CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Chemical substances are materials which can be produced or used in chemical processes. Chemical processes include such reactions as combustion. Since the rise of the modern chemical industry in the nineteenth century, numerous chemical substances have been developed and created include acids, bases, fertilizers, ceramics, catalysts, dyestuffs, fabrics, explosives, paints, plastics, petrochemicals, pharmaceuticals, agricultural chemicals, specialty chemicals, automotive materials, and home and commercial electronics components (Yoshida et al., 1994).

Major accidents have been defined as “an occurrence such as a major emission, fire, or explosion resulting from uncontrolled developments in the course of the operation of any establishment and leading to serious danger to human health and/or the environment, immediate or delayed, inside or outside the establishment, and involving one or more dangerous substances” (Casal, 2008). Major accidents involve the release – instantaneous or over a relatively short period – of significant amounts of energy or of one or more hazardous materials.

One of the major contributors of these major incidents is uncontrolled chemical reaction. This is the treat pose by chemical reactivity hazards. A chemical reactivity hazard is a situation with the potential for an uncontrolled chemical reaction that can result directly or indirectly in serious harm to people, property or the environment (Shabazz, 2010).

Clearly not all chemical reactions are dangerous. In evaluating which reactions can become uncontrolled, one must understand the critical variables for a given reaction, which can be different for different situations. In situations involving storage, this may mean control of external temperature and segregation of incompatible materials. For sites doing intentional chemistry, this may mean control of the feed rate of a key reactant or control of the temperature of a reactor through flow of a coolant.

Historically, the types of uncontrolled reactions that have been involved in major incidents have fallen into two general categories: exothermic reactions and reactions that generate hazardous products (Cozzani et al., 1998).

Chemical reactivity hazards have been involved in some of the most severe industry incidents in history (Johnson et al., 2003):

- The 1976 runaway reaction at Seveso, Italy that resulted in the contamination of several square miles of land with dioxin
- The 1984 methylisocyanate release in Bhopal, India that resulted in 2000 fatalities
- The 2001 massive ammonium nitrate explosion near Toulouse, France that led to 30 fatalities ,2500 injuries, damage to nearly a third of the city of Toulouse, and the permanent closing of the facility.

When energy release is the primary concern from an uncontrolled reaction, physical damage is the primary result. Energy released by a chemical reaction might (Shabazz, 2010):

- Generate a blast wave
- Evaporate a liquid phase
- Increase temperature
- Increase reaction rate
- Initiate another reaction
- Exceed a construction material thermal limit
- Pressurize an enclosure to the point of rupture

When release of reaction products are the primary concern, the physical damage is often not direct but comes about through exposure to the materials which are released. Gas evolved by a chemical reaction might be (Shabazz, 2010):

- Flammable
- Hot
- Toxic / corrosive
- Able to pressurize an enclosure to the point of rupture

Solid / liquid product might be (Shabazz, 2010):

- Hot
- Thermally sensitive
- Shock sensitive
- Corrosive

Reaction path can dictate whether the products are the desired products or an undesired and hazardous byproduct. Thermodynamics gives the amount of heat released from the reaction and what the stable products are. Kinetics gives the rate of heat release and product generation.

Table 2.1 lists the type of Chemical Reactivity, although not an exhaustive list, by any means, this gives an idea of the types of reactivity, or reaction paths, which are of greatest concern from a reactivity management standpoint. Notice that when dealing with certain chemicals, that inadvertent mixing of materials is not required in order for a problem to occur. Many materials are capable of energetic reaction with themselves (Shabazz, 2010).

Table 2.1: Type of Chemical Reactivity (Shabazz, 2010)

Main Category	Subcategory
Readily Self React	Polymerizes Decomposes Rearranges Condenses
Readily Reacts with Common Environmental Substances	Reacts with Nitrogen Reacts with Oxygen Reacts with Water Reacts with Ordinary Combustibles Reacts with Metals
Readily Reacts with Other Chemicals	Reacts with Acids Reacts with Bases Reacts with Hydrogen

2.2 Material Safety Data Sheet (MSDS)

Material Safety Data Sheets (MSDS) are chemical information sheets. They give basic information about a product's content, potential hazards and physical characteristics as well as providing information necessary to allow the product to be used safely (Auburn, 1994).

The earliest written material has been found in the tombs of the Egyptians, either on the walls of their tombs or on papyrus records. These date back over 4,000 years and include the prescriptions of Imhotep, the first great Egyptian physician. This data while basically a pharmaceutical description of the materials used in the treatment of the various diseases prevalent also included the sources, names, preparation, storage and application procedures, as well as warnings against improper use and application (Kaplan, 1986).

The MSDS provides employers, self-employed persons, workers and other health and safety representatives with the necessary information to safely manage the risk from hazardous substance exposure. It is important that everyone in the workplace knows how to read and interpret a MSDS (www.deir.qld.gov.au , 2010).

The following example is based upon the OSHA recommended MSDS format (Form #174) and explains each section of the MSDS. It may be helpful to refer to one of the MSDS in the regional area as its review this information (Auburn, 1994).

- **Identity:**

This line will give the name of the product as it is listed on the product label to allow easy matching of the appropriate MSDS to the product.

- **Section I Manufacturer Information:**

This section provides the name and address of the manufacturer as well as a telephone number to be used to obtain product information and a telephone number to be used for emergency information.

A date of preparation appears on each sheet to allow the user to be sure they have the most current information.

- **Section II: Hazardous Ingredients/Identity Information:**

This section contains:

  - the chemical name of hazardous ingredients or
  - if a mixture, the chemical names of the hazardous ingredients that make up at least 1% or the mixture (0.1% if the ingredient is a carcinogen (cancer causing) agent.)
  - CAS Number: a unique number assigned to chemicals or materials by the Chemical Abstracts Service
  - Synonyms and/or chemical formulas

- Exposure Limits (if available). Table 2.2 indicates the main limits.

Table 2.2: Exposure Limit (Auburn, 1994)

Exposure Limits (Sources of safe limits for individual exposure.)
PEL Occupational Safety and Health Administration (OSHA) Permissible Exposure Limit. **The regulated maximum concentration an employee may safely be exposed to in any 8-hour working day as measured by a time-weighted average.** **Ceiling limits (C) indicate an exposure level that may not be exceeded for any length of time during the working day.** **STEL or Short Term Exposure Limit indicates the average exposure level that may not be exceeded for a specified, short length of time (normally 15 minutes).** **A “Skin” notation indicates that the chemical may be absorbed through the skin.** **See the OSHA Air Contaminants Standard 29 CFR 1910.1000 for a more detailed explanation or to view the PELs.**
TLV American Conference of Governmental Industrial Hygienists (ACGIH) Threshold Limit Values. **These values are not legal limits but are industry standard. TLVs are more current than regulatory limits. They are one source of industry standards used in creation of new regulations.**
REL National Institute for Occupational Safety and Health (NIOSH) Recommended Exposure Limits. **This is a government funded, non-regulatory source of current exposure limit recommendations. They are one source of industry standards used in creation of new regulations.**
Corporate Exposure Limit A recommended exposure limit based upon information gathered by the manufacturer or distributor.

- **Section III: Physical/Chemical Characteristics:**

This section outlines the physical properties of the material. This information may be used to determine conditions that may enhance exposure potential. Table 2.3 explains the elements of the physical properties of the material.

Table 2.3: Elements of the Physical Properties of the Material (Auburn, 1994)

Boiling Point: (BP)	Temperature at which liquid changes to vapor state.
Vapor pressure (mm Hg)	As a rule of thumb, higher vapor pressure materials evaporate more quickly.
Vapor density (Air = 1)	The weight of a gas or vapor compared to weight of an equal volume of air. Density greater than 1 indicates it is heavier than air. Vapors heavier than air can flow along or hover just above ground, where they may pose a fire or explosion hazard.
Solubility in Water	The percentage of material that will dissolve in water.
Appearance and Odor/odor threshold	What should the product look like and or smell like. Often a odor threshold is included indicating the smallest amount of the material that can be detected by the human nose.
Specific Gravity (H 0 =1)	The weight of a volume of liquid or solid compared to the weight of an equal volume of water. Materials with a specific gravity of greater than 1 will sink in water; less than 1 will float.
Melting Point	Temperature at which a solid begins to change to liquid state
Evaporation Rate (Butyl Acetate =1)	The rate at which a material evaporates when compared to a known material's evaporation rate
Other physical information will be given as appropriate.	

- **Section IV: Fire and Explosion Hazard Data:**

This section includes information concerning the flammability of the material and information for fighting fires involving the product. Table 2.4 shows the Flammability and its characteristic.

Table 2.4: Flammability and its characteristic (Auburn, 1994)

LEL - Lower Explosive Limit or **LFL–Lower Flammability Limit** **(Terms are synonymous.)**	The minimum concentration (percent by volume) of flammable vapor in air that will allow ignition. A product's flammable range is between the LEL and the UEL.
UEL - Upper Explosive Limit **UFL – Upper Flammability Limit** **(Terms are synonymous.)**	The maximum concentration of flammable vapor (percent by volume) in air above which ignition cannot occur. (The mixture above the UEL becomes "too rich" to support combustion.)
Flashpoint	The lowest temperature at which a liquid gives off enough vapor to ignite when a source of ignition is present.
Autoignition Temperature	The lowest temperature at which a flammable gas-air mixture will ignite spontaneously.
Extinguishing Media	The appropriate fire extinguishing agent(s) for the material.
Fire-fighting Procedures	Fire-fighting Procedures Appropriate equipment and methods to be used in limiting hazards encountered in fire situations.
Fire or Explosion Hazards	Unusual conditions which may cause or lead to fire or explosions.

- **Section V: Reactivity Data:**

This section includes information regarding the stability of the material and special storage or use recommendations. Table 2.5 explains on the stability and use recommendations of the material.

Table 2.5: Stability and use recommendations of the material (Auburn, 1994)

Stability	"Unstable" indicates that a chemical may react violently, decompose spontaneously under normal temperatures, pressures, or mechanical shocks, or rapid decomposition may produce heat, cause fire or explosion. Conditions to avoid are listed in this section.
Incompatibility	Indicates chemicals or chemical families that may react violently or unpredictably in contact with the product. Incompatible chemicals should be separated during storage.
Hazardous Decomposition or Byproducts	Hazardous substances that may be created when the chemical decomposes or burns.
Hazardous Polymerization	Indicates if the product is prone to rapid polymerization causing potential for explosion. Conditions to avoid are listed in this section.

- **Section VI: Health Hazard Data:**

This section indicates the medical signs and symptoms that may be encountered with overexposure to this product or its components. Health hazard information may also distinguish the effects of acute (short term) and chronic (long-term) exposure. Table 2.6 shows the Health Hazard Data.

Table 2.6: Health Hazard Data (Auburn, 1994)

Routes of Entry	○ Inhalation: through the respiratory tract. ○ Ingestion: through the gastrointestinal tract(i.e., by eating contaminated foods or by touching the mouth with contaminated fingers.) ○ Absorption: transference through the skin. ○ Injection: direct contact with the blood stream (i.e., through needle stick or glass cut.)
Health Hazards	Identification of target organs or systems that may be adversely affected by overexposure
Carcinogenicity	Substances which are suspected or known to cause cancer in humans. See the carcinogen listing on the EHS web page.
Signs and Symptoms of Exposure	Identification of the outward appearance or feel of overexposure.
Medical conditions generally aggravated by exposure	Medical conditions that may be aggravated by normal exposure or overexposure.
Emergency and First Aid Procedures	Recommended emergency and first aid procedures based on the toxicity of the product, degree of exposure and route of contact.

- **Section VII: Precautions for Safe Handling and Use:**

This section provides general information for safe handling and use. Local regulations must also be taken into consideration in dealing with spills and waste disposal. Table 2.7 explained on the Precautions for Safe Handling and Use.

Table 2.7: Precautions for Safe Handling and Use (Auburn, 1994)

Spill or Release Data	Materials and methods to use in a small, moderate or large spill situation.
Waste Disposal Method	Indicates if the product must be disposed of as a hazardous waste. Utilize University guidelines in determining disposal methods and procedures.
Precautions to be taken in Handling and Storage	This section may contain incompatibility information as well as special precautions for use or storage.
Other Precautions	Other hazards or precautions not elsewhere listed.

- **Section VIII: Control Measures:**

This section includes general information about appropriate personal protective equipment for handling this material. Many times, this section is written for large scale use of the material. Consider the amount and use of a material in choosing the right personal protective equipment. Table 2.8 shows the Control Measures and its explanations.

Table 2.8: Control Measures (Auburn, 1994)

Respiratory Protection	Indicates the type of respirator recommended. Some respirators supply air while others filter room air. Use of a respirator requires amedical exam, training and fit testing. Contact EHS prior to any respirator use.
Protective Gloves	Use compatible glove materials based upon the chemical used. See glove compatibility charts on the EHS web page or ask the glove supplier or manufacturer for more information.
Eye Protection	Safety glasses or Splash goggles must be ANSI approved for the intended use. Look for the ANSI imprint on the lens. Standard prescription glasses are not suitable safety glasses
Protective Clothing	Recommended clothing may not be appropriate for lab use.
Ventilation	Recommendations for general room ventilation and/or point source local exhaust ventilation.
Work/Hygienic Practices	Special recommendations for use.

2.3 Physical and Chemical Properties

Physical and thermodynamic property data for organic and inorganic chemicals are of special value to engineers in the chemical processing and petroleum refining industries. The engineering design of process equipment often requires knowledge of such properties as heat capacity, enthalpy, density, viscosity, thermal conductivity and others. Usually, misidentification of these properties can produce a huge accident in chemical plant. That is why all of these properties are important even it is a small value can make a huge impact to the plant (Crowl et al., 2002).

The properties such as physical state basically is measures at 15^{o}C and 1 atm and is defined as the statement indicates whether the chemical is a solid, liquid, or gas after it has reached equilibrium with its surroundings at “ordinary” conditions of temperature and pressure (Mcleod, 2009).

Molecular weight is defined as the value is the weight of a molecule of the chemical relative to a value of 12 for one atom of carbon. The molecular weight is useful in converting from molecular units to weight units, and in calculating pressures, volumes and temperatures relationships for gaseous materials. The ratio of the densities of any two gases is approximately equal to the ratio of their molecular weights. The molecular weights of mixtures can be calculated if both the identify and quantity of each component of the mixture are known (Yoshida et al., 1994).

The other properties of chemicals are boiling point and freezing point. Boiling point at 1 atm is defined as the value is the temperature of a liquid when its vapour pressure is 1 atm. For example, when water is heated to 100^{o}C, its vapor pressure rises to 1 atm and the liquid boil. The boiling point at 1 atm indicates whether a liquid will boil and become a gas at any particular temperature and sea-level atmospheric pressure. Freezing point is the temperature at which a liquid changes to a solid. For example, liquid water changes to a solid ice at 0^{o}C. Some liquids solidify very slowly even when cooled below their freezing point. When liquids are not pure (for example, salt water) their freezing points are lowered slightly (Tweeddale, 2003).

The specific gravity of a chemical is the ratio of the weight of the solid or liquid to the weight of an equal volume of water at 4^{o}C (or at some other specified temperature). If the specific gravity is less than 1.0 (or less than 1.03 in seawater) the chemical will float; if higher, it will sink. For vapour phase, the value is the ratio of the weight of vapour to the weight of an equal volume of dry air at the same conditions of temperature and pressure. Buoyant vapours have a vapour specific gravity less than one. The value may be approximated by the ratio M/29, where M is the molecular weight of the chemical. In some cases the vapour may be at a temperature different from that of the surrounding air. For example, the vapour from a container of boiling methane at -113.33^{o}C sinks in warm air, even though the vapour specific gravity of methane at 15.55^{o}F is about 0.6 (Knight et al., 2003).

Latent heat of vaporization is also the properties that need to be considered. The latent heat of vaporization is defined as the value is the heat that must be added to the specific weight of a liquid before it can change to vapour (gas). It varies with temperature; the value given is that at the boiling point at 1 atm. The units used are Btu per pound, calories per gram, and joules per kilogram. No value is given for chemicals with very high boiling points at 1 atm, because such substances are considered essentially non-volatile (Reynolds et al., 2002).

Heat of combustion is also taken as consideration for chemical properties. Heat of combustion is defined as the value is the amount of heat liberated when the specified weight is burned in oxygen at 25^{o}C. The products of combustion, including water, are assumed to remain as gases; the value given is usually referred to as the ‘lower heat value”. A negative sign before the value indicates that heat is given off when the chemical burns. The units typically used are Btu per pound, calories per gram, and joules per kilogram (Blackman, 2001).

Heat of decomposition is the amount of heat liberated when the specific weight decomposes to more stable substances. Most chemicals are stable and do not decompose under the conditions of temperature and pressure encountered during shipment. A negative sign before the value simply indicates that heat is given off during the decomposition. The value does not include heat given off when the chemical burns. The units typically used are Btu per pound, calories per gram, and joules per kilogram (Cheremisinoff, 1999).

Heat of solution is the value represents the heat liberated when the specified weight of chemical is dissolved in a relatively large amount of water at 25^{o}C (“infinite dilution”). A negative sign before the value indicates that heat is given off, causing a rise in temperature. A few chemicals absorb heat when they dissolve, causing the temperature to fall. The units used are Btu per pound, calories per gram, and joules per kilogram. In those few cases where the chemical reacts with water and the reaction products dissolve, the heat given off during the reaction is included in the heat of solution (Fingas, 2001).

Heat of polymerization is the value that the heat liberated when the specified weight of the compound (usually called the monomer) polymerizes to form the polymer. In some cases the heat liberated is so great that the temperature rises significantly, and the material may burst its container or catch fire. The negative sign before the value indicates that the heat is given off during the polymerization reaction. The units used are Btu per pound, calories per gram, and joules per kilogram (Florczak et al., 2001).

Liquid heat capacity is the heat (in Btu) required raising the temperature of one pound of the liquid one degree Fahrenheit at constant pressure. For example, it requires almost 1 Btu to raise the temperature of 1 pound of water from 20^{o}C to 20.5^{o}C. The value is useful in calculating the increase in temperature of a liquid when it is heated, as in a fire. The value increases slightly with an increase in temperature (Davletshina et al., 1998).

Liquid viscosity is the value (in centipoises) that is a measure of the ability of a liquid to flow through a pipe or a hole; higher values indicate that the liquid flows less readily under a fixed pressure head. For example, heavy oils have higher viscosities (i.e. are more viscous) than gasoline. Liquid viscosities decrease rapidly with an increase in temperature. A basic law of fluid mechanics states that the force per unit area needed to shear a fluid is proportional to the velocity gradient. The constant of proportionality is the viscosity (Houghton, 2008).

The properties of solubility in water are also taken in the consideration because water is the universal solution. The value represents the pounds of a chemical that will dissolve in 100 pounds of pure water. Solubility usually increases when the temperature increases. The following terms are used when numerical data are either unavailable or not applicable: The term “Miscible” means that the chemical mixes with water in all proportions. The term “Reacts” means that the substance reacts chemically with water; thus, its solubility has no real meaning. “Insoluble” usually means that one pound of the chemical does not dissolve entirely in 100 pounds of water. However, weak solutions of “Insoluble” materials may still be hazardous to humans, fishes, and waterfowl (Yoshida et al., 1995).

2.4 Chemical Reactivity

There are a lot of reaction exists between chemicals but the reactivity also can be classified into some classes which are reactivity with water, reactivity with common materials, stability during transport, neutralizing agents for acids and caustics, polymerization and inhibitor of polymerization.

For the reactivity with water, the term “No Reaction” means that no hazard results when the chemical reacts or mixes with water. When there are hazard does result, it is described for specific chemicals .The reactivity with common materials is limited to hazardous reactions with the fuels and with common materials of construction such as metal, wood, plastics, cement, and glass. The nature of the hazard, such as severe corrosion or formation of a flammable gas, is described for specific chemicals (Cheremisinoff, 1999).

For the stability during transport, the term “stable” means that the chemical will not decompose in a hazardous manner under the conditions of temperature, pressure, and mechanical shock that are normally encountered during shipment; the term does not apply to fire situation. For neutralizing agents for acids and caustics, in all cases involving accidental discharge, dilution with water may be followed by use of the agent specified, particularly if the material cannot be flushed away; the agent specified need not necessarily be used (Houghton, 2008).

There are also a few chemicals can undergo rapid polymerization to form stickly, resinous materials, with the liberation of much heat. Under these conditions the chemical’s containers may explode due to internal pressure build up. The chemical names and concentrations of inhibitors added by the manufacturer to prevent polymerization are given where appropriate (Patnaik, 2007).

2.5 Hazards

2.5.1 Health Hazards

Personal Protective Equipment is the items that recommended by manufacturers, either in technical bulletins or in Material Safety Data Sheets, the Manufacturing Chemists Association, or the National Safety Council, for use by personnel while responding to fire or accidental discharge of the chemical. They are intended to protect the lungs, eyes and skin (Kutz, 2009).

For the toxicity by inhalation, the threshold limit value (TLV) is usually expressed in units of parts per million (ppm). For example, the parts of vapor (gas) per million parts of contaminated air by volume at 25°C and atmospheric pressure. For a chemical that forms a fine mist or dust, the concentration is given in milligrams per cubic meter (mg/m^3). The TLV is defined as the concentration of the substance in air that can be breathed for five consecutive eight hour workdays (40-hour work week) by most people without adverse effect (ACGIH, 1972). As some people become ill after exposure to concentrations lower than the TLV, this value cannot be used to define exactly what is a "safe" or "dangerous" concentration (Davletshina et al., 1998).

In the Short-Term Inhalation Limits, the parts of vapor (gas per million parts of contaminated air by volume at 25°C and atmospheric pressure is given. The limits are normally given in milligrams per cubic meter for chemicals that can form a fine mist or dust. The values given are the maximum permissible average exposures for the time periods specified. The term Short Term Exposure Limit (STEL) is also used and is considered interchangeable with Short - Term Inhalation Limit. The STEL designation is derived from OSH standards. In some instances the values disagree, or the short-term limits overlap the TLV. These are not errors; the values were supplied by several laboratories, each of which used its own experimental techniques and methods of calculation (Santoleri, 2000).

For toxicity by ingestion, the term LD_{50} (meaning "lethal dose at the 50th percentile population") signifies that about 50% of the animals given the specified dose by mouth will die. Thus, for a chemical whose LD_{50} is below 50 mg/kg, the toxic dose for 50% of animals weighing 70 kg (150 lb) is 70x 50 = 3500 mg = 3.5 g, or less than one teaspoonful; it might be as little as a few drops. For a chemical with an LD_{50} of between *5* to 15g/kg, the LD_{50} would be between a pint and a quart for a 150 lb man. All LD_{50} values have been obtained using small laboratory animals such as rodents, cats, and dogs. The substantial risks taken in using these values for estimating human toxicity are the same as those taken when new drugs are administered to humans for the first time (Yoshida et al., 1994).

For the late toxicity, where there is evidence that the chemical can cause cancer, mutagenic effects, teratogenic effects, or a delayed injury to vital organs such as the liver or kidney, a qualitative description of the effect is often given on a material safety data sheet. The term can be interpreted as implying long term or chronic effects due to exposure to the chemical. In this respect, a distinction must be made between acute and chronic effects. An acute effect is one in which there is a short term or immediate response, usually due to exposure of the chemical at a high concentration. A chronic effect implies a long term exposure to small doses, with symptoms sometimes taking years to materialize (Maczulak, 2009).

For vapor (gas) irritant characteristics since MSDS often provide non-qualifying statements, the most appropriate of five statements listed below is given (NASCHM, 1970).

- Vapors are non-irritating to eyes and throat.
- Vapors cause a slight smarting of the eyes or respiratory system if present in high concentrations. The effect is temporary.
- Vapors cause moderate irritation such that personnel will find high concentrations unpleasant. The effect is temporary.
- Vapors are moderately irritating such that personnel will not usually tolerate moderate or high concentrations.
- Vapors cause severe irritation of eyes and throat and can cause eye and lung injury. They cannot be tolerated even at low concentrations.

2.5.2 Fire Hazards

Flash Point is defined as the lowest temperature at which vapors above a volatile combustible substance will ignite in air when exposed to a flame. Depending on the test method used, the values given are either Tag Closed Cup (C.C.) (ASTM D56) or Cleveland Open Cup (O.C.) (ASTM 093). The values, along with those given below, provide an indication of the relative flammability of the chemical. In general, the open cup value is about -12.2°C to -9.4°C higher than the closed cup value (Yoshida et al., 1994).

For the Flammable Limits in Air the percent concentration in air (by volume) is given for the lower (LFL) and upper (UFL) limit. The values, along with those for flash point and ignition temperature, give an indication of the relative flammability of the chemical. The limits are sometimes referred to as "lower explosive limit" (LEL) and "upper explosive limit" (UEL) (Crowl et al., 2002).

Flammability Range defined as the difference between the UFL and LFL. This difference provides an indication of how wide the flammability limits of a chemical are. Generally, the wider the range, the more hazardous the chemical may be considered from a fire standpoint (Blackman, 2001).

For special hazards of combustion products some chemicals decompose or bum to give off toxic and irritating gases. Such gases may also be given off by chemicals that vaporize in the heat of a fire without either decomposing or burning. If no entry appears with a chemical, the combustion products are thought to be similar to those formed by the burning of oil, gasoline, or alcohol; they include carbon monoxide (poisonous), carbon dioxide, and water vapor. The specific combustion products are usually not well known over the wide variety of conditions existing in fires; some may be hazardous (Florczak, 2001).

Ignition Temperature is the minimum temperature at which the material will ignite without a spark or flame being present. Along with the values of flash point and flammable limits in air, it gives an indication of the relative flammability of the chemical. It is sometimes called the "auto ignition temperature” (Gallant, 2006).

2.6 Response to Discharge

In every case of a discharge or leak, it is obvious that an effort should be made to reduce, stop, or contain the flow of material at its source if this can be done safely. The purpose of the terms used in this section is to describe in a general way the cautionary and corrective responses that are well recognized by trained emergency response personnel (Davletshina et al., 1998).

i) **Issue warning** is used when the chemical is a poison, has a high flammability, is a water contaminant, is an air contaminant (so as to be hazardous to life), is an oxidizing material, or is corrosive. This type of response warning is most often applied for cautionary purposes to restrict ignition, and to restrict contaminated water for human use, farm use, and industrial use.

ii) **Restrict access** is used only for those chemicals that are unusually and immediately hazardous to personnel unless they are protected properly by respirators, eye goggles, protective clothing, etc. This type of cautionary response is sometimes used in a broader sense to ensure exclusion of spectators and others who might ignite flammable compounds.

iii) **Evacuate area** is used primarily for unusually poisonous chemicals or those that ignite easily. The same expression can be used for a cautionary response.

iv) **Mechanical containment** is used for water-insoluble chemicals that float and do not evaporate readily. The corresponding corrective response is "Contain".

v) **Should be removed** is used for chemicals that cannot be allowed to disperse because of their harmful effect on humans or on the ecological system in general. The term is not used unless there is a reasonable chance of preventing dispersal, after a discharge or leak, by chemical and physical treatment.

vi) **Chemical and physical treatment** is recommended for chemicals that can be removed by skimming, pumping, dredging, burning, neutralization, absorption, coagulation, or precipitation. The corrective response may also include the use of dispersing agents, sinking agents, and biological treatment.

vii) **Disperse and flush** is used for chemicals that can be made non-hazardous to humans by simple dilution with water. In a few cases the response is indicated even when the compound reacts with water because, when proper care is taken, dilution is still the most effective way of removing the primary hazard.

2.7 Hazard Classification

Table 2.9 shows the hazard classification for most chemical. This classification basically is the common classification that we use today in most of the places that contain several chemicals. The hazard class specified in the Code of Federal Regulations which is chemicals not specifically listed within have been classified as “Flammable” if their flash point (closed cup) is below 37.78^{o}C (Crowl et al., 2002).

There are also classes and divisions in hazard. According to UN Hazard Classes and Divisions, the hazard class of a material is indicated either by its class (or division) number, or its class name. For a placard corresponding to the primary hazard class of a material, the hazard class or division number must be displayed in the lower comer of the placard (Fingas, 2001).

Table 2.9: Hazard Classification of the materials (Cheremisinoff, 1999)

Classification	Definition				
	Health Hazard (Blue)	Flammability (Red)	Reactivity (Yellow)	Other (White)	
4	Materials which on very short exposure could cause death or major residual injury even though prompt medical treatments were given.	Materials which will rapidly or completely vaporize at atmospheric pressure and normal ambient temperature, or which are readily dispersed in air and which will burn readily.	Materials which in themselves are readily capable of detonation or of explosive decomposition or reaction at normal temperatures and pressures.	ALK	Alkaline
3	Materials which on short exposure could cause serious temporary or residual injury even though prompt medical treatments were given.	Liquids and solids that can be ignited under almost all ambient temperature conditions.	Materials which in themselves are capable of detonation or explosive reaction but require a strong initiating source or which must be heated under confinement before initiation or which react explosively with water.	ACID	Acidic
2	Materials which on intense or continued exposure	Materials that must be moderately heated or exposed	Materials which in themselves are normally unstable and	COR	Corrosive

	could cause temporary incapacitation or possible residual injury unless prompt medical treatment is given.	to relatively high ambient temperatures before ignition can occur.	readily undergo violent chemical change but do not detonate. Also materials which may react violently with water or which may form potentially explosive mixtures with water.		
1	Materials which on exposure would cause irritation but only minor residual injury even if no treatment is given.	Materials that must be preheated before ignition can occur.	Materials which in themselves are normally stable, but which can become unstable at elevated temperatures and pressures or which may react with water with some release of energy but not violently.	OX	Oxidizing
0	Materials which on exposure under fire conditions would offer no hazard beyond that of ordinary combustible material.	Materials that will not burn	Materials which in themselves are normally stable, even under fire exposure conditions, and which are not reactive with water.	~~W~~	Material that react violently. Similar to Reactivity Classification

Table 2.9 shows hazard classification for the chemicals. Basically, this information is useful when it comes to the work in laboratory and plant. Every laboratory required this kind of information to ensure the safety of the laboratory. Also for the plant work, Health, Safety and Environment (HSE) department in every chemical company is responsible to put this information to ensure the safety of the plant.

2.8 Summary of Other Reactivity Software

There is some software that has been used by the people to overcome the problem when it comes to the Chemical Process Safety. The examples of the software are Chemical Reactivity Worksheet (CRW2) and Chemistry Database (ChemDB).

Basically, CRW2 is use to find out a chemical's intrinsic hazards (such as flammability, explosiveness, or polymerizability) by looking at the chemical datasheets. The CRW database contains hazard information for over 5,000 common materials. The user can add chemicals to the Reactivity Worksheet to determine the compatibility hazards (such as heat generation, gas generation, or water-soluble toxic product formation) that might occur while mixing any two materials together (CRW2 User Guide). This software has been developed by U.S Environmental Protection Agency and Emergency Response Division of National Oceanic and Atmospheric Administration with collaboration of Center for Chemical Process Safety. The software can be downloaded from the following websites: http://software.informer.com/

Chemistry Database (ChemDB) provides the useful information such as material information, safety information of the chemical, reactivity of the chemical, emergency response and others. This software has been quite useful tool as it has been use by most of the people to predict the chemical hazards. This software has been developed by the ATSOFT organization. The software can be downloaded from the following website: http://www.softpedia.com/