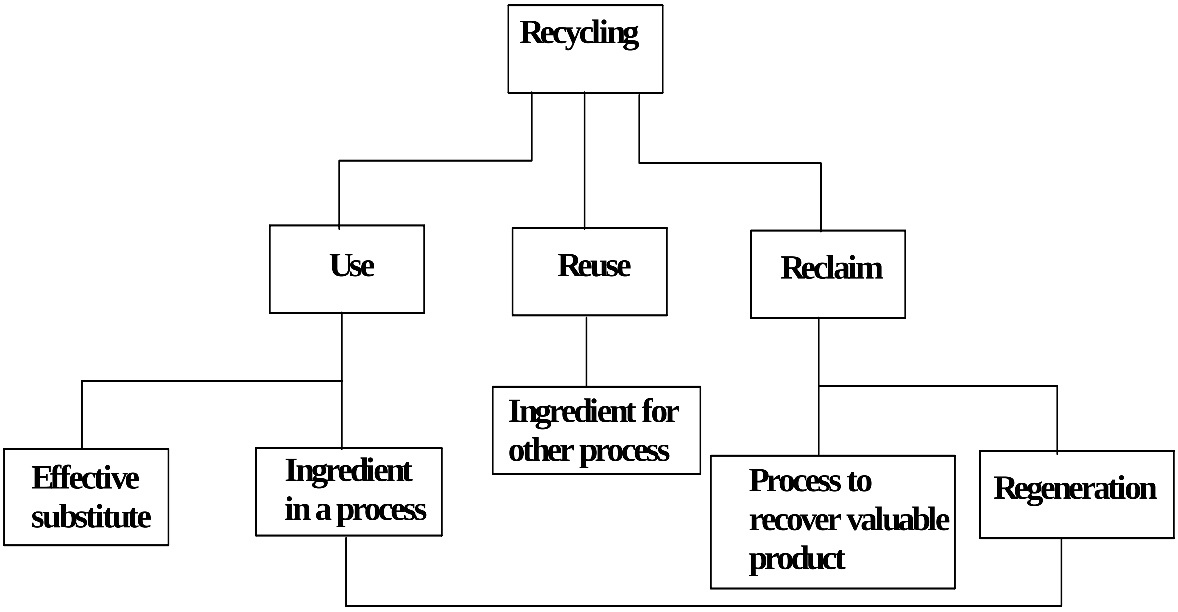
Reformulation of compositional changes involves manufacturing products with none or lower composition of toxic substances in order to reduce the amount of hazardous waste generated during the product's formulation and end-use. However, the use of a more toxic solvent in place of a hazardous solvent can still reduce the waste but the quality of the final product should not be compromised [8].

3.8 RECYCLING

There are two types of recycling processes. One is pre-consumer recycling and the other is post-consumer recycling. The pre-consumer recycling involves raw materials, products and by-products that have not reached a consumer for an intended end-use, but they are typically reused within an original process. The post-consumer recycled materials are those that have served their intended end-use and have been separated from solid waste for the purpose of recycling.

Recycling through use of re-use involves returning waste material either to the original process as a substitute, or to another process as an input material. This technique allows waste material to be used for a beneficial purpose. Reclamation in the recycling process for a valuable material or for regeneration helps to eliminate waste disposal costs, reduce raw material costs, and provide income from saleable waste.

It is important to note that sometimes reducing the amount of waste generated at the site will often be more economical than recycling. The effectiveness in recycling depends upon the ability to separate any recoverable waste from other process's waste that is not recoverable [9].



3.8.1 Options in Recycling

(1) Onsite use/reuse

(2) Offsite recovery

(3) Energy recovery

3.8.1.1 Onsite Use/Reuse

After the recycling process, the removed material can be used directly and carefully in a way that does not affect the quality of the product. The economic value of the waste and its recycling cost should be competitive.

Onsite recycling results in less waste leaving a facility leading to reduction in the waste. The availability and consistency of the recyclable waste determines the need for the set up of the on-site recycling process. Although onsite recycling does not involve transportation, other economical parameters, such as additional equipment, need for operators, and training can determine the feasibility of the onsite recycling process.

3.8.1.2 Offsite Recovery

Offsite recovery is preferable when the onsite-waste is not available in sufficient amount to make an in-plant recovery system cost-effective. The cost of an offsite recycling process depends upon the purity of the waste and the market for the recovered material. The offsite process is also preferable when this facility exists for other plants.

3.8.1.3 Energy Recovery

Energy can be recovered through the use of waste as a fuel alternative or fuel supplement in a power generation unit for running a facility producing the waste. For example, in a cane sugar factory the waste generated from used wash dried cane can be used for the generation of power as a fuel supplement.

3.8.2 RECYCLING TECHNOLOGIES

There are many treatment technologies available for recovering a useful component from a waste. These technologies are applied to recover liquid from liquid, liquid from solid, solid from solid, solid from gas etc.

3.8.2.1 Vapor Liquid Separation

The two important techniques used for the separation of vapor from liquid are:

(i) Distillation

(ii) Evaporation

3.8.2.1.1Distillation

Distillation is the most widely used liquid phase separation process for recovering organic components from a hazardous waste product stream. This method is based upon heating the liquid to convert it into vapors, which is condensed into liquid. This process can be done through continuous fractional distillation (CFD) or by batch distillation. CFD is used for the liquids having close boiling points. While in a batch process, liquid having wide differences of boiling points can be separated. Distillation cannot be used to separate thick wastes such as sludges or slums.

3.8.2.1.2Evaporation

The evaporation is a technique that is conducted to remove volatile compounds and liquid solvents from slurry and sludge, suspended solids or dissolved solids. The objective of evaporation is to concentrate a solution consisting of a nonvolatile solute in a volatile solvent. This can be achieved by heating the solutions containing solids to remove the vapors of liquid. The resulting thick liquor is collected. There are different types of evaporation technologies, including open vat evaporation, multi effect evaporation, drum dryer, tube dryer, agitator drying tube etc. For example, the removal of fine straws of cane from molasses in a sugar industry is an example of a drum dryer type or removing solid from liquid.

3.8.2.2 Solid Liquid Separation

The techniques available for the separation of solids and liquid include filtration, centrifugation and sedimentation.

3.8.2.2.1 Filtration

The process by which suspended solid particles are removed from liquid is called filtration. The liquid containing suspended solid particles is passed through a porous medium. A clear liquid is obtained. The porous medium may be a fabric, a canvas, a paper, a screen, or a bed of sand. For small particles a filter with very small pores is used but for longer particles sand may be used. The liquid flow may be passed through the filter under the influence of gravity, positive pressure or vacuum. Depending upon the size of the solid particle, a different medium is used.

3.8.2.2.2 Centrifugation

Separation of solids from liquids under the influence of a centrifugal force is called centrifugation. The liquid containing various particles of different densities are rotated at a very high speed in a closed system, where these get settled at the base according to their densities. This is commonly used as a preliminary step before the use of an additional recycling method.

3.8.2.2.3 Sedimentation

The principle of sedimentation is almost the same as centrifugation but under the influence of gravity only. Small particles are settled at the bottom of settling tanks. This technique is not energy intensive and is mainly used for waste streams containing both liquid and solids that contain a low concentration of contaminated solid.

3.8.2.3 Liquid-Liquid Separation

Liquid-liquid separation can be achieved by two methods: solvent extraction and decantation.

3.8.2.3.1 Solvent Extraction

In this method, organic molecules, soluble metals and other materials are extracted from aqueous and non-aqueous streams with the help of other organic solvents. Although it is a very well established technique, but pollutants are seldom treated by this technique. Only very few organic pollutants like CFC and phenols are removed by this technique. This is a method in which one can pre-concentrate the pollutant and recover it.

3.8.2.3.2 Decantation

When two immiscible liquids are mixed, and the one containing the pollutant can be separated from the other on the basis of densities. The liquid is fed into a settling tank where a high-density liquid is allowed to settle at the bottom and the two layers are separated. For example, the decantation process is used to separate cutting oils from wastes.

3.8.2.3.3 Solute Recovery

So far we have discussed the waste management of a solute in a solvent. Now we are going to discuss solute recovery for reuse. There are different methods of solute recovery, e.g., precipitation, ion exchange, ultra filtration and reverse osmosis.

3.8.2.3.4 Precipitation

This involves the alteration of ionic equilibrium to produce an insoluble precipitate. A precipitating agent such as caustic soda, lime, sulfide, sulfate, or carbonates are added to different solutions depending on the requirement to precipitate the metals of interest. Background knowledge is necessary for precipitation. Most of the metals recovered from the waste stream are precipitated through this technique. For example, chromium and cadmium are precipitated in the form of sulfides.

Precipitation is an effective and reliable treatment method. The resulting sludge can be reprocessed for metal recovery or to ultimate disposal.

3.8.2.3.5 Ion Exchange

Ion exchange is a process in which soluble ions of metals, inorganic, and organic acid absorbs on a solid surface containing opposite charge carrier species in a column or bed. Then the adsorbed column beds are treated to remove the specifically adsorb metals, ions, acids, etc. Ions, which are collected through this process, may be harmless or harmful depending upon their need to be reused or disposed.

For example, the common application of ion exchange is the method of recovery of hexavalent chromium from plating waste. The other examples are the removal of copper and lead in making brass and batteries, respectively.

3.8.2.3.6 Ultra-Filtration

A membrane with a very small pore size is used to remove solute or colloids from pressurized waste streams. It retains the larger particles and allows the solvent and small particles of interest to pass through it.

Through this process, very small particles of metal ions can be filtered to be used in electrophoretic paint industry. The retained big size particles are returned to the electropaint tank for reuse.

3.8.2.3.7 Reverse Osmosis

Reverse osmosis is a process by which a solute form is allowed to move across a semi permeable membrane under the influence of a concentration gradient. This process can remove dissolved organic and inorganic compounds from an aqueous stream by allowing a solvent molecule to pass through the membrane and retaining the solute molecules. The membrane is micro, or mesoporous, ionic or non-ionic in nature. A sufficient pressure gradient is applied to the concentrated solution to overcome the aromatic pressure and force a net flow through the membrane towards a dilute phase. This process constantly increases the solute concentration on one side of membrane, while a relatively pure solvent is transported through the membrane. Ions and small molecular compounds in true solution can be separated from a solvent by this technique.

This process is widely used in a seawater desalination plant of seawater, where purified water is obtained against a high salt concentration of seawater. In the metal making industry this purification method is used in the oil water mixed jet cutting tool emulsions that contain high concentration of metals. A reverse osmosis unit separates the oil from water to be reused again.

3.9 WASTE TREATMENT

Before discussing the ultimate methods of waste disposal, the other physical, chemical & biological methods of recycling should be considered in rendering the waste non-hazardous. According to the EPA definition, treatment is "any practice, other then recycling, designed to alter the physical, chemical or biological character or composition of a hazardous substance pollutant, or contaminant, so as to neutralize said substance, pollutant, or contaminant or to render it non hazardous through a process or activity separate from the production of a product or the providing of a service".

The physical, chemical and biological methods are used to treat the waste just after its generation.

The physical methods are used to concentrate, reduce waste volume, and for a separation of different phase of waste, while the chemical treatment method is used to convert a hazardous waste into non-hazardous by-products.

Biological treatment is carried out with the help of microbes and enzymes to achieve the same goal as with the chemical treatment especially for organic waste.

Although incineration is the main process used for waste disposal, it is costly. Other methods, whenever possible are chosen as alternatives ways are used in conjunction with the other unit process. For example, a typical process sequence might be decantation, sedimentation, biodegradation, followed by sludge agitation and finally land filling.

The toxicity associated with the waste is a determining factor for the selection of different onsite or offsite physical, chemical and biological methods.

For a proper management of waste, technical consideration involved in the selection of a specific treatment process may include the characteristics of the waste including the physical form, the constituents, the concentration of each contaminant, the volume of the waste, the availability of the treatment methods and their applicability.

The objective of the treatment procedure is another key factor in the selection of a particular treatment method. It may be desired to reduce the component or destroy it and then isolate it. The end product waste should be compatible with the ultimate disposal procedure to be used for the waste. For example, if the waste is to be disposed of by dumping it in the deep ocean, the end product of the waste treatment should consist of waste encapsulated in concrete.

In selecting a particular physical, chemical and biological method of treatment, the economic feasibility of the method is an important factor as well. The cost of treatment procedure and the amount of the waste to be treated is also a strong factor. Moreover, the on-site and offsite treatments should also be considered in determining the cost of the process, the initial capital investment, and the operating cost and expenses on final waste disposal. Before discussing the waste treatment and its disposal, lets look at the waste minimization and disposal hierarchy [Fig 3.6]

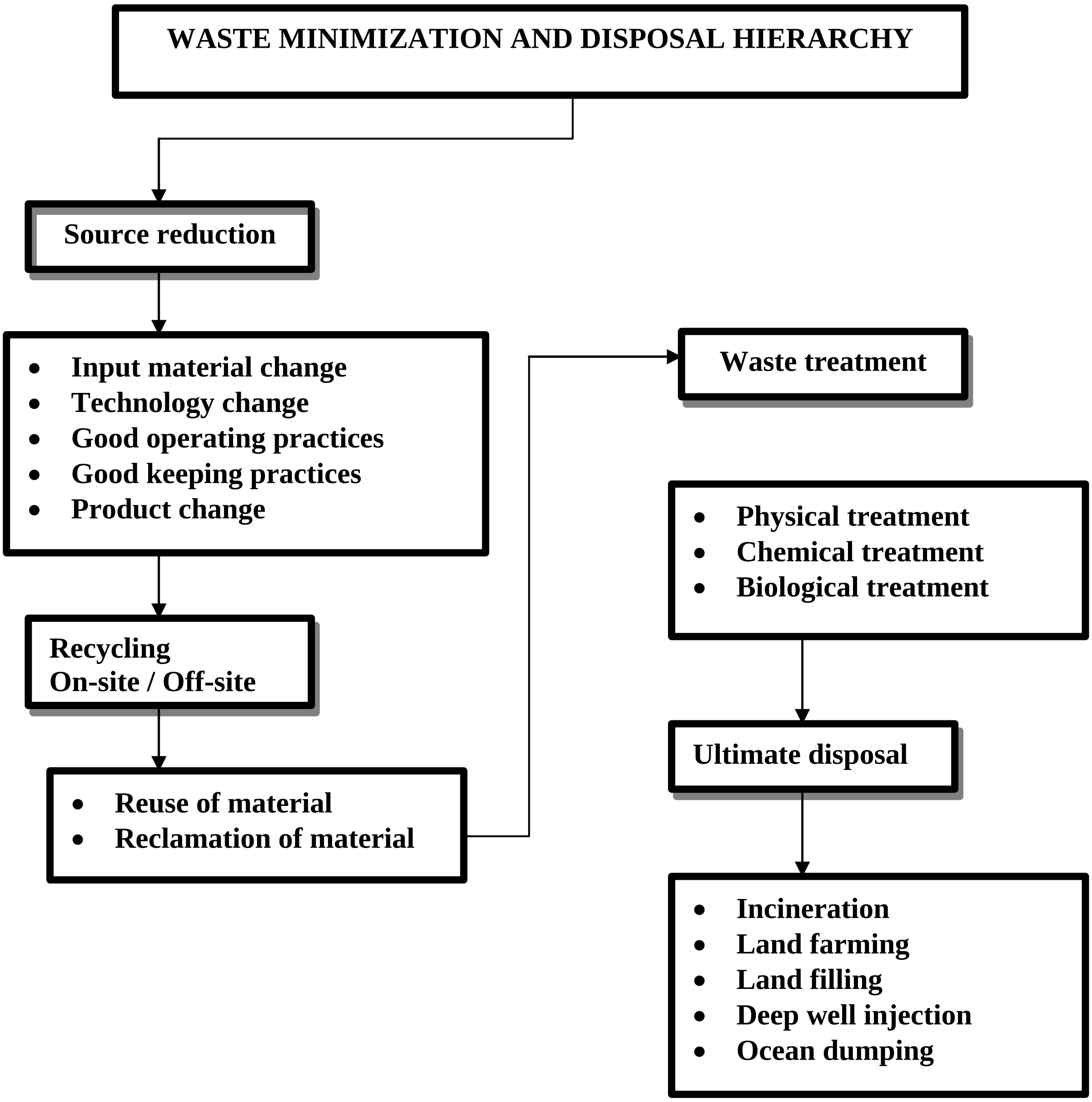


Figure 3.6. Waste Minimization and Disposal Hirarchy

3.9.1 PHYSICAL TREATMENT

Physical methods are employed to separate, reduce or concentrate the waste. There are many physical methods available for waste treatment. Among them only few have found application at the industrial level. Some methods are either in their infancy like zone refining, freeze drying and electrophoresis, while others have found little potential application due to their operational cost.

The most common processes today are sedimentation, filtration, flocculation, adsorption, distillation and solvent evaporation. These treatment methods are used for phase or component separation purposes.

To reduce or concentrate the waste volume, phase separation should be carried out for sludges, slurries and emulsions.

The separation of waste components containing large particles, filtration, centrifugation or flotation may be used. Flocculation is carried out for colloidal systems. The removal of volatiles can be carried out by distillation or evaporation.

Ion exchange, reverse osmosis, ultra filtration, and air stripping can also be used for separating waste components, especially for wastewater treatment.

3.9.1.1 Resin adsorption

The resin adsorption is a good option for the selective removal of waste. This technique is normally used for the removal of thermo labile organic solutes from aqueous waste streams. The solute concentration of solute ranges from 1-8 %. Moreover, synthetic cationic and anionic resins may be used to remove a hydrophobic, hydrophilic or neutral solute, which can be also be recovered by chemical methods. These resins are also used with a high concentration of dissolved inorganic salts in the waste stream. Their applications include phenol, fat, organics and color removal from wastewater. They can be applied for the removal of pesticides, carcinogens and chloro-fluro compounds.

3.9.1.2 Electrodialysis

In electrodialysis, separation of an aqueous stream is achieved through the use of synthetic membranes and an electric field. The membrane allows only one type of ions to pass through and may be chosen to remove other ions that move in the opposite direction.

Therefore, it produces one stream rich in particular ions and another stream depleted of those ions. The two streams can be recycled or disposed of. This technique is commonly used in the desalination of brackish water. The other uses are in acid mine drainage treatment, the desalting of sewage plant effluents, and in sulfite liquor recovery.

3.9.1.3 Flotation

This method is used to remove suspended organic and inorganic solids from waste streams or slurries. This technique is basically a physical process in which solutions carrying suspended particles are agitated with the stream of air bubbles or a mechanical agitator. A froth forms at the surface of the liquid or slurry, which is then removed by skimmers or scrapers. Individual or combinations of similar materials may be removed by this method from wastewater streams.

Flotation has been used in removing oil and greases from wastewater. Selective flotation can be achieved by adding certain surfactants for the removal of metal ions, cyanides, fluorides and carbonyl from hazardous wastes.

3.9.1.4 Air stripping

Air stripping is used to reduce the concentration of noxious gases, e.g., ammonia, and hydrogen sulfide from biologically treated waste streams. It can also be used to remove volatile organics and other pollutant gases absorbed in waste streams. This method is also highly efficient for untreated wastewater. Wastewater containing lime for phosphate removal is sent first to a mixing tank and then to a settling tank to settle out calcium phosphate and calcium carbonate. The treated water is then fed at the top of a two-packed tower, while air is fed counter currently through the tower to remove ammonia. The stripped gas is treated to decrease its concentration and waster water is also treated.

3.9.1.5 Steam striping

A steam stripping process is carried out in a distillation column, which may be either a packed or tray tower. Steam is introduced from the bottom and waste is flowing downward. The obtained stream, which is rich in volatile components, is further treated to remove the volatile materials. Air stripping may also be required to remove the volatile materials.

Steam stripping is similarly used to remove ammonia, hydrogen sulfide, and other volatile components from aqueous waste streams. It has also been used to recover sulfur from refinery waste and organics from industrial wastes.

3.9.1.6 Solidification

Solidification is a physico-chemical process that transforms a hazardous waste into a non-hazardous solid by fixation or encapsulation. In fixation, a solidifying agent is used to solidify the waste. While in encapsulation, the waste is surrounded by a binder after it has been solidified. Both processes produce durable, impermeable and environmentally safe products.

Based on the solidifying agent, this process is divided into five categories: silicate and cement, lime, thermoplastic, organic polymer and encapsulation techniques. All these processes are used to treat hazardous wastes.

Previously, solidification was used for the disposal of radioactive wastes. Recently, it has gained popularity for other waste treatment due to the strict environmental regulations.

This process is suitable for sludges from stack gas scrubbers and for fly ash from cement, iron industries as well as plating and lead smelting plants.

In the silicate and cement based process, Portland cement and other additives are added to either a wet or sludge–like waste, which produces an impermeable rock-like solid. The degree of solidification can be achieved by controlling the composition of the waste and the type of solidifying agent. Then these solids are used for land reclamation and road construction.

The advantages of this process include the inexpensive additives and the availability of the equipment.

In the lime-based process, both lime and siliceous materials are used to solidify waste. Additives such as fly ash are also added to increase the strength of the end product. The degree of solidification depends on the reaction of the lime with the other components forming the cement. A product known as pozzolanic cement is formed, which is mainly used for land filling, mine reclamation fill, or capping material.

In thermoplastic-solidification, the initial waste is dried and then combined with bitumen and polyethylene at higher temperature, which upon cooling the mixture becomes a solid. In the second step, the solid waste is thermoplastically coated and then disposed of. This process is used for inorganic and radioactive wastes.

In the organic polymer process, a monomer and a catalyst are combined with the waste stream, and the polymer is allowed to form. The product is then containerized and disposed of. The polymer used in this technique is urea of formaldehyde (melamine). The advantages of this technique are that both solid and semi-liquid waste can be processed and the weight of the processed solid is less than those produced from just being cement based, but they are biodegradable and must be containerized.

The encapsulation process deals with the dried wastes. The dried waste is first chemically treated and then coated with a binder usually polyethylene. The advantages of this process are that the encapsulated waste is very durable and resistant to water and deterioration and the final product does not need to be stored in containers. The disadvantage is that it is an expensive process and applicable on only small volumes of wastes.

3.9.2 CHEMICAL TREATMENT

There are numerous chemical processes for the treatment of wastes that are used in conjunction with other methods. These methods include calcination, precipitation, catalysis, electrolysis, hydrolysis, neutralization, photolysis, cholrinolysis, oxidation and reduction.

3.9.2.1 Calcination

Calcination is a well established single step process for the treatment of complex wastes containing organic and inorganic components in slurries, sludges, tar and aqueous solutions by heating at higher temperatures in the absence of air to remove volatiles.

The real application of this process is the recalcination of lime sludges from water treatment plants, coking of heavy residues and tars from petroleum refinery operations, concentration and volume reduction of liquid, radioactive wastes, and treatment of refinery sludges containing hydrocarbons, phosphorus and compounds of calcium, magnesium, iron and aluminum.

3.9.2.2 Electrolysis

Electrolysis is a process in which oxidation or reduction reactions take place at the surface of conductive electrodes immersed in an electrolyte under the influence of an applied potential.

This method is applicable to any component carrying an electronic charge either positive or negative. The most common use of this method is for recovering heavy, toxic metals of economical importance from concentrated solutions. For example, copper, chromium and cadmium can be recovered from waste solutions. Electrolysis is not very useful for organic waste. Pilot application includes oxidation of cyanide waste. Gas emissions may occur during the process. In case these gases are hazardous, further treatment (scrubbing) is required.

This process can be also applied to radioactive wastes containing metals in ionic forms. The removal of collected ions from the electrodes is not difficult. These ions can be recycled and reused or can be disposed of.

3.9.2.3 Neutralization

Neutralization is a process of adjusting the pH of a waste solution to near 7 (neutral) by adding acid or base. The wastes might have different chemical and physical changes such as precipitation or evolution of a gas occurring due to a chemical reaction. The process has wide application to aqueous and non-aqueous liquids, slurries and sledges and is widely used in waste treatment. Some applications include pickle liquor, mine drainage, acidic and basic waste, plating waste, etc.

Neutralization is carried out in batch or continuous process reactors by mixing acidic and alkaline streams together or by passing acidic wastes through packed beds of limestone. Also, the addition of solutions of concentrated bases such as caustic or soda ash to acid liquids or compressed CO_2 to basic waste streams can be applied. The choice of acid or base depends upon the process requirement as well as on its cost. Lime and sulfuric acid are inexpensive but their use is still limited. Treatment of sulfate bearing waste with lime produces calcium sulfate as a precipitate. However, caustic and soda ash are more expensive but widely used. Neutralization of waste containing cyanide and sulfide results in the evolution of toxic gases like hydrogen cyanide and hydrogen sulfide. These wastes require special treatment devices for neutralization such as a scrubber.

3.9.2.4 Chlorinolysis

This process is applied to chlorinated organic wastes, which are ultimately converted into carbon tetrachloride (CCl_4). In this process, the organic feed is introduced to a reactor at 900^{o}F along with chlorine gas under 20 atmospheres. Chlorine reacts with hydrocarbons to form carbon tetrachloride in addition to other chlorinated products, which are removed by distillation.

This process is only applicable to the waste streams containing proper organic waste. Moreover, chlorinolysis produces hydrochloric acid and phosgene gas as an effluent, which are further treated. The leakage of chlorine is another hazard associated to this process.

3.9.2.5 Oxidation

Oxidation is a process that involves the transfer on one or more electrons. This can be carried out by adding an oxidizing agent or via electrochemistry. This process is used for the detoxification of hazardous waste; the oxidation of cyanide to cyanate and further decomposition into CO_2 & N_2 is a good example. Metals can be oxidized to their higher oxidation state thus making them insoluble and recoverable as a precipitate.

Some industrial applications include the oxidation of cyanide with chlorine and ozone to cyanate. Ozone coupled with UV light is used to oxidize halogenated organic compounds, which are usually resistant to oxidation alone with ozone.

Cyanide, phenol, sulfur compounds and metal ions can be oxidized with hydrogen peroxide. Potassium permanganate ($KMnO_4$) is an excellent oxidizing agent that reacts with aldehydes, mercaptanes, phenols and unsaturated acids. It has been used to destroy organics in waste and potable water. The reduced form of $KMnO_4$ is manganese dioxide, which can be removed from water by filtration.

3.9.2.6 Reductions

In the reduction process, electrons are transferred from one reacting species to the chemical being reduced. As a result of this transfer, the valance state of the chemical is lowered. The resulting chemical may become less toxic or easy to precipitate. In this process, the reducing agent may be a gas, solution or divided powder. The reduction reaction is followed by a separation step such as precipitation to remove the reduced compounds. For example, chromium is used in industries such as metal finishing, inorganic chemical manufacture, coil coating, corrosion proofing, aluminum forming, iron and steel manufacture, electronic manufacture, leather tanning and pharmaceuticals. Chromium is a very toxic chemical in its Cr^{6+} state, while Cr^{3+} is much less toxic and can be precipitated in alkaline solution. Therefore, the reduction of chromium (Cr^{6+} to Cr^{3+}) is carried out with sodium metabisulfite and sodium bisulfite.

The other applications are mercury reduction by sodium borohydride ($NaBH_4$) and lead reduction by alkali metal hydride (MH).

3.9.3 BIOLOGICAL TREATMENT

Biological processes involve chemical reactions carried out by microorganisms. The microorganisms either absorb a compound inside their cell body or decompose it with the help of enzymes, or they excrete enzymes to bring it for decomposition outside the cells. The most common use of the biological process in waste treatment is the decomposition of organic compounds. These microorganisms decompose both organic and inorganic compounds.

Different biological processes used for the treatment of wastes are activated sludge aerated lagoons, anaerobic digestion, composting enzyme treatment, trickling filter and waste stabilization ponds.

These processes are known to be reliable and environmentally friendly. Chemical additives are usually not needed and the operational expenses are relatively low. Therefore, the biological treatment methods are expected to have an important role in the future of waste treatment facilities.

3.9.3.1 Activated Sludge

Activated sludge is the most widely used treatment in the biological waste treatment processes. The process uses microorganisms to decompose organics in aqueous waste streams. These microorganisms are thoroughly mixed with the organics. These microbes take the organics into the cell, through the cell membrane, into the cytoplasm, where enzymes break down these organic compounds into smaller fragments *via* different reactions. Microorganisms derive energy and cellular material from these reactions. They also adsorb colloidal matter, suspended solids, and metals onto their cell surface.

There are certain controlling factors for efficient decomposition:

- the extent of mixing,
- the amount of dissolved oxygen,
- the concentration of toxic metals,
- the type and concentration of organic compounds.

Among the various organics that can be successfully decomposed by the activated sludge process include proteins, polysaccharides, fats, oils, aldehydes, alkenes, aromatics, halogenated hydrocarbons and isoalkenes.

The advantages of this process arise from the fact that the system does not typically require chemicals and, therefore, the decomposition of organics is an environmental friendly degradation process. However, this process has limitations and cannot handle slurries, tars, or a high concentration of suspended solids. In fact, this process has been used extensively to treat waste streams from iron and steel, pulp and paper, petroleum refining, organic chemical manufacture and pharmaceutical manufacture industries.

3.9.3.2 Aerated Lagoon

The aerated lagoon is similar to that of the activated sludge process but different in a way such that biological sludge is not recycled. The aerated lagoon is an earthen basin, which is lined to make it impermeable and is artificially aerated. Aerated lagoons usually require less energy than activated sludge processes and since recycling systems are not needed, more land is required.

The aerated lagoon is fed with waste streams containing less than one percent solids, in order to avoid settling some of these solids. Therefore, the removal efficiencies are not high as those for the activated sludge process. The residence time of an aerated lagoon is longer than that of the activated sludge process.

This process has been used for petrochemical, textile, pulp and paper mills, leather tanning, gum and wood processing and some other industrial waste streams.

3.9.3.3 Composting

Composting uses aerobic digestion by microorganisms in the soil in order to decompose organics. This task can be accomplished by the piling of waste in the ground and aerating it occasionally by turning and moving the soil. The collection of leachate and run off that is produced is normally required to protect the ground water contamination.

The process, unlike some other biological processes, can tolerate some toxicants and metals. Composting is commonly used for organic wastes and a complete digestion requires 3 to 6 months depending upon the climatic conditions of the region. Composting has been successful with municipal repulse, high concentration organic sludges, and some petroleum refineries.

3.9.3.4 Trickling Filters

In place of making ponds and lagoons the trickling filter uses microorganisms which are held in a support media in a stack and wastewater is trickled over them. Usually waste streams are sprayed over the supported filter to absorb oxygen before passing through the support media. The area of the filter, size, and number of filters are important variables to control the efficiency. Trickling filters are normally used in combination with other methods due to their less efficiency. They are normally used for the treatment of different industrial wastes such as canneries, pharmaceuticals, petrochemicals and refineries. The composted material is used in land filling.

3.9.3.5 Waste Stabilization pond

For a long time, the ponds have been commonly used for sewage treatment and dilute industrial wastes. These are normally shallow basins in which wastes are fed for biological decomposition. Aeration is provided by wind, and anaerobic digestion may also occur near the bottom of the pond.

Waste stabilization ponds are normally used as a final treatment step because they are not efficient enough to be used on their own. The industries using this process include steel, textile, oil refineries, paper and pulp and canneries.

3.10 WASTE DISPOSAL BY INCINERATION

The EPA pollution prevention hierarchy includes:

(i) source reduction,

(ii) recycling,

(iii) treatment,

(iv) ultimate disposal.

So far we have covered the source reduction and recycling of wastes. In the next section, we are going to discuss their ultimate disposal including incineration and land filling.

Incineration is a well known process that involves the conversion of toxic and hazardous waste into a less or non-toxic waste by heating at a very high temperature to convert them into gaseous and particulate matter. Incineration is considered as an attractive option after source reduction and recycling. This method is sometimes preferred over the other treatment methods because it destroys permanently the hazardous components in the waste material.

It is also preferable to destroy completely or reduce any hazardous waste instead of keeping them in long-term land based disposal containment.

Properly designed incineration and ancillary equipment is considered capable of highest overall degree of destruction and control for broadcast range of hazardous waste streams. Incineration employs thermal destruction at very high temperature (>1000°C) to destroy the organic fraction through an oxidation process of the waste and converts them into inoffensive gases.

Normally all kinds of organic waste or combustible materials are the potential candidate for incineration. Even contaminated water and soils are currently disposed by incineration.

The most common type of incinerators:

(1) Rotary kiln

(2) Liquid injection

(3) Fluidized bed

(4) Open hearth (multiple heart) units

3.10.1. Rotary kiln Incinerators

Rotary kiln is a cylindrical refractory lined shell that is mounted at an angle from the horizontal and rotated at a certain speed. The rotation helps in mixing and moving the solid or liquid waste inside the kiln. It can handle any kind of solid or liquid waste. This incinerator is fed with feed from top. It has different length to diameter ratios depending upon the requirement. The working temperature ranges from 1500°F to 3000°F and rotating speed may ranges from 0.2-2 inch/sec.

The slurries and liquids are injected with the help of nozzles while solid feed is introduced through a pack-and-drum system. The rotational speed and angle at which it is positioned controls the residence time of the solid in the kiln. Normally solid waste is converted into CO, particulate matter or ash. For complete oxidation of flue gases and particulate matter, the kiln is also provided with a secondary combustion chamber. The volatilized combustibles exit the kiln and enter the secondary chamber where a complete oxidation tube is placed.

A wide variety of wastes can be incinerated in a kiln simultaneously without stopping it. Numerous hazardous wastes that previously were disposed of by land filling and deep well injection are currently being safely and economically destroyed by use of rotatory kiln incinerators. These include CFC, PVC, PCB, chlorinated coolant oils, etc.

3.10.2 Liquid Injection Incinerators (LII)

The liquid wastes, which can be pumped, injected and converted into an aerosol under high pressure, are burned in a facility called liquid injection incinerator (LII). There are three types of LII: vertical, horizontal and tangentially fired vortex combustors. The horizontal and vertical are basically similar in operating condition. The tangentially fired unit has a much higher heat release and generally superior mixing than the other two units, making it more attractive for disposal of high water-content wastes and poorly combustible materials. The temperature ranges for these LII is 1300°F-3000°F.

Normally, a liquid injection incinerator consists of two stages. The primary chamber is a burner where combustible liquids and gaseous wastes are incinerated. Non-combustible liquid and gaseous wastes usually bypass the burner and are introduced downstream of the burner into the secondary chamber. These wastes are introduced in the form of an aerosol. The aerosol is brought by pressure pump, which pumps the wastes in addition to air inside the combustion chamber through an atomizer or nozzle. A good atomizer guarantees the complete burning. The liquid waste fuel is transferred from drums into a feed tank. The tank is fed into the incinerator under high pressure. Normally a liquid fuel or a gas preheats the incinerator before waste introduction. Filtration may be required to remove solids prior to injection through the burner.

High-density liquid waste can be pumped after preheating them in order to decrease their viscosity, which not only helps in pumping but also help in aerosol production in the incinerator.

The waste liquid which contains alkali, organic matter, toxic substances or a catalyst is thermally decomposed for non-hazardous treatment and simultaneously recovered alkali salt. Such waste liquid as the above mentioned is atomized and sprayed into the flame of a high temperature by used of a high heat release and short flame burner (Vortex burner) for complete decomposition (Figures 3.7-3.8) [12].

The performance of this type of incinerator can be summarized:

1. Alkali waste liquid: NaCl, Na_2CO_3 or Na_2SO_4 can be recovered by oxidized roasting.
2. Organic waste liquid: Waste liquid containing amine, nitrile or ammonium sulfate can be thermally decomposed.

3. Hazardous waste liquid: Waste liquid containing organic halogen or metal plating can be made non-hazardous.

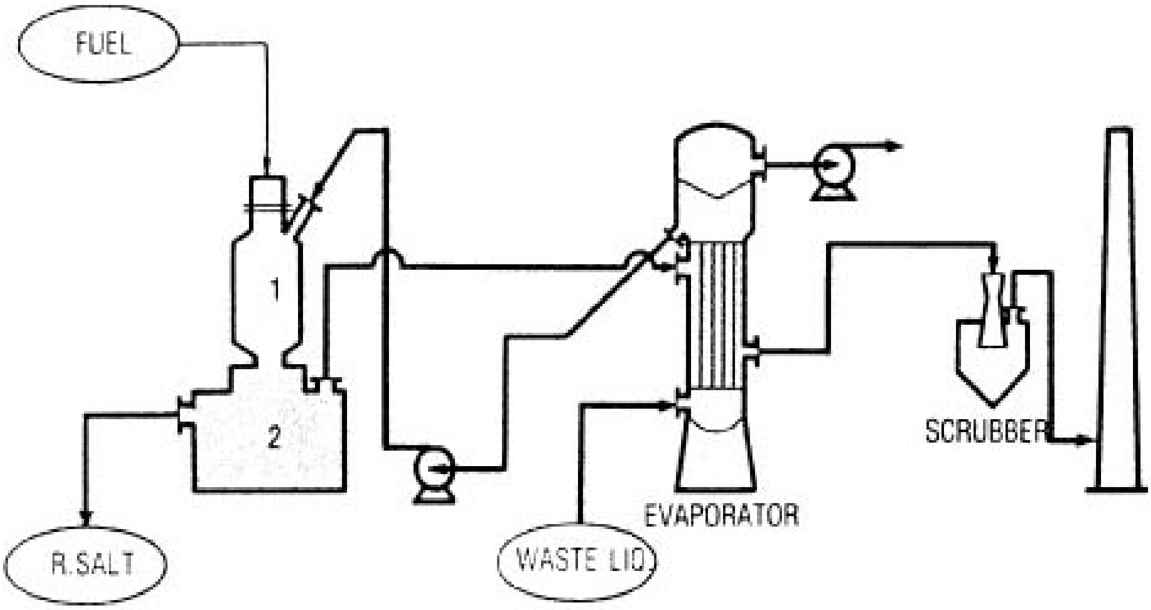


Figure 3.7. Flow sheet of alkali waste liquid treatment

Figure 3.8. Scheme of waste liquid treatment unit. Nittetu Chemical Engineering Co., Tokyo 174-0041 Japan

3.10.3 Fluidized Bed Incinerators

The fluidized bed incinerators are used to burn finely divided solids, sludges, slurries and liquid. The bed consists of granular material like sand, which is suspended by pressurized air in a highly turbulent state, which makes the bed as a fluid above the combustion chamber floor. Waste is conveyed into the fluidized bed at a very high temperature, and upon direct contact it burns and gets converted into gases and ash. The gases move out of the combustion chamber while ash caught in the bed material is eventually removed when the bed material is replaced.

The advantages of fluidized bed incinerators include simple compact design, low cost, high combustion efficiency, low gas temperatures, and large surface area for reaction. The disadvantages are the ash removal and carbon that build up in the bed. They are mainly used in petroleum and paper industries, wood chips and sewage sludge disposal.

3.10.4 Multiple Hearth Incinerators

Multiple hearth incinerators consist of a series of flat hearths laying in a series from bottom to top having a central rotating shaft and supplied with rabble arms and teeth for each hearth. The hearths are lined with refractory material and also supplied with an air blower, fuel burners, ash removal system and a waste feeding system. Solid waste is fed through the roof, while liquid and gases are introduced from burner nozzles. The central shaft with rabble arms distributes the waste across the top of the hearth to drop holes. The waste then falls to the next hearth in a series, until discharged as ash at the bottom. Temperature ranges from 500°F at the top hearth to 1800°F in the middle hearth. An incineration tube is placed in the middle hearth. Due to higher residence time, material with low volatility can be vaporized. Evaporation of large quantities of water is an added advantage [10]

3.11 ULTIMATE DISPOSAL

Another alternative option in the pollution prevention hierarchy is the ultimate disposal. This method consists mainly of land farming, land filling, deep well injection, and ocean dumping.

3.11.1 Land farming

The oldest, simplest, easiest and safest waste disposal method is the land farming. The wastes are dumped on a land to be sterilized by natural environmental processes. The wastes mainly containing organics especially from food and petroleum industries are dumped by this method. The important criteria for land farming of a waste is the biodegradability of the wastes containing organic materials, and they should have a neutral pH and contain moisture. These wastes should not contain materials that are capable of polluting air or contaminating ground water. Bacteria and yeast normally decompose these wastes, which result in leaching of water-soluble nutrients, volatilization, and finally incorporation into the soil.

The major steps involved in land farming are, site selection, site preparation, waste analysis, waste application, soil waste blending and post waste addition care. There are several advantages of land farming: it is effective while maintaining low cost disposal method, it is an environmentally safe and simple process, featuring a less processing of waste and it is also helpful in increasing the fertility and nature of the soil.

3.11.2 Land Filling

Land filling is used for wastes in the form of sludges. There are two types of land filling: area filling waste disposal at the soil surface and trenching.

Wastes are subjected to pretreatments such as solidification, degradation, volume reduction, and detoxification before being land filled. It also reduces the chances of toxic gas production and leaching out to ground water.

Area fill can be done by mixing the waste with soil forming a mound with the mixture and covering it with soil. Area fill layer is prepared by spreading alternate layers of soil and soil waste mixture over the area and by filling a containment area surrounding the dikes with the waste and then covering it with a soil layer.

The trenching involves placing the waste in a trench and covering it with one more layers of soil. Depending upon the size of the trenches, there are two types:

1. Narrow trenches of 2-10 feet wide, mainly used for sludges with low solid contents.
2. Wide trenches of more than 10 feet wide used for sludges with high solid contents. In selecting an area for landfill various factors like technical, economical and public acceptance should be considered.

Both area filling and trench filling have their advantages and disadvantages. Area filling requires less manpower and machinery and a less likely chance of contaminating ground water. Trench filling requires excavation, manpower, machinery and constant monitoring of the site. Both methods use lime and other chemicals to control odors caused by gas production, which can lead to explosions or harm of the vegetation and contamination of the water.

3.11.3 Deep Well Injection

For petroleum waste management a deep well injection disposal process has long been used. This method transfers liquid wastes underground and away from fresh wastewater sources. It is also used to dispose of saltwater in oil fields.

For the selection of a deep well injection process many factors are taken into account. The depth of the well is selected to avoid the contamination of fresh water and takes into consideration the nature of the underlying rock. The rock should be stronger but permeable enough to adsorb the liquid wastes. The site must be tested on a pilot scale before it is actually used.

The depth of the well is determined by the type and nature of the wastes. The more toxic the waste, the farther down the disposal zone must be.

The waste water to be disposed of should be low in volume, high in pollutant concentration, and must be difficult to treat with other methods. The waste water should not make any reaction in the disposal zone and should be also biologically inactive. Nuclear wastes and petroleum wastes are often disposed of by this technique.

3.11.4 Ocean Dumping

The ultimate dumping method is ocean dumping. It describes two forms of waste disposal: one into shallow offshore waters and the other into deep ocean waters. Before dumping any wastes it must be treated to reduce its volume and should be less toxic to the marine environment. This dispersal actually dilutes the contaminant and converts it biologically to a non-hazardous form.

Different kinds of wastes are still dumped in the ocean without treatment through runoff waters, but the long term effects to the marine environment have not been well monitored. There is a possibility of very damaging and long-term consequences [11].

There are certain advantages and disadvantages of offshore and deep-ocean dumping. The advantages of offshore dumping are that more information and experience are available, transportation costs to the sites are lower, and any resulting pollution is localized. However, the disadvantages are related to the problems with the fishing industry and ruining offshore mineral deposits. The advantages of deep-ocean dumping are spreading the waste over large area; thus, diluting the contamination. However, higher transportation cost together with the difficulty in monitoring the total effects of contamination are the disadvantages.

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