Chapter 1

Introduction
1.1 General introduction:

In our time research finds its utmost place in the advancement of scientific and technological progress. Every aspect of development in the world majorly relevant to the progress occurs in varied scientific areas. However, the necessities of life continuously bring new dimensions in it for the further advancement and create different demand to the society for the living beings on the earth. The scientific community always plays a very significant role for the contentment of the demand of society by various means of research outcome in different field areas. Among these, Polymer science is one of the fascinating areas for the scientist of today’s age to innovate and discover the findings to make an impact on every aspect of life in this very beautiful earth. It is being said that the life is polymeric. Its enormous perspective related to the possibility of the work opens extensive ways for the researcher and scientists to innovate the findings for its most applicative use in the world. The most noticeable applications of polymer science perceive in the field of communication technology, automobile, transportation sector and construction areas. In all means the natural as well as synthetic polymers are used in vast applications that provide the stepping-stone in terms of scientific and technological advancement towards the better sphere. The modification of polymer or polymerization by various means of synthesis and processing techniques attracted much attention for their use. It is believed that the products after polymerization process or polymers are used in almost all the fields of the applicative areas. Although the field of polymer science and technology is very much attracting the worldwide attention still the various difficulties continuously bound to its application wise use. These relevant problems of the polymers are being resolved by field workers and subsequently positive effort
have been made in a view that the polymer end product will fulfill the demand of the property application relationship. Further, the new scientific and technological concept like nanotechnology and supramolecular chemistry in material science makes supplementary advancement in the field of polymer science which results in the better outcome of the perused objective of happy, healthy and comfortable life.

1.2 Polymer:
The term polymer derived from Greek words poly and meros means many parts. Polymer is a substance that has a molecular structure built up chiefly or completely from a large number of similar single units (monomer) bonded together to form a long chain molecule having high molecular weight [1, 2]. By various means we come across polymers each and every minute we live on this planet. Polymers show very unique and desired set of properties that make their use very abundant on the planet earth; either in natural or artificially prepared form. The general features of polymer [3] are given in following figure.

Figure 1.1 General features of polymers
Naturally occurring polymers are cellulose, starch, wool, latex and including living organism’s body building unit like polysaccharides, proteins etc. Artificially or synthetically produced polymers include different types of plastics, elastomers (rubbers), fibers, and materials of intermediate characteristics.

1.3 Polyvinyl Chloride (PVC):

Polyvinyl chloride (PVC) was first recognized and characterized more than a century years ago [4]. It is one of the three most important synthetic thermoplastic polymers currently used worldwide along with polypropylene (PP) and polyethylene (PE) in the world consumer market.

PVC is formed by addition polymerization of vinyl chloride (chloroethane) monomer (VCM) units in head-to-tail alignment. The polymerization reaction is written as:

\[
\begin{align*}
\text{H} & \quad \text{C} & \quad \text{H} \\
\text{H} & \quad \text{Cl} & \quad \text{Cl}
\end{align*}
\]

\[
\text{polymerization}
\]

\[
\begin{align*}
\text{H} & \quad \text{C} & \quad \text{H} \\
\text{H} & \quad \text{C} & \quad \text{Cl}
\end{align*}
\]

\[
\text{H} & \quad \text{C} & \quad \text{H} \\
\text{H} & \quad \text{C} & \quad \text{Cl}
\]

\[
\text{vinyl chloride} \quad \text{poly(vinyl chloride)}
\]

**Figure 1.2 Structure of Poly(vinyl chloride) (PVC)**

PVC may be produced by a variety of polymerization techniques such as suspension, emulsion, micro suspension and bulk. The molecular weight of PVC is controlled by altering the polymerization temperature and by controlling the monomer concentration. The higher the polymerization temperature, lower is the molecular weight. The average molecular weight of PVC polymer is usually expressed in terms of viscosity number as intrinsic viscosity of the polymeric unit or more generally as K value. It is made commercially at several molecular weights (Mw) depending on the intended use of applications either as rigid or flexible one: from Mw = 39000
1.4 Physical properties of PVC:

- Colorless, Amorphous Thermoplastic
- Glass Transition Temperature ($T_g \approx 86^0C$)
- Melting Temperature ($T_m 240^0C$)
- Density (1.4 g/cc)
- Flame Retardant
- Water Repellant and Corrosion Resistant
- Low Thermal Resistant and in Low Resistant in UV light

PVC is soluble in some organic solvents like cyclohexanone, dimethyl formamide, tetra hydrofuran (THF). PVC is resistant to sulfuric, nitric, hydrochloric acid, sodium hydroxide, sodium hypochloride. It is not recommended for use when aromatic and or chlorinated hydrocarbons such as mono or dichlorobenzene, ketones, and alcohols are handled. PVC withstands to boiling water up to 140 $^0F$, moderately resistant to detergent water and is not recommended for greases or oils [5].

Typically PVC consists of 57 % chlorine (derived from industrial grade salt) and 43% carbon (derived predominantly from oil / gas via ethylene). This chlorine is responsible for its excellent fire resistance property; when PVC is set on fire, the
flames go out as the fire source is removed due to the material’s self-extinguishing properties. PVC is less dependent on crude oil or natural gas and hence can be regarded as natural resource saving plastic, in contrast to plastics such as PE, PP, PET and PS, which are totally dependent on oil or gas.

Vinyl Institute [6] believes that PVC is the world’s most versatile polymer due to its ease in modification. The required performance oriented properties of PVC end products (e.g., flexibility, elasticity, impact resistance, anti-fouling, prevention of microbial growth, anti-mist, fire retarding) can be freely designed through formulation with plasticizers and various other additives including modifiers, and coloring agents. The versatility of the PVC products during processing gives an edge over other polymer for the extensive use of applications. This is because PVC is one of the cheapest polymers to make and has a large range of end properties in rigid as well as flexible form (plasticized) PVC so can be used to make hundreds of desired products. Bacaloglu and Fisch [7] reported that the consumption of PVC is expected to remain important among thermoplastics polymer due to its good compatibility with large number of other products. Thermoplastics are those polymers which possess glass transition temperature of desired range in which moulding and remoulding can be accomplished. According to Chemical Marketing Associates Inc. (CMAI), the global consumption of PVC in 2010 was almost 34.8 million metric ton (mt) from an overall capacity of 46 million mt, and accounted for 18% of the total consumption of polymers. The global demand for PVC in future is estimated to rise to 44 million mt and the global PVC capacity is expected to rise to about 55 million mt by the end of 2015.
1.5 Polymer degradation and stabilization:
Degradation of polymer takes place during unfavorable dynamic processing conditions such as elevated temperature and shear deformation etc. which may vary for specific polymer because of the irregularities present within the polymer matrix. These processing conditions of polymer may determine the polymeric durability during its lifelong use. Polymer degradation is characterized by the breaking of the primary chemical bonds in the polymer chain and because of the differences in chemical structure; the mechanism of degradation of every polymer is unique. According the Hawkins [8] degradation rate of polymer occurs at a rate equivalent to that of the accumulative activation energies of influencing factors such as temperature, shear rate and light radiation. He also commented that polymer degradation commences with macromolecular polymer chain starts breaking down. Therefore the role of stabilizing compound consisting of function-specific ingredients is very much important in order to ensure a stable polymeric material that can be added to the specific polymer formulation while processing.

1.6 Thermal degradation of PVC:
Although, PVC is considered as one of the most commonly used thermoplastic polymer because of its wide applications, its polymers and copolymers are susceptible to degradation by heat (the thermal degradation is sometimes referred to as “thermolysis”) and by light (photolysis, also called photo degradation); that may be rapid and more severe in the presence of oxygen [9-12]. This instability of the polymer results due to the various structural defects present in PVC which has been postulated to the unwanted degradation of polymer itself at elevated temperature during the processing [13].
The major polymer chain degradation of PVC occurs by the elimination of HCl (Dehydrochlorination, zipper elimination reaction) and simultaneous formation of conjugated double bond along the length of the polymer backbone (scheme 1) leading to a color change (progressing with the extent of breakdown from light yellow, through reddish brown, to almost black in severe cases) which causes the deterioration of physical, chemical and electrical properties of the PVC end product [14-20].

![Dehydrochlorination of PVC](image)

**Figure 1.3 Dehydrochlorination of PVC**

Dehydrochlorination occurs at only moderately elevated temperatures (about 100°C). It is catalyzed by the HCl evolved (autocatalysis; the product itself acts as catalyst) and can also be promoted or initiated by other strong Lewis acids [21]. The evolution of HCl (Dehydrochlorination) takes place by elimination of labile chlorine, as HCl from the PVC backbone to create double bond. This renders the next adjacent chloride allylic and more labile chlorine that gets eliminated as HCl now producing two conjugated double bonds and rendering the next secondary allylic chloride and hence labile one. In this subsequent manner, HCl is eliminated creating a polyene sequence of three conjugated double bonds. Thus, PVC degradation proceeds via so-called unzipping mechanism of elimination of HCl from labile chloride in PVC to produce long conjugated double bonds with the evolution of large amount of HCl. Polyene sequence in polymer containing six or more conjugated double bonds are
chromophores and give rise to yellowing coloration to the polymer and further gross discoloration when PVC is heated [22]. The discoloration results from the formation of such conjugated polyene sequences of 5 to 30 double bonds referred as primary reactions or primary degradation in PVC backbone.

Additionally due to the reactivity of polyenes formed in PVC polymer resin, they may react to form cross-linked polymer chains along with fragmentation of some low molecular weight molecules from the base PVC. This secondary reaction also results in the modification of mechanical as well as discoloration behavior of the polymer matrix [23]. The process of PVC degradation causes severe damage to the polymer itself and on its overall performance properties as a whole. Therefore all the preventive efforts are focused on the appropriate stabilization of PVC to formulate the polymer of good standard for its application means. To overcome degradation problem heat or thermal stabilizers along with different additives are essential to make the PVC as per desirable product. Numerous stabilizers have been developed to neutralize the released HCl during degradation of PVC and prohibit further degradation by preventive reactions of respective stabilizers.

1.7 Stabilizers and thermal stabilization of PVC:

Heat or thermal stabilizer is a substance added in PVC resin which removes labile chloride ion, prevents oxidation, scavenge evolved HCl and stops the growth of double bond as polyene sequences during the degradation of PVC. The main noticeable indications of thermal degradation of PVC (at temperatures sensibly below those of pyrolytic decomposition and combustion, against which no stabilization is possible) are the evolution of HCl, development of color from light yellow, through reddish brown, to almost black in severe cases and deterioration of
physical, chemical and electrical properties of the polymer [13]. This entire process of degradation is accelerated by the presence of oxygen, HCl and HCl salts of weak bases.

Heat stabilizers are incorporated in all PVC compositions to protect the PVC polymer against thermal degradation at high temperatures of composition and also subsequently in service by eliminating the labile chlorine atom near the double bond present in the polymer matrix [24]. Therefore these additives are necessary to incorporate in PVC during processing at elevated temperature to inhibit the unwanted degradation effects. During the degradation of PVC the ways in which various types of stabilizers counteract and modify the degradation process, have been widely studied for many years. As mentioned in the literature, PVC stabilizers are broadly divided as primary and secondary stabilizers based on their mode of action on the stabilization of PVC during the degradation process.

**Primary stabilizers:**

Primary stabilizers are chemicals which are capable of reacting with labile chlorine atom in the structures and accept HCl to inhibit the initiation of PVC degradation that prevents further dehydrochlorination [8]. As the degradation starts, it proceeds very fast, therefore to stop such reactions, it is necessary to use a very active nucleophile which must be associated with labile chlorine atom of PVC. These types of primary stabilizers must exhibit Lewis acidic properties in order to form complexes with chloride radical or anion and able to reduce long polyene sequences in PVC during the degradation.
Secondary stabilizers:
Secondary stabilizers inhibit or reduce the PVC degradation by accepting thermo-oxidative groups and function by scavenging the evolved HCl/Cl radical during degradation of PVC. These stabilizers are effective in the propagation step during the degradation of PVC [8]. Such stabilizers do not protect the PVC against short time discoloration, but delay catastrophic degradation of the PVC material. Thermal stabilizers of PVC possess one or more of the following features in addition to capacity for absorption and neutralization of HCl evolved by PVC during degradation:

1. An ability to replace or displace active, labile substituent groups, such as tertiary and allylic chlorine atoms
2. A capacity to render pro-degradant substances e.g. heavy metal chlorides, inactive
3. An ability to modify chain reactions, by interrupting conjugated polyene formation and inhibiting the elimination of HCl.

1.8 Types of heat/thermal stabilizers:
All PVC heat or thermal stabilizers systems in industrial use are of the “external” kind in the application sense, in that they are additives incorporated in the PVC by physical admixing. The development and production of suitable heat or thermal stabilizers is connected with the production of PVC from the very beginning and also constitute the precondition for the processing and its future applications. Applicable PVC stabilizers are heavy metal containing lead, cadmium based and Organotin based compounds, as well as mixed metal inorganic soaps along with organic co-stabilizers, depending on the desired product properties [2]. PVC can be
protected with a variety of stabilizer systems. Primary and secondary stabilizers are generally used in combination.

On the basis, the compounds used as heat stabilizers for PVC may be divided into the following general groups:

a) Lead based compounds as stabilizers for PVC
b) Organotin based compounds as stabilizers for PVC
c) Compounds of other mixed metals as stabilizers for PVC
d) Organic compounds as stabilizers for PVC

**a) Lead based compounds as stabilizers for PVC:**

These types of stabilizers are the oldest and most widely used PVC heat stabilizers containing either lead salts or lead soaps (e.g. salts with stearic acid). The main advantage of these old established stabilizers is cost-effective, good heat-stabilizing efficiency and particular suitability for use in electrical insulation application. It does not alter the melt rheology but it is an effective heat stabilizer and the opacity it produces that assist in protection against UV degradation. However, they are not suitable for clear compositions, where their toxicity presents a hazard, as, for example, in food contact applications (e.g. packaging films, containers), for medical products, or children’s toys [21]. Some of the well-known commercial lead stabilizers are basic lead carbonate, tribasic lead sulphate, dibasic lead phosphate, lead silicate and lead stearate. The main concern of lead stabilizers is their toxicology which has severely limited their use in industrial applications by environmental friendly alternative stabilizers system.
b) **Organotin based compounds as stabilizers for PVC:**

Organotin compounds are the most effective and most expensive PVC primary heat stabilizers used at commercial level. They are preferably used in clear rigid PVC applications worldwide. Tin stabilizers for PVC compounds are characterized by a central tin atom, surrounded by alkyl and acidic groups. Mixtures of mono and dialkyl tin salts are used. Commercially used tin stabilizers typically vary the ratio, depending on the performance and property requirements of the final PVC product.

![General structure of tin stabilizers](image)

Where, R = Methyl, Butyl, Octyl Ester, Y = active part such as: Mercaptides, Organotin Sulfides and Organotin Carboxylates, Maleates etc.

All Organotin stabilizers are derived from tetravalent tin (Sn$^{+4}$). The characteristic of these compounds is that at least one carbon atom is directly connected with a tin atom. Usually this is a straight chain alkyl group. There are three main groups of organotin stabilizers. Carboxylate derivatives, Sulphur containing organotins and carboxylate-mercaptides. Sulphur containing compounds likely to produce black stains during the stabilization of PVC. Octyl-tin compounds are regarded as non-toxic stabilizers and suitable for PVC in food contact applications or for potable water pipes and fittings. The amount of tin and ligand structure affects the stabilizing efficiency in PVC [22]. In sum, organotin stabilizers have good compatibility with all other additives used in PVC, such as lubricants, impact modifiers etc. which
minimizes possible processing difficulties such as plate-out of incompatible compounds on the processing equipment.

c) **Compounds of other mixed metals as stabilizers for PVC:**

Apart from those of lead and tin based PVC stabilizer, certain compounds are also of interest as stabilizers for PVC. Particularly fatty acids of stearates and laureates of zinc, calcium, aluminum, barium, antimony, lithium, magnesium, sodium, potassium and cadmium have been used and named as mixed metal stabilizers. Mixed metal stabilizers are complex mixtures of mixed metal salts and soaps which rely on the interaction of at least two different types of metal salts in PVC generally contain Ba-Cd types, Ba-Zn types, Ca-Zn types etc. According to Frye-Horst mechanism, an esterification reaction takes place where the chlorine atom is bonded to the molecule between PVC and fatty acid salt of metal ion. Strongly basic carboxylates derived from K⁺, Ca⁺² or Ba⁺² that have weak or no Lewis acidity are mostly HCl scavengers; however, carboxylates derived from Zn and Cd, which have stronger Lewis acidity, are able to scavenge HCl and also to react with allylic chlorine atoms [23]. In this way these may act as primary as well as secondary stabilizers for PVC. Further, combinations of two or three of these compounds are also used as PVC stabilizers. Composite metal stabilizers are also widely used in solid (powder, flake), liquid, or paste forms [20]. Also mixed metal types of stabilizers particularly Ca/Zn based compounds are used to replace the heavy metal based PVC stabilizers in significant compositions. Because of the characteristics of calcium/zinc stabilized PVC materials they are widely used in different flexible and rigid PVC applications. This type of stabilizing system can give products having a high degree of clarity, good mechanical and electrical properties, excellent organoleptic properties and
good outdoor weatherability. As a result, calcium/zinc stabilizers have been incorporated and established in a wide range of applications which include toys, healthcare products such as blood bags, semi-rigid and flexible foil for food packaging, bottles for potable water, as well as for potable water pipe. It is also believed that viable success of mixed metal PVC stabilizers depends on their use in conjunction with significant amount of synergists.

d) Organic compounds as stabilizers for PVC:

Compounds of organic stabilizers are widely used in PVC because they are mostly non-toxic, uniformly and intimately dispersible in PVC compositions. The thermal stabilizing efficiency of organic based stabilizers are too low to use them alone in PVC degradation, therefore they are used as co-stabilizers or synergists in metal based stabilizers system to improve overall thermal stability of the PVC. Still the limited compatibility with plasticizers or particular plasticizer/resin combinations in plasticized PVC has posed some problems. Some of the organic compounds as co-stabilizers may have been utilized in the PVC stabilizer system such as,

- Esters of aminocrotonic acid,
- Urea derivatives (phenyl urea, diphenyl urea),
- Epoxy compounds,
- Organic phosphates and
- Miscellaneous organic co-stabilizers [17].

1.9 Layered double hydroxide (LDH):
Layered double hydroxide (LDH) is anionic inorganic clay minerals having a double layered structure. The general chemical formula of LDH clays is written as:

$$\text{M}_{1-x}^{II}\text{M}_x^{III}(\text{OH})_2]^x^+ (A^{n^-})_x^{n^-}\text{H}_2\text{O}$$

where, $\text{M}^{II}$ is a divalent metal ion, such as $\text{Mg}^{2+}$,
Ca\(^{2+}\), Zn\(^{2+}\), etc, M\(^{\text{III}}\) is a trivalent metal ion, such as Al\(^{3+}\), Cr\(^{3+}\), Fe\(^{3+}\), Co\(^{3+}\), etc and A\(^{n-}\) is an anion, such as Cl\(^{-}\), CO\(_3^{2-}\), NO\(_3^{-}\), stearate etc. The anions occupy the interlayer region of these layered crystalline materials. When LDHs are synthesized any appropriate anion can be placed in the interlayer. They can be of both synthetic and natural origin. The most commonly known naturally occurring LDH clay is hydrotalcite having chemical formula Mg\(_6\)Al\(_2\)(OH)\(_{16}\). CO\(_3^{2-}\).4H\(_2\)O. Hydrotalcite is the first mineral of this group whose structure and properties were studied extensively and often taken as the representative of the LDH clay materials. Hence, the LDHs are also known as hydrotalcite like compounds. LDH’s have positive charge on the brucite-like sheets compensated by interlayer anions. LDH possesses a similar structure and composition as Mg(OH)\(_2\) which makes them promising for applications as thermal stabilizers and flame retardants.

The application of the LDH materials depend on the nature of the cation, existing in the brucite-type layers, others depend on the nature of the interlayer anion and in some case the material is partially or totally decomposed to yield new ones with
specific properties. Miyata [24] reported that the optimum Mg/Al-ratio with respect to its heat stabilizing efficiency is 2:1. At this ratio, the spacing between the HT layers is at its widest. This improves the ability of HT to exchange its anions for the malevolent chlorine anions that resulted from PVC dehydrochlorination. The neutralization of these ions would limit autocatalysis, thus yielding a more stable PVC product.

The usages of LDHs is widespread in diverse fields, like catalysis, nanofillers, controlled chemical release, etc. that are well realized by researchers. In case of thermal stabilizing properties, there are at least three different possibilities to explain HCl absorption of LDH in PVC [25], namely:

1. The HCl reacts just with the anion, e.g. $\text{CO}_3^{2-}$, $\text{OH}^-$ located as counter ion between the cationic LDH layers
2. The HCl reacts with the LDH layers only
3. The HCl reacts with the LDH layers and the counter ions between the layers.

Layered double hydroxides (LDHs) either naturally available or can be synthesized by various chemical methods such as co-precipitation, ion exchange and calcinations method (Memory effect method).

1.10 Techniques for the determination of thermal or heat stability of PVC:

There are a wide variety of tests methods existing to evaluate the performance of PVC stabilizers in terms of thermal stability of polyvinyl chloride (PVC). Consequently the most important test procedures for thermal stability evaluation also include dynamic and rheometer tests:

- Dynamic milling (two roll mill) test,
- Press clarity and color,
• Oven stability test,
• Torque rheometer stability and gel-time (fusion time),
• Thermogravimetric analysis (TGA) and
• DHC (Dehydrochlorination) and Congo-red test

For the first three tests color changes of the test specimen are visually monitored. In addition, it is common to quantify color changes by plotting color parameters like yellowness index (YI), whiteness or brightness against exposure time at the set processing temperature. A torque rheometer test can be used to determine the fusion behavior and torque rheometer stability time. The PVC compound is mixed under defined conditions (temperature, blade speed, mass/volume of compound) and mass temperature as well as torque is plotted against time. Heat stability in the rheometer test is defined as the time starting from completed fusion until onset of crosslinking. While thermal stability of PVC by TGA is studied as exposure of PVC to elevated temperatures which results in dehydrochlorination and polyene formation in PVC matrix. This change is determined in terms of increase in onset temperature and variation in maximum temperature of the PVC samples in TGA. Congo-red test and DHC test basically measure the amount of HCl released when PVC degrades at a set elevated temperature. Congo-red test according to ASTM D 4202 and ISO 182-2 measures the time until color change of an indicator paper mounted in a test tube above the sample to be tested.

1.11 Synergism:

Synergism comes from the Greek word "synergos" meaning working together. It refers to the interaction between two or more "things" when the combined effect is
greater than if you added the "things" on their own (a type of "when one plus one is
greater than two" effect).

In chemistry’s point of view this action occurs when the combined effect of two or
more chemicals is equal to the sum of the effect of each agent given alone [26]. For
the relevant study of PVC thermal degradation to have good stabilization of PVC
with good early color and long term stability, the two types of stabilizer should be
combined appropriately for each particular PVC formulations. Stabilization is
complicated by the fact that primary stabilizers become strong Lewis acids by
reacting with the HCl that catalyzes the initiation and propagation of PVC
degradation. To avoid this, secondary stabilizers should react efficiently with HCl to
protect the primary stabilizers. Another possibility is to include compounds called
coo-stabilizers in the system. Co-stabilizers form relatively stable complexes with the
chloro-derivatives of primary stabilizers (the Lewis acids) and suppress their
degradative effect. For technical applications the thermal stabilizers, e. g. mixed
metal stearates, have to be supported by organic co-stabilizers [27].

1.12 Applications of PVC:

The utilization of PVC is based on the compounding (mixing of additives with
polymer) of the polymer all over the world. The process of preparing typical recipe
for the compounding is known as Formulation. The proper selection of particular
additive in formulation is dependent on the end use of the PVC product in various
applications. The compatibility of PVC with a wide range of additives results in a
broad product range of additives from flexible cables to rigid PVC pipes and
window profiles. PVC products can be rigid or flexible, opaque or transparent,
colored and insulating. It is found in a wide range of consumer products such as
packaging, cling film, bottles, credit cards, audio records and imitation leather as well as construction materials such as window frames, cables, pipes, flooring, wallpaper and window blinds. It is also used by manufacturers for car interiors, instrument panel and door panel coverings in automobile industry and in hospitals for safe storage and use of blood in vinyl bags and for other medical disposables.

The application of PVC in view of different types of plastic market is shown in following diagram.

![Figure 1.6 PVC market by volume in world](image)

**Figure 1.6 PVC market by volume in world**

PVC opens up functional and design opportunities that are both visually striking and fundamentally practical. In short, people everywhere benefit from this material. Sometimes invisible but always reliable, PVC products make the difference when it counts.

**1.13 Objectives and scope of the work:**

As a result of the worldwide increase in environmental awareness, attention is now being focused on non-toxic and environmentally friendly based compounds. It is
believed that Ca/Zn based stabilizers system which acts as primary non-toxic stabilizers have less stabilizing efficiency as compared to heavy metal based stabilizers. Therefore the use of some synergists or co-stabilizers to improve their effect on the thermal stabilization of PVC is very much needed. In this regard some environmentally friendly non-toxic compounds as synergists were investigated as thermal stabilizers for PVC.

The main objective of the work was:

- To evaluate the thermal stability of PVC with different non-toxic heat stabilizers such as Ca-stearate, Zn-stearate and glutarate, layered double hydroxides (LDH), Pentaerythritol, Eugenol, nano CaCO₃ etc.

  The thermal stabilities of PVC were determined by the techniques of Congo red method, Static oven test and Thermo-gravimetric analysis (TGA)

- To investigate the synergistic effect on the thermal stability of PVC by various synergists or co-stabilizers like Pentaerythritol, Eugenol, nano CaCO₃ along with layered double hydroxides (LDH) on PVC degradation was studied.

- To understand the advantages and disadvantages of synergists used in PVC stabilizer system with respective to relevant properties of PVC.

- Comparison between PVC stabilizer systems having various synergists with varied composition has been made.

The results of all these investigated schemes are presented and discussed in the following pages.
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