2.1 Extrusion technology

Extrusion technologies are novel and versatile manufacturing technique in food industry for conveying and shaping fluid forms of processed raw materials like doughs and pastes (Guy, 2001). In 1797, Joseph Bramah from England used extrusion principle to develop hand operated piston press to extrude seamless lead pipe (Raiz 2000). Extrusion is a process of shaping by forcing softened and plasticised materials through dies or holes by pressure (Riha et al. 1996). Food ingredients of various types may be processed by extrusion and are referred to as extrudates (Paul and Dennis, 2009). Earlier extrusion methods were simple conveying devices and became sophisticated in the last decade. Presently, processing steps include conveying, mixing, shearing, separation, heating or cooling, shaping, co-extrusion, venting volatiles and moisture, flavour generation, encapsulation and sterilisation. Extrusion application of food industry includes ready to eat breakfast cereals, baby foods, pet foods and confectionary products (Hulya, 1999). It was found that the extrusion process is continuous in nature. In order to obtain the desired output, the process variables should be standardised.
2.1.1 Food extruder

Food extruder is equipment used for the shaping and restructuring process for food ingredients. Extrusion processing equipment has become popular in many food industries throughout the world (Riaz et al. 1996). The screw is the heart of the extrusion process and its design and speed of rotation greatly influence the extrusion operation. The screw has got three functions: conveying, shearing, heating and mixing. The feeder section accepts moistened granular feed materials and conveys them down the length of the screw to the exit. As the feed materials move along the screw, they encounter great friction, restriction or compression, causing them to completely fill the channel or the space existing between the screw flights. The energy necessary to make the viscous materials flow is supplied by a large drive motor turning the screw. Dies are provided at the exit to attain desired shape of the material and is cut into desired length using a cutter attachment fitted at the end of the discharge.

2.1.1.1 Classification of extruders.

There are mainly two types of extruders. they are single screw extruder and twin screw extruder. Both single-screw and twin-screw extruders are used for commercial production of a wide variety of food products, ranging from snack half-products, textured vegetable protein, animal feed (including pet foods), expanded ready-to-eat cereals, and flat breads (Paul and Dennis, 2009). In all extruders, the premixed ingredients are conveyed through the barrel by a conveying screw.

2.1.1.1 Single screw extruder

In a single screw extruder, conveying action results from friction between screw and the product. Similarly friction between barrel and the
In a single-screw extruder, barrel can be divided into three processing zones: feeding zone, kneading zone and the final cooking zone (Berset, 1989). The feeding zone generally has deep channels which receive the feed. The preconditioned or dry material entering this zone is conveyed to the kneading zone. As the material is conveyed into the kneading zone, its density increases. At the end of this zone, the feed material is a viscoamorphic mass at or above 100°C (Faubion et al. 1982). Temperature and pressure are maximum in this region because of the extruder screw configuration. Shear is highest in this zone, and product temperature reaches its maximum and is held for less than five seconds before the product is forced through the die (Harper, 1978). The desired product can be obtained by placing different die. The product expands as a result of moisture vaporization as it exits through the die into a region of lower pressure and takes the shape of the die. The extruded material can be cut into desired lengths by the knife attachment (Riaz, 2001). In single screw extrusion, there are two types of extruders. They are wet extruder and dry extruder. In wet extrusion, steam and water can be injected into the barrel during processing. Barrels of these machines are provided with heating and cooling jackets. The products produced range from fully cooked, light density corn snacks, to dense, partially cooked and formed dry pasta (Rokey, 2000). In dry extrusion, the extruder does not have provision for external source of heat or steam for injection or jacket heating. In this extrusion, heating is accomplished by mechanical friction (Said, 2000). This type of extruder was developed initially for processing whole soybeans on the farm.
2.1.1.1.2 Twin screw extruder

The term ‘twin-screw’ applies to extruders with two screws of equal length placed inside the same barrel. Twin-screw extruders are more complicated than single screw extruders. They provide much more flexibility and better control. Twin screw extruders are generally categorized according to the direction of screw rotation inside the barrel viz. counter-rotating twin-screw extruders and co-rotating twin-screw extruders. In the counter-rotating position, the extruder screw rotates in the opposite direction, whereas in the co-rotating position, the screw rotates in the same direction. These two categories can be further subdivided on the basis of
position of the screw in relation to one another viz. intermeshing and non-intermeshing (Miller, 1990). The non-intermeshing twin-screw extruder is like two single-screw extruders sitting side by side with only a small portion of the barrels in common (Clark, 1978). These types of extruders attain temperature as described in single screw extruders. In non-intermeshed extruders, neither pumping nor mixing is positive. Their design does not provide a positive displacement action for pumping the product forward.

Plate-2. Twin screw of extruder (Raiz, 2001)

Figure-2. Schematic diagram of a co rotating twin screw extruder
2.1.1.1.3 Comparison of single and twin screw extruders

The main difference between single and twin screw extruder is the conveying mechanism (Sahay and Singh, 1994). In a single screw extruder, the conveying action is the result of the friction effects; the friction between screw and the product and the friction between barrel and product. The single screw extruder needs the barrel wall for the good conveying action. The product may co-rotate along with the screw. Whereas, in a twin screw extruder, the product is enclosed between the intermeshing screws and barrel and is conveyed positively towards the die. Due to such positive displacement action, the product is prevented from co-rotating with the screw. In twin screw extruder the friction at the barrel is of less importance. A single-screw extruder is the simplest food manufacturing device and is very economic to operate. Jianshe and Andrew (2009) suggested that single-screw extruders are only suitable for manufacturing of foods that contain less than 4% fat, 10% sugar and 30% water. The presence of high contents of fat, sugar and moisture will significantly reduce the friction between food material and the inner barrel surface and, therefore, impair the mixing and flow of food. Twin-screw extruders consist of two intermeshing
screws either co-rotating or counter-rotating against each other. They have much higher mixing capability than single-screw extruders. One significant advantage of twin-screw extruders is the much extended product range. Food that contain 20% fat, 40% sugar and 65% moisture and can be handled by a twin-screw extruder (Jianshe and Andrew, 2009).

2.1.1.2 Advantages of extrusion cooking

A wide range of products, many of which cannot be produced easily by any other process, is possible by changing the ingredients, extruder operating conditions and dies. Lower processing cost of extrusion and higher productivity than other cooking and forming processes. Extruder can operate continuously with high throughput product quality: Extrusion cooking involves high temperatures applied for a short time, retaining many heat sensitive components of a food. The whole process is environmental friendly, as low-moisture process, extrusion cooking does not produce significant process effluents, reducing water treatment costs and levels of environmental pollution (Smith, 1971; Riaz, 2000).

2.1.1.3 Disadvantages of extrusion cooking

Single-screw extruders have relatively poor mixing ability, they are usually supplied with premixed material which often has been preconditioned with added steam and water. Since the single-screw extruder has only one shaft, it will not self-clean as completely at the end of the operation. ‘Wet extruders’ have higher capital investment than ‘dry extruders’.

2.1.1.4 Extrusion cooking of cereals with fish

Research on extrusion of fish muscle started in the 1980’s (Choudhury and Gogoi, 1995; Ratankumar et al. 2014). A number of
studies have reported successful incorporation of fish flesh or fish powder into starch-based materials by extrusion processes to produce nutritious extruded products that were acceptable by consumers (Binoy et al. 1996; Suknark et al. 2001). Choudhury et al. (1998) undertaken several studies to develop dry expanded snack food products from fish mince and starchy ingredients using single and twin-screw extruders and they found that incorporation of fish hydrolysates along with cereals improve the nutritional quality of extrudates. Rice flour and varying amounts (10–35%) of deboned minced carp were coextruded resulting in a precooked blend which had a shelf life of six months stored at room temperature (Joseph and Reddy, 1985). Rhee et al. (2004) successfully developed a snack food by extrusion of minced catfish with corn and defatted soya flour. Gry (1981) standardised conditions for best extrusion using cod mince, wheat flour and potato flour. Murray et al. (1980) reported that texture of the extruded product was improved by the addition of fish which also reduced the temperature required for optimal texturization during extrusion. During twin-screw extrusion of rice flour and pink salmon blends, the influence of location and spacing of reverse screw and kneading elements on specific mechanical energy input and product attributes were studied by Binoy et al. (1996). Thermal and physicochemical properties of rice flour fish mince based extruded products were studied by Dileep et al. (2010). The advantages of developing fish-based extruded products will help in supplying nutritious and balanced diets to undernourished people in developing countries (Venugopal and Shahidi, 1995). Clayton and Das (1982) suggested that fish with cereal flours offers shelf stable foods with better nutritional quality.
2.1.1.5 Extrusion of noodles

Extrusion processing is currently being used to produce fabricated foods. It has been widely used to produce ready to-eat foods and snacks that depend on the expansion at the die to produce the desired texture and size (Parsons et al. 1996). Extrusion is also used in the production of pasta, macaroni, spaghetti and other noodle products. Sefa-Dedeh and Saalia (1997) modified a laboratory screw oil expeller and adapted it as an inexpensive extruder for the extrusion of maize cowpea blends. The effects of alkaline salt (kansui) and lactic acid on the rheological properties of wheat flour dough and characteristics of extruded noodles were studied by Shiau and Yeh, 2001. Titus and Glory (2011) demonstrated production on extruded noodles from eight cassava mosaic disease (CMD) resistant varieties.

2.1.1.5.1 History of noodles

The first written account of noodles dates from the Chinese East Han Dynasty (Lajia archaeological site) between 206BC and 220AD (Bin, 2008; Hatcher, 2000; Hou and Kruk, 1998). However Chinese, Arabs, and Italians have all claimed to have been the first to create noodles. Later, noodles were transferred to Japan by the Japanese invasion on China. It is then transferred to other Asian countries. The word “noodle” was derived from the German “Nudel” (Harper, 2009). Noodle technology was transferred to Europe by Marco Polo in 13th century where noodles were evolved into the current pasta products (Hou, 2001). Noodles are very important in Chinese culture especially, symbolizing longevity. By eating the noodles, it was believed that a long life would be achieved. Noodles are made of unleavened dough which is rolled flat and cut into one of a variety of shapes. While long thin strips may be the most common, many varieties of
noodles are cut into waves, helices, tubes, strings, shells, folded over, or cut into other shapes.

2.1.1.5.2 Classification of noodles

There are different types of noodles available in this world. These varieties come arise for different culture, climate, region and many other different factors. The modification of formulation and processing is necessary due to regional eating habits, taste preference, and advances in technology (Hatcher, 2000). The local uniqueness of formulation and processing has created many country-specific systems for noodle classification. There exist wide differences in the nomenclature for noodles among countries. The major classification of noodles was made by type of raw material, salt used, size of the product and processing method used.

2.1.1.5.2.1 Based on raw materials

The main ingredient for the manufacturing of noodles is wheat flour. The combination of wheat flour made from hard wheat with buck wheat flour (ie, wheat flour containing less than 40% buck wheat flour is called soba). This is mainly consumed in Japan and in Korea. The characteristics of this noodle are light brown or gray with a unique taste and flavour. Noodle made from hard wheat flours is termed as “Chinese type” which is characterized by a bright creamy white or bright yellow colour and a firm texture; whereas, “Japanese noodles” prepared from wheat flour of medium protein and it is characterized by a creamy white colour and a soft and elastic texture (Hou, 2001).
2.1.1.5.2.2 Wheat

Wheat grain belongs to the monocotyledonous family, Grammeae or grass family. The other principal cereal crops are rice, maize, sorghum, millet, barley, oats and rye. Among these rice and wheat are chief cereals of human consumption. Wheat is powdered in the form of flour for the production of different products like bread and other bakery products. “Chapatti” is a common food that is consumed mostly in India is made of wheat. Wheat is classified according to the texture of the endosperm and the protein content. Wheat types are classified as hard or soft and as strong or weak. Internationally wheat is arranged according to the degree of hardness as extra hard, hard, medium and soft. Hardness is due to the adhesion between starch and protein present in the endosperm. Usually the flour used in the noodle production is wheat. Wheat milled and having a particle size of 130µm or less is usually used for noodle preparation. Other than wheat flour, flours used are rice flour, multi grain flours, buckwheat flour, and starches derived from potato, sweet potato, and pulses. General protein content in the flour ranges from 10.5–13.5% (Hatcher, 2000). Different type of noodles has different protein content according to the flour used. Starch content also plays an important role in noodle texture. The starch pasting property was studied by Moss (1980). Starch and protein quality requirements of Japanese alkaline noodles was studied by Crosbie et al. (1999). Hou (2001) suggested that there is an optimum starch quality range for noodle eating quality. Low ash content in the range of 1.4% or lower is used for noodle preparation. The ash content is mainly got from the wheat used for preparation of noodles. Kruger (1996) reported that ash content is also having an effect on the colour of the noodles.
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2.1.1.5.2.3 Based on salt used

Noodles can be classified as white/regular salted and yellow alkaline noodles. White salted noodles contain common salt. Yellow alkaline salt contains alkaline salt (mainly Na\textsubscript{2}CO\textsubscript{3} and/or K\textsubscript{2}CO\textsubscript{3}) (Hou, 2001; Bin, 2008).

2.1.1.5.2.4 Based on size

Japanese noodles are classified into four types based on the width of noodle strand. They are So-men (0.7–1.2 mm wide), Hiya-mugi (1.3–1.7 mm), Udon (1.9–3.8 mm wide), Hira-men (5–6 mm wide) (Hou, 2001).

2.1.1.5.2.5 Based on processing method

In this classification, noodles are manufactured either by handmade or by machinery. The processing operations include mixing raw materials, dough sheeting, compounding, sheeting/rolling and slitting. This noodle strand is further processed to produce different varieties. Among the manufacturing processing there are fresh, dried, boiled steamed, and steamed and fried noodles.

Fresh noodles are made by the noodles coming out of the slitting rolls and are cut and packed without any processing. Dried noodles are prepared by drying either in sun light or in a drying chamber. Boiled noodles are prepared either parboiling or by fully cooking. Steamed noodles are prepared by steaming in a steamer and softened with water through rinsing or steeping noodle strands. Instant noodles are prepared by waving and steaming fresh noodles and deep frying in hot oil (Hou and Kruk, 1998).
2.1.1.5.3 Different types of noodles available in the market

2.1.1.5.3.1 Cellophane noodles

It is also known as thread vermicelli or glass noodles. Thin, opaque threads are made from mixture of mung bean and tapioca starch having glutinous texture. These noodles absorb flavours well very ideal for soups and braised dishes.

2.1.1.5.3.2 Dried rice noodle sticks

It is translucent, flat noodles which are broader and thicker than rice vermicelli. These noodles need to be soaked in warm water for 15-20 min before use cooked so as to be still firm when consumed.

2.1.1.5.3.3 Dried rice vermicelli

It is one of Asia’s most popular and versatile noodles made from rice flour paste, These noodles need to be soaked in boiling water for 6-7 min before use in stir-fries or soups when deep-fried, will expand to approximately four times its original size often used as garnish.

2.1.1.5.3.4 Hokkien noodles

They are thick, fresh egg noodles which have been cooked and lightly oiled before packaging. This is most often vacuum packed and need only one minute boiling before being used in stir-fries, soup, or salads.

2.1.1.5.3.5 Egg noodles

It is made from wheat flour and eggs, the most wide spread in Asia sold in variety of widths which can be stored in refrigerator for up to 1 week. These noodles need 1 minute for boiling in water while dried noodles need 3-4 min cooking.
2.1.1.5.3.6 Fresh chinese egg noodles - bamee

Chinese egg noodles is basically eggs and flour, just like pasta. These egg noodles are not normal American wide egg noodles (with the see through egg on the package). They are freshly made and keep well in freezer for a long time. It is the size of angel hair pasta. In the old days it was made by pulling the dough until getting the desire thickness instead of by extrusion or cutting. Making the noodles by pulling the dough is a real skill.

2.1.1.5.3.7 Fresh rice sheet noodles

White, flat noodles made from rice flour steamed and lightly oiled before being packaged. In boiling water they get loosened and separate and used after draining. It shouldn’t be stored in refrigerator. They will go hard and commonly used in soups and stir-fries.

2.1.1.5.3.8 Ramen noodles

Japanese wheat flour noodles usually with broth or sachet. Popular snack all over Japan and are sold in instant form, available also in fresh or dried, need to be cooked in boiling water for 2-5 min.

2.1.1.5.3.9 Shanghai noodles

They are thick, round egg noodles very similar to Hokkien noodles, but have not been cooked or oiled, sold package loosely and dusted with flour.

2.1.1.5.3.10 Soba noodles

They are made from buckwheat or wheat flour and sometimes flavoured with green tea powder. This is usually consumed by adding in soups or served cold with dipping sauces. These noodles are available
either fresh or dried and need to be cooked in boiling water for about 5 min for consumption.

2.1.1.5.3.11 Somen noodles

Fine, white Japanese noodles made from wheat flour most are commonly eaten cold or sometimes with a little broth need to be cooked in boiling water for 2 min before consumption.

2.1.1.5.3.12 Udon noodles

White Japanese noodles made from wheat flour made in a variety of widths, both fresh and dried should be boiled for 1-2 minutes before use most often eaten in soups, but can also be served cold or braised dishes.

2.1.1.5.3.13 Wheat noodles

Available fresh and dried egg-free noodles are extremely versatile. These noodles need to be cooked for 2–4 min in boiling water and rinsed in cold water. Fresh noodles can be kept in refrigerated storage for up to 1 week.

2.1.1.5.3.14 Couscous

A convenient, versatile staple of North African diets. The tiny nuggets of durum-wheat semolina cook up light and fluffy. Complementing flavours from sweet to savoury, this couscous is incredibly versatile and ready to serve in 5 min.

2.1.1.5.3.15 Capellini

Thicker than angel hair pasta, this long, narrow pasta pairs well with thin tomato sauces and light vegetable ragouts. This is served with zesty sauce zingara, flavored with mushrooms, garlic, ham, and tarragon, finished with Madeira wine and chopped truffles.
2.1.1.5.3.16 Instant noodles

Momofuku Ando invented “Chicken Ramen TM,” the world’s first instant noodle product manufactured by Nissin Foods, Japan, in 1958 (Neelam et al. 2014). Another achievement was the introduction of cup noodles by Nissin in 1971. Instant noodles are made from wheat flour, starch, water, salt or kansui (an alkaline salt mixture of sodium carbonate, potassium carbonate, and sodium phosphate), and other ingredients that improve the texture and flavour of noodles, partially cooked by steaming and further cooked and dehydrated by a deep frying process (Kim, 1996a; Neelam et al. 2014).

2.1.1.5.3.16.1 Types of instant noodles

Instant noodles are classified into two types on the basis of methods used for the removal of moisture, i.e., instant dried noodles and instant fried noodles. Instant dried noodles are produced in a fully automatic production. The noodle after steaming is fed into a continuous drying chamber using hot air as the drying medium. In fried noodles after steaming it is then deep fried in oil. Frying the noodles in oil decreases the moisture content to 2–5%, whereas, in hot air dried noodles, it is about 8–12%. Both frying and drying facilitates rehydration process by cooking the noodles.

2.1.1.5.4 Quality parameters of noodles

Quality factors important for instant noodles are colour, flavor, texture, cooking quality, rehydration rates during final preparation, and absence of rancid taste after extended storage. Sensory evaluation of noodles is carried out to judge the quality and acceptability of the final product (Neelam et al. 2014).
2.1.1.5.4.1 Colour

A bright and light yellow color is desirable for instant noodles (Kim, 1996a; Kubomura, 1998). Hutchings (1977) described its major role in the total human perception of food. Due to problems with subjectivity and an overall lack of reproducibility, Instrumental colour measurements for quality grading are most often carried out in the food industry (Hunter, 1975). Colour is usually measured by spectrocolourimeter. Instrumental methods like HunterLab colorimeter in terms of L* (brightness or lightness), a* (redness), and b* (yellowness) color scale are also used for quality evaluation. Protein quality parameters also exhibit a significant relationship with b* value of instant noodles (Park and Baik, 2004b).

2.1.1.5.4.2 Texture

The texture of instant noodles should be rubbery, firm, or smooth (Kubomura, 1998). Sensory and instrumental methods are used for the evaluation of noodle texture (Oh et al.1983; Lee et al.1987; Hou et al. 1997). Textural parameters are smoothness, softness, hardness/firmness, stickiness, cohesiveness, elasticity, chewiness and gumminess (Konik et al. 1993; Byung-Kee et al. 1994; Yun et al. 1997). Instrumental measurement of cooked noodle texture is reliable, convenient and alternative to the sensory evaluation (Oh et al. 1983; Lee et al. 1987; Hou et al. 1997; Kovacs et al. 2004). The basic methods used are compression, including simple compression and texture profile analysis (TPA) and tensile tests. TPA provides a number of textural characteristics like chewiness, hardness or firmness, gumminess and cohesiveness in a single test and is similar to the chewing in mouth.
2.1.1.5.4.3 Cooking quality

Cooked instant noodles should have a relatively strong bite with a firm, smooth surface, and good mouth feel according to Hou (2001). Cooking quality of instant noodles is influenced by several factors, such as protein content (Matsuo et al. 1986), ash content (Okada, 1971), damaged starch, starch quality (Mestres et al. 1988), thickness of noodle strands, and frying conditions. Rehydration rate, cooking time, and cooking loss are the measure of cooking quality and ease of preparation. Protein content and amylase content correlate positively and negative, respectively, with the optimum cooking time of noodles (Park and Baik, 2004a).

2.1.1.5.5 Commercially available noodles in India

In India, noodles have come a long way since its introduction in 1983. It was manufactured by Nestle India Limited's Maggi noodles, which has been dominating the instant noodles market in India for nearly three decades. Due to ease of cooking, Maggi today is the predominant brand consumed in the Indian market. A number of new entrants such as Hindustan Unilever's (HUL) Knorr Soupy noodles, GlaxoSmithKline's Horlicks Foodles, Top Ramen and Big Bazaar's Tasty Treat, Sunfesat yippee are among the other predominant brands. Apart from this, local made Chinese noodles are also available in the market. Instant noodles brands constantly enhance their product offerings by adding new flavours including Indo-Chinese, Chinese, tomato, etc. have been launched.
2.2 Thermal processing

Thermal processing is a method of preserving food by heating in hermetically sealed containers to eliminate the microbial pathogen at a given temperature and specific time. The first recorded work reported on canning was by Nicholas Appert, where he packed food into wide mouth glass bottles, corked and heated and preserved them. However, it was in 1860, Louis Pasteur explained that the heating process killed (or inactivated) the microorganisms which extended the shelf-life of food.

2.2.1 Principles of thermal processing

Since the art of thermal processing was invented in 1809, it continued to be the most common sterilization method for microbial destruction in food preservation. The effect of heat on microorganisms and enzymes was investigated and explained by Louis Pasteur in 1860. He found that both microorganisms and enzymes could be inactivated by heat in order to prolong the shelf life of food. His discoveries form the basis of pasteurization, which is still applicable in many areas such as the dairy and citrus industry.

Depending on the severity of the heat treatment and the purpose of the process, different thermal process regimes such as pasteurization and sterilization can be described (Lund, 1975). Pasteurization involves application of mild heat treatment with the purpose of inactivating enzymes and destroying spoilage vegetative microorganisms (bacteria, yeast, and molds) present in low-acid foods (pH<4.6). Alternatively, if the pH of the foods were high (pH>4.6) the main concern would be the destruction of pathogenic microorganisms of public health risk. Such process is referred to as commercial sterilization. It is carried out in combination with other
external factors such as controlling the storage temperature and packaging environment for ensuring long-term safety.

### 2.2.2 Thermal processing and destruction kinetics

Inactivation of microbes by heat has been found to follow a logarithmic order. Using a kinetic approach the equation describing the logarithmic destruction has been derived. From the standpoint of food sterilization, bacteria may be considered dead if they have lost their ability to divide. The most possible explanation for this observation has been accepted as the one given by Rahn (1945), who stated that the loss of reproductive power of bacteria subjected to heat is due to the denaturation of one gene essential for reproduction. Acceptance of death of bacteria to be of logarithmic nature allows its mathematical description in the same way as a unimolecular or first order bimolecular chemical reaction. Unimolecular reaction involves only one substance, and its rate of decomposition is directly proportional to its concentration.

Traditionally, heat inactivation curves of both enzymes and microorganisms are found to follow first order decay kinetics. The common basic equation for studying reaction kinetic for inactivation or degradation of biological materials is generally given as:

\[-\frac{dC}{dt} = k_c c^n\]  \hspace{1cm} (1.00)

where \(C\) is the concentration of a reacting species at any time \(t\), \(k_c\) is the specific reaction rate, with units \([\text{concentration}]^{1-n} [\text{time}]^{-1}\), and \(n\) is the order of the reaction. Many authors reported that heat inactivation of microorganisms, enzymes or quality factors can be satisfactorily described by the zero order (Equation 1.01), first order (Equation 1.02) or second order reaction models (Equation 1.03):
where \( C \) is the measured concentration of microorganisms, enzymes, or quality attributes, \( C_o \) the initial concentration, \( t \) the heating time and \( k \) the reaction rate constant (\( \text{min}^{-1} \)). If \( N_o \) stands for the initial number of cells like \( C_o \) and \( N \) represents number of surviving cells after treatment time \( t \), then:

\[
t = \frac{2.303}{k} \log \frac{N_o}{N}
\]

(1.04)

The time required to kill 90% of the initial cell population is the time required for the curve to pass one log cycle. Therefore if this time is taken as \( D \), then the slope of the survivor curve can be represented as:

\[
\frac{\log N_o - \log N}{D} = \frac{1}{D}
\]

(1.05)

Substituting in the general equation of a straight line gives,

\[
\log N_o - \log N = \frac{1}{D} t \quad \text{Or} \quad D = -\frac{t}{\log N / N_o}
\]

(1.06)

where \( N \) is enzyme/microbial concentration at time \( t \); \( N_o \) is initial concentration, “\( t \)” is the pasteurization/sterilization time and \( D \) is the decimal reduction time (the time to reduce 90% of enzyme or microbial concentration at a specific temperature).

In many cases, the Bigelow (TDT) model (Ball and Olson, 1957) is frequently employed especially in the microbiology studies.

\[
D = \ln(10)/k
\]

(1.07)

\[
D = D_{\text{Ref}} * 10^{(T_{\text{Ref}} - T)/z}
\]

(1.08)
where D is the decimal reduction time (time required for the concentration of microbial spores to be reduced by a factor of 10 at a given temperature, min), \( D_{\text{ref}} \), the decimal reduction time at reference temperature (min), \( T_{\text{ref}} \), the reference temperature (°C) and z, the z-value (number of degrees celsius required to reduce the D value by a factor of 10).

In thermal death time studies on spore suspension, the logarithmic survival curve is used to calculate this decimal reduction value. In reality, the criterion of process adequacy is based on the reduction of the bacterial population to a tolerable level. In low acid canned foods (pH<4.5) the organism of primary concern is the pathogenic anaerobe *Clostridium botulinum*. It has been established that the minimum safe heat process given to low-acid food should decrease the population by 12 logarithmic cycles (from an initial spore level of one spore per gram of food) the basis of the 12D concept or “Botulinum Cook”. The D value for *C. botulinum* is estimated as 0.21 min (1D at 121.1°C) with a z-value of 10 °C.

2.2.4 Evaluation of thermal destruction rates

Two systems are used to evaluate the impact of temperature on the thermal destruction of food components: the D and z model (or, the TDT model), based on decimal reduction; and the Arrhenius model, which is based on thermodynamic concept of chemical reaction rate constant, which relate the reaction rate constant, activation energy and absolute temperature. The systems are of practical purposes equivalent. The D and z system has the advantage of allowing the direct calculation of accumulated lethality (\( F_o \)) of complex temperature histories. Clifcorn et al. (1950) reported that the destruction of bacteria increases tenfold for each 18 °F (10°C) rise in temperature while the reaction rate responsible for quality deterioration is
only doubled. However, this situation may pose a problem in optimizing the process since enzymes are also inactivated more slowly than microorganisms. Consequently, there is a possibility of having residual enzymatic activity, which by itself or by regeneration of the enzyme negatively influence the quality during storage. Lund (1977) has compiled, generalized and tabulated the thermal resistance of various food components. The table is presented in Appendix-1. Examination of these data conveys two points of great practical significance:

Nutrient and quality factors are upto six orders or more of magnitude more resistant to thermal destruction than spores and vegetative cells.

Nutrient and quality factors show markedly less temperature dependence than spores or cells.

These two features allow for the possibility of optimization of canned foods.

2.2.5 Heat penetration in foods in rigid containers

Numerous works have been carried on the aspects of heat penetration and process evaluation with respect to canned foods. The design of the required thermal process for a given food product is affected by how the heat is transferred to the product and inside the food. The heat transfer inside the package depends on the properties of the food system and on the filling (headspace). The heat transfer from the retort heating or cooling medium to the product (surface of the containers) is determined by the heating medium temperature and the heat transfer coefficient.
2.2.5.1 Measurement of heat penetration in rigid containers

An attempt to determine the temperature of the slowest heating part in canned food (called the cold spot) by placing a small maximum thermometer inside the can was made by Prescott and Underwood (1898). Bitting and Bitting (1917) were the first to use thermocouples for this purpose. Ecklund (1949) and Alstrand and Ecklund (1952) developed non-projecting, plug-in type thermocouples. They also described the fundamental techniques of heat penetration testing. Ball and Olson (1957) and Stumbo (1965) have compiled information on the basic heat penetration studies. Bee and Park (1978) have outlined the contemporary equipments and techniques of conducting heat penetration tests. Developments in heat penetration testing include elimination of conduction errors by thermocouples and wires, attachment to digital thermometers, using computers for retort control, and employing time-temperature integrators (TTIs) whose response can be related to their time-temperature history (Nott and Hall, 1999).

2.2.5.2 Factors influencing the rate of heat penetration

Various factors have been studied and shown to influence the rate of heat penetration into canned foods. The characteristics of the container, contents, retort, heating medium and mode, arrangement of cans inside the retort, steam distribution and all such factors have been studied (Balachandran, 2001). Some of the important works are as follows:

Prescott and Underwood (1898) observed that irrespective of the temperature of the retort, centre of the can reached the retort temperature in approximately the same time. Effect of processing temperature on the rate of heat penetration was studied by Duckwall (1905). Kochs and
Weimhausen (1906) gave detailed information on the effect of filling media on the rate of heat penetration in several canned food items. Ingredient related factors also affect heat penetration in cans, where fatty tissues are poor conductors of heat. Solids with gelling properties also absorb water and change solid liquid ratio thereby affecting heat transfer. Liquid and semi-liquid foods are mainly heated by convection while solid foods are heated by conduction. In semi-liquid products heating is by both convection and conduction implying a longer process time due to the slow rate of heat transfer (Clifcorn et al. 1950). Zavalla (1916) reported that the concentration of syrup seems to exert definite action on the rapidity of heat penetration. Penetration of heat into the cold spot of food is confronted by convective resistance, from heating medium to outer surface of the container and from inner surface to product, as well as the resistance of the packaging material. The internal resistance depends on the thermo physical properties, geometry and dimensions of the product (Silva et al. 1992). The mechanism of heat transfer through the container wall is by conduction. For metallic containers of normal thickness and thermal conductivity, there is no appreciable resistance to heat transfer. With regard to the heat transfer from the container wall into the product the mechanism largely depend on the consistency of the food. Foods behave differently during processing. However, increase in viscosity and presence of solid particles in semi liquids retard the rate of heating and make the process more complex. Consequently, semi-liquid products are heated by both convection and conduction implying a longer process time due to the slow rate of heat transfer. In such instances, movement of contents along the can wall is usually slow resulting in over cooking and scorching of the product (Clifcorn et al. 1950). In general the foods nearest to the can surface will
sterilize before the food at slowest heating point. In canned solid foods heated by conduction, the slowest heating point is at the geometrical center of the can while in convection heating foods; the cold point is below the centre of the can. To ensure that adequate sterilization is achieved, sufficient time must be allowed for the cold point to reach the desired temperature and lethality.

**2.2.6 Thermal process evaluation**

The basic objective of process calculation procedure is to establish the time at a reference temperature that will result in the reduction of a hypothetical population of spores to some small (although infinite) value. Assuming that an end point of reduction to an assumed population of spores can be established, the calculation process is then one of determining the combination of time and temperature necessary to accomplish that objective, given the heating characteristics of the product and the thermal inactivation characteristics of the spores in the product. When these calculations are made, specific values of parameters that characterize the product with respect to heating response and heating inactivation are necessary. These values then must be determined experimentally (Lund, 1978). Many works have been done in the area of process evaluation and these have been reviewed critically. The two well-established techniques for evaluating thermal processes are the *in situ* approach and the physical-mathematical method. In the *in situ* method, changes in the actual quality or safety attribute are determined before and after processing to have a reliable estimate on the status of the attribute of interest. On practical ground, however, measurement of microbial counts, texture, and vitamin content and
organoleptic quality by in situ method is usually slow, costly and sometimes unfeasible due to detection limit or sampling difficulties.

2.2.6.1 Fo-value

In the physical-mathematical method, the time-temperature profile is integrated to evaluate the impact of a thermal treatment on the parameter of interest. The exercise is carried out either to determine the F-value for a given process time or to calculate the process time for a given F-value. F-value is defined as the number of minutes at a specific temperature required to destroy a specific number of organisms having a specific z value. The required information is the time-temperature history of the product at the slowest heating point and the “fi” and “ji” values. The calculation requires solution of the basic integral equation of Fo or its Arrhenius counterpart.

\[
F_o = \int_0^t 10^{(T - T_{ref}) / z} \, dt
\]  

(1.09)

\[
F_o = \int_0^t e^{2.303(T - T_{ref}) / z} \, dt
\]  

(1.10)

Lethality (F-value) is a measure of the heat treatment or sterilization processes. To compare the relative sterilizing capacities of heat processes, a unit of lethality needs to be established. For convenience, this is defined as an equivalent heating of 1 min at a reference temperature, which is usually taken to be 121 °C for the sterilization processes. Thus the F value would represent a certain multiple or fraction of the D-value depending on the type of the microorganism.
2.2.6.2 Cook value

Another closely related parameter for evaluating a thermal process impact on food is the cook value. Cook value is the measure of heat treatment with respect to nutrient degradation and textural changes that occur during processing. Hersom and Hulland (1980) defined it as a “food quality related heating effect that results from 100 °C for one minute”. It is given by

\[ C = \int_0^t 10^{(T - T_{\text{ref}}) / z_c} \, dt \]  

(1.11)

where \( T_{\text{ref}} \) is the reference temperature of 100 °C and \( z_c \) is usually taken as 33 °C, which is the thermal destruction rate for quality factors analogous to \( z \)-factor for microbial inactivation. Similar equation has been developed for pasteurization value but with a different reference temperature and \( z \) value.

2.2.6.3 Heating and cooling rate indices (\( f_{hr}, f_c, j_{ch}, \) and \( j_{cc} \))

These indices are considered as prerequisite tools for proper calculation of process time. They can be evaluated from the temperature-time profile. It has been shown that when the logarithm of the temperature difference between the retort and the product center known as temperature deficit (\( T_r - T \)) during heating is plotted against time on a linear scale, a straight line is obtained after the initial lag. The intercept is obtained by extending the straight line portion of the curve to the y axis representing \( T_{\text{pih}} \) such that

\[ T_r - T_{\text{pih}} = j_{ch}(T_r - T_o) \, . \]

Or

\[ j_{ch} = \frac{T_r - T_{\text{pih}}}{T_r - T_o} \]  

(1.12)
where \( j_{ch} \) is the heating lag factor, which is a measure of the thermal lag (or delay) of the beginning of uniform heating in the product. The corresponding value during the cooling period is \( j_{cc} \) and is given by

\[
j_{cc} = \frac{T_{pec} - T_w}{T_{ie} - T_w}
\]

(1.13)

Part of the lag is due to the slow come-up time of the retort and this is accounted for by determining the new zero time for the process. Ball and Olson (1957) used 58\% of the come-up time as useful contribution to the process and this is widely accepted (Holdsworth, 1997). This implies that 42\% of the come-up time should be added to the process time at retort temperature. The slope of the line is given by the tangent of the angle between the line and the \( t \)-axis, which represents time for the curve to traverse one log cycle. The negative reciprocal of this slope for the heating part is referred to heating rate index (\( f_h \)) and the corresponding value for the cooling period is the cooling rate index (\( f_c \)). \( f_h \) is an indicator to the heating rate. The higher this value the longer it takes for the line to traverse one log cycle indicating slow rate of heat penetration.

### 2.2.6.4 Process time determination by formula method

The starting point of all formula methods is a formula which gives the temperature of the food as an explicit function of time. The Ball formula method is the simplest and also the most widely used (Stoforos, 1995). Using formula methods for process time is also considerably faster than using the general method. It is also versatile in that it can be used to determine both the process time and lethality of a given thermal process, whichever is the one to be determined.
The data recorded by the data-logging system were fed to and analyzed using a computer. The heat penetration data were plotted on an inverted semi log paper with product temperature (PT) on vertical log scale against time on the linear horizontal scale as described in NCA manual (1968). Lag factor for heating (Jch), slope of the heating curve (fh), time in minutes for sterilization at retort temperature (U) and lag factor for cooling (Jcc) were determined. Cooling curve was plotted and cooling process parameters were determined as described by Ramaswamy and Singh (1997). The process time was calculated by mathematical method described by Ball and Olson (1957). Actual process time is determined by adding process time (B) and the effective heating period during come-up time i.e. 42% of the come up time.

\[ B = f_h \times \log \left( \frac{J_{ch}}{g_c} \right) \]  
\[ T_p = B - (0.42 \times t_c) \]  
\[ T_B = B + (0.58 \times t_c) \]

It is based on the equation-1.14 established on the heat penetration curve the parameters described previously. This formula gives the Ball Process Time (B), which is inclusive of the effective come-up time. To determine the Operator’s Process Time (Tp), this effective come-up time is to be subtracted as shown in equation 1.15. To arrive at the total process time (TB), 58% of the come-up time is added to the ball process time (Equation-1.16). Operator’s process time is the time interval measured from the time the retort or autoclave reaches the design process temperature to the time steam is turned off. Total process time is measured from the time of steam-on to the time of steam-off.
Stumbo formula method is essentially similar to the Ball formula method except that it is somewhat more versatile in accounting for the thermal effects of cooling when the cooling lag factor \((j_{cc})\) differs from equation- 1.41 as assumed by Ball. The results obtained by the Stumbo’s formula are found to show better agreement with the ones obtained by the General method of calculation than the ones from Ball’s formula method.

### 2.2.7 Optimization of thermal processing

Where safety is a desired effect of the thermal process, quality degradation is an undesired aspect. The objective of extending shelf life of foods through thermal processing is to make available a varied diet that provides adequate nutrients. Thus the process ultimately used should meet two criteria. It must accomplish the process objective from a microbial or enzymatic standpoint and, it should yield a maximum retention of nutrients. For commercial sterilization, optimization is not as easy as that for blanching or pasteurization. The mode of heating becomes an important factor. For those products that heat by convection, the high temperature short time processes may result in optimum nutrient retention. But a proper account of heat resistant enzymes should be taken in these products. The process may be adequate for destroying the microbes but not for these enzymes.

For the convection heating products, an assumption is made that solids in liquid receive the same lethal treatment as the liquid. The assumption is valid when the food particulates are sterile in the center and have a large heat transfer coefficients. In conduction heating products, each point in the cross section of the container receives a different thermal process than every other point, and the process is based on the slowest heating point. At the conclusion of heating and the start of cooling, a
complexity arises since the slowest heating point continues to heat for a significant period. In this situation, the overall lethality for the process is the integrated effect of the heat treatment at every point in the container. The methods developed for the optimization are time consuming and apply only to conduction heating foods. Teixiera et al. (1969) have given one of the most widely used models of time-temperature treatments that provide equal microbial lethality and retention of nutrients with different $z$ values. If the product receives sufficient mixing or when processed in scraped surface heat exchangers, the HTST technique can be applied. When optimization is to be applied for conduction heating products heated in classical heating techniques, the slow heating towards the interior of the product will result in surface quality degradation. In such cases the optimal temperature will depend on a number of factors including the heating rate of the product (the lower the heating rate of the product the lower the optimal temperature) and the temperature sensitivity the quality index (the less temperature sensitive the quality attribute, the higher the optimal temperature) (Silva et al. 1992). Optimal sterilization processes leading to a maximization of overall quality retention have been calculated using systematic search procedures, graphical optimization, and mathematical optimization techniques. A critical review of mathematical methods available to optimize heat sterilization of prepackaged foods is presented by Silva et al. (1993). The use of variable retort temperature (VRT) profiles to improve mass average quality retention has been investigated (Teixeira et al. 1975; Bhowmik and Hayakawa, 1983; Banga et al. 1991). It was concluded that optimal constant retort temperature (CRT) profiles are as good as optimal VRT profiles when the optimization of the overall quality is of concern, but VRT profiles show some advantages to minimize the processing time and the surface quality retention.
2.2.8 Effect of thermal processing on quality parameters

2.2.8.1 Biochemical changes

Thermal processing also increases the digestibility of foods by breaking down poorly digestible carbohydrates and proteins. Legumes are a good example of foods that demonstrate markedly improved digestibility with cooking (Liener, 1989). Digestive proteases and amylases produced in the human gastrointestinal tract cannot efficiently digest most raw foods. Heating partially denatures proteins, gelatinizes starches and softens cell walls allowing digestive enzymes better access to the food components. Heidelbaugh and Karel (1970) reported the quality changes in pouch foods. Probably this was the earliest report on the retortable pouches. Severe heat treatment and the presence of certain catalysts in the fish muscle favours lipid oxidation and hydrolysis resulting in off flavors and loss of nutrients (Hsieh and Kinsella, 1989: Harris and Tall, 1994). Aubourg et al. (1990) reported a general reduction in lipid content of canned and cooked samples. A significant increase in FFA and phospholipid was noticed during canning, while during storage both decreased. A decrease in TBA value, TMA and vitamin B1 (thiamin) for shrimp, rainbow trout and Alaska Pollock (Chia et al. 1983) and a decrease in the TMA-O content of squids (Kolodziejska et al. 1994) after heat processing, have been reported.

2.2.8.2 Texture

A major challenge facing food developers is how to accurately and objectively measure texture and mouth-feel. Texture is related to a number of physical properties. (e.g., viscosity and elasticity), and the relationship is complex. A general agreement has been reached on the definition of texture, which evolved from the efforts of a number of researchers. It states
that “texture is the sensory and functional manifestation of the structural, mechanical and surface properties of foods detected through the senses of vision, hearing, touch and kinesthetic” (Szczesniak, 2002). Instrumental Texture Analysis is a multi parameter attribute, and the sensations involved are classified into different categories so as to have a proper description of texture. The classification of textural terms for solids and semi-solids gave rise to a profiling method of texture description (TPA) applicable to both sensory and instrumental measurements. Instrumental methods can give mechanical instrumental results. These are those attributes of food manifested by the reaction of the food to stress (Szczesniak, 1963). These include among others, hardness (force required to bite through), cohesiveness (deformation of the sample by the teeth before breaking), and springiness (rate at which a deformed food piece returns to its undeformed shape). The mechanical process of mastication has been simulated using Texture Profile Analysis (TPA). This objective method measures the compression force of a probe and the related textural parameters of a test food during two cycles of deformation. The TPA of various food stuffs including fruits, vegetables, bakery and meat products have been reported. Aitken and Connell (1979) reported that unless supported by sensory texture evaluations, instrumental methods are of limited use, and are of value only to processors and researchers for studying textural changes. With the sensory method, the evaluation includes several steps outside and inside the mouth, from the first bite through mastication, swallowing and residual feel in the mouth and throat. With the instrumental method, texture profiling involves compressing the test substance at least twice and quantifying the mechanical parameters from the recorded force-deformation curves. Its use
is based on standard scales for the mechanical parameters (Szczesniak et al. 1963), which are also employed for selecting and training of panel members

2.2.8.3 Colour

Colour is a very important quality factor in thermally processed products, since it influences consumer acceptability. There are many reactions that can take place during thermal processing that affect colour. Among them, the most common are pigment degradation, and browning reactions such as the Maillard reaction (Mauron, 1981). Tarr (1952) reported a brown discoloration in white-fleshed fish upon heating. Moss (1971) distinguished different ways in quality of noodles. First, the whiteness or brightness of the dried noodle decreases with increasing protein level. Second, the color varies with textural changes during boiling and quality may be affected by the quality of the wheat from which they are prepared. As protein content increases, the eating quality becomes more attractive, yet the colour becomes more objectionable (Baik et al. 1994).

2.2.8.4 Sensory analysis

Objective of sensory testing is to measure the intrinsic sensory attributes of a sample through the analytic sensory perceptions of human assessors. The overall quality of seafood is comprised of both wholesomeness and sensory acceptability by the consumer (Sikorski and Sun Pan, 1994). The wholesomeness is affected by chemical and microbial factor where as sensory factors are determined by flavor and texture (Sawyer et al. 1988). Sensory analyses of fish and fishery products have always been a part of the production process (York and Sereda, 1994). Flavour development during heating involves the Maillard browning reactions, fatty acid oxidation and the formation of low molecular weight
volatile compounds like ammonia and hydrogen sulfide. It involves inter and intra molecular cyclization, and reaction between intermediate products also. During the heating of meat, numerous volatile compounds are formed that contribute to the meaty flavour. Measurement of sensory properties of different types of fishery products was reviewed by different authors (Connell and Shewan, 1980; York and Sereda, 1994). Cooked instant noodles should have a relatively strong bite with a firm, smooth surface, and good mouthfeel (Hou, 2001).

2.3 Containers for packaging of thermal processed products

2.3.1 Rigid containers

2.3.1.1 Metal cans

Metal cans were first developed in the early 19th century. As with many technological advances, their development was hastened by military necessity; in this case Napoleon's interest in preserving foods for lengthy campaigns. In the years following the Napoleonic wars, can making begin in earnest in England and the first USA canning operation opened in 1819. Following the success of Nicholas Appert, “glass bottles” were extensively used in the early days of canning. Although the tin containers have been used from ancient times, it was in 1810 a patent for its use as a container for packing foods obtained by Peter Durand in England. The tin plate metal containers were called “canisters” from which the term ‘can’ is believed to have derived. Each container has certain exclusive uses; in the course of development we can see that one container is invading other fields. The selection of one container over the other is usually decided on the basis of process and product, cost of production etc. Today there are several choices are available i.e. Standard tin plates, light weight tin plate, double reduced
tin plate, tin free steel and vacuum deposited aluminium on steel and aluminum. For food products packing they are coated inside to get desirable properties like acid resistance and sulphur resistance. But care has to be taken to avoid tainting of the lacquer.

2.3.1.2 Tin cans

Most frequently used container for packing food for canning is tin plate can. Tin plate containers made their appearance in 1810. The tin can is made of about 98% steel and 2% tin coating on either side. The base steel used for making cans is referred as CMQ or can making quality steel. Corrosion behavior, strength and durability of the tin plate depend upon the chemical composition of the steel base. The active elements are principally copper and phosphorous. The more of these elements present the greater the corrosiveness of steel. Depending upon the degree of workability, strength and corrosion resistance required in the case of tin plates four types of steel are specified. They are type L, type MR, type MC and type M. First three are produced by cold reduction process. Type M is similar to type MC in composition but produced by hot reduction process.

2.3.1.3 Aluminium cans

The organoleptic qualities of foods packed in tin containers gradually decreased when they are kept for longer periods. This led to the introduction of another important container, the aluminium alloy can. Aluminium containers were used for packing meat and fish products as early as 1918. These are now being used extensively in European countries because of the availability of the raw material and less cost for its production due to plenty of electricity in those countries.
2.3.1.4 Tin-free steel cans

This was developed in Japan under different names such as Can super, Hinac coat, Hi-top by different manufactures. They are prepared by electroplating cold roller steel sheet with chromium in chromic acid. TFS is an important alternative to tin can. TFS has a steel base with a chromium/chromium oxide coating on the surface replacing tin in conventional cans.

2.3.1.5 Glass containers

Glass containers have been used for many centuries and still are one of the important in food packaging. Due to its certain properties, glass has its unique place in food packaging. It is strong, rigid and chemically inert. It does not appreciably deteriorate with age and is an excellent barrier to solids, liquids and gases, and gives excellent protection against odour and flavor contamination. The transparency of glass provides product visibility. Glass can also be moulded to variety of shapes and sizes. But it has disadvantages like fragility, photo oxidation, heavier in weight etc. Glass containers include bottles, jars, tumblers and jugs.

2.3.2 Semi-rigid containers

Semi rigid plastic containers are thermoformed containers which are economical and offer convenience to the user. The containers are thin in profile and three dimensional in shape with a filling volume. The filling volume varies depending on the size and use of the container. The containers are produced by cold forming by using a vacuum forming die and compressed air (Conley and Cornmann, 1975). The heat setting fixes the shapes and can also facilitate sealing of the filled containers. The original semi rigid containers were made of aluminium coated on the interior with polypropylene
films. The disadvantage of aluminium was that it was easily prone to denting. The plastic containers developed in the 1980’s were laminates of polypropylene/EVOH or PVDC/polypropylene. The widely used high barrier retortable plastic containers consist of polypropylene or polyester/ PVDC or EVOH/polypropylene. Total thickness of these containers may be about 2 mm. Thermoformed containers can be made into various shapes and sizes and can be handled without the fear of breakage as in the case of glass. This makes it possible for convenient handling and built in safety. The plastics are light in weight, stable, can be combined with other materials and resistance to chemical attack. They are also recyclable and some energy can be recovered from the disposed material (Brown, 1992).

The major advantages of the trays over other rigid and flexible containers as per Hoddinott, 1975 are as follows

- Easy to open and cheap and economical
- High barrier properties and wide variety of shape and sizes
- Vacuum filling and gas flushing possible
- Easy to fill and use and transport
- The flat form helps in quick retorting
- Large surface area can be used for advertising
- Faster heat penetration rate during retorting due to the thin profiles
- Microwave-ovenable

Physical properties required for semi rigid containers as per Long (1962)

- Oxygen transmission rate less than 1cc/100 inch²/24hrs /1atm
Water vapour transmission rate less than 0.05 g/100 m²/ 24hrs / 90±2% RH/ 37°C

Temperature resistance from 32°F to 25°F

Low hydrophilic properties

Low cost of material and production cost

Heat sealability over a wide temperature range

Should meet FDA standards

Resistant to penetration of oil, fat or other foods component.

Dimension stability and chemical inertness, with no tendency to impart objectionable odour or flavor to foods.

Physical strength to resist any handling abuse.

Consumer appeal; transparency (or opaqueness, depending on product) gloss, agreeable feel.

Capability of being handled on automatic fabrication and filling equipment.

Good ageing properties.

Good printability.

### 2.3.3 Opaque and see through retort pouch

The concept of pouch as a container was developed by the US Army Natick Laboratories and a consortium of food packaging companies in the early 1960s (Herbert and Betteson, 1987). The technical and commercial feasibility of using retort pouches for thermo-processed products have been
proven by (Hu et al. 1955). In 1967, Chinese dumplings and curry were packed in aluminum foil containing retortable pouches and marketed. In the year 1968-69 commercialization of curry in foil free and aluminum foil containing pouches were undertaken and this started the era of retort pouches in Japan (Tsutsumi, 1972). The boil in bag concept of warming the food before consumption gives an edge for pouches over cans (Arya, 2001). Retort pouched products are shelf stable ready to eat products which can be used as per the convenience of the consumer (Rangarao, 2002). The most comprehensive work on flexible packaging for thermal processed foods was prepared by Lampi (1977). Heat sterilized low acid solid foods in pouches created a new segment within the canned foods category (Brody, 2003). Sara et al. (1989) studied the effect of increased over pressure levels, entrapped air and temperature on the heat penetration rates in flexible packages. Sacharow, (2003) did market studies in USA and Europe and reported a bright future for retortable pouches.

2.3.4 Thermoforming

Thermoforming is a generic term encompassing many techniques for producing useful plastic articles from flat sheet. Thermoforming is simply the manual dropping of a temporary soften sheet over a simple mould shape. For thermoformed trays, polyvinyl chloride (PVC), high impact polystyrene (HIPS) and high density polythene (HDPE) are mostly used. Thermoformed trays can be produced from a variety of materials including both single thickness and laminated structures. Thermoforming offers processing advantages over competitive processes such as blow molding, rotational molding and injection molding. Relatively low forming pressures are needed and so mold costs are low and parts of relatively large size can
be economically fabricated. Parts with very small thickness-to-area ratio can be fabricated. For thin wall parts, fabrication time is extremely short, making the process very economical for many parts. Since the molds see relatively low forces, molds can be made of relatively inexpensive materials and mold fabrication is very short. Thus lead time is very short. Thermoforming is the method most usually selected for prototype and display parts to be made by other processes. There are basically three types of thermoforming namely, vacuum forming, pressure forming and matched mould forming.

2.3.4.1 Different types of thermoforming

2.3.4.1.1 Vacuum forming

In its simplest form, vacuum forming equipment consists of a vacuum box with an air outlet and a clamping frame, a mould, a heating panel and a vacuum pump. The mould, which is partly hollow underneath and is perforated, is placed over the air outlet. The thermoplastics sheet is then placed over the open top of the vacuum box and securely clamped by means of frame giving an airtight compartment. The sheet is heated until rubbery, the heater is withdrawn, and the air in the box is rapidly evacuated by the vacuum pump. Atmospheric pressure above the sheet forces it down into close contact with the mould where it is cooled sufficiently to retain its shape. The clamping frame is then released, the formed sheet is removed from the mould, and the excess material trimmed off. The sequence is shown in Figure-4 (Gopal et al. 2007).
2.3.4.1.2 Drape forming

Here the mould is mounted on a piston within the vacuum box. The piston rises and pushes the mould into the heat softened sheet, immediately prior to the vacuum being applied. This gives a certain amount of pre-forming and so lessens thinning of the sheet at the corners of the mould Figure-5.

2.3.3.1.3 Pressure forming

Similar to vacuum forming with the exception that a positive air pressure is applied to the top surface of the sheet. As in vacuum forming, this has the effect of forcing the heat softened sheet into contact with the mould. The main advantage is that the pressure on the sheet can be greater than in the case of vacuum forming which is of course, limited to atmospheric pressure. Pressure forming thus gives reproduction of mould detail (Gopal et al. 2007).
2.3.4.1.4 Matched die moulding

The heated sheet is formed into shape by trapping it between matched male and female moulds. The mould detail as one would expect, is even better using this technique but it is more expensive in tooling costs and the mould halves have to be made to tight tolerances.

Only the HDPE and PP trays offer a reasonable water barrier whilst only the PVC and PS trays offer reasonable oxygen barriers. As in the case of flexible materials, the properties of trays can be tailored, to some extent, by using composite materials. Laminates such as PVC/Polythene and Polystyrene/Polythene are used to produce trays having improved water barrier, sealability and strength, compared with trays made from non-laminated PVC and PS sheeting. Trays are also available, made from co-extruded structures containing an ethylene/vinyl alcohol layer, which provides improved oxygen barrier characteristics. For the packaging of battered and breaded fish products conventional packaging materials like flexible plastic films alone are not suitable for these products as they provide little mechanical protection to the products and as a result the products get damaged or broken during handling and transportation. Hence thermoformed containers are commonly used for this purpose.

![Figure-6. Schematic diagram for thermoformed tray packaging](image)
2.3.4.2 Lids for thermoformed containers

High barrier Lidding material is also available for top sealing of the trays. They can be used for single or multi compartment plastic trays and can be used for protection of ready to eat, thermal processed meals. The outer polyester layer and the metallic layer can be used for printing. Easy to open lids and closures are available in the market (Gerald, 1978)

2.4 Thermal process operation of food in retortable trays

2.4.1 Filling

The filling operations are to be very carefully done to avoid contamination of the heat seal area. Both volumetric and gravimetric filling can be done by the nozzles and controlling the dosage automatically. Correct positioning of the trays on the filling line and sealing station should be maintained.

2.4.2 Vacuumisation or air removal

The air and gases present inside the container is removed by applying vacuum. This is made effective by using a vacuum sealing machine, wherein the air is removed and simultaneously the lid is sealed on to the container. The removal air is necessary to counter the internal pressure developed in the container due to the heating and expansion of the gases and to ensure a uniform heat transfer during retorting. In addition to vaccumisation steam flushing can also be done to remove the air, hot steam displaces the air inside the container.

2.4.3 Sealing

There are two methods of sealing; hot bar sealing method and thermal impulse sealing method. In the hot bar sealing, a constant temperature, resistance heated metal bar sealing against a rubber fixture helps in sealing.
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Thermal impulse sealing, the seal areas are held together by a pair of jaws, heated to fusion temperature by short electrical impulses and simultaneous cooling under pressure is done. The main problems with impulse sealing are wrinkles to the top film, seal contamination and imperfect surface due to impulse sealing.

2.4.4 Retorting

Retorting is done in over pressure autoclave which may be a steam air or steam water mixture retort. Counter air or pressure is used to counter balance the internal package pressure and seal integrity (Yamaguchi et al. 1972).

2.4.5 Cooling

Cooling is done within the retort itself by pumping in chill water and at the same time maintaining the pressure. Once the product is sufficiently cooled it is removed with the help of trolleys or pulleys.

2.4.6 Racking or stacking

The containers are then wiped clean, checked for any deformation, seal integrity and labelled and packed. They are then stacked before final inspection and distribution.

2.5 Migration of constituents

A number of resins and adhesives are used during the manufacture or lamination of the different layers of the containers. The overall migration in the containers into the food may be higher at 121.1°C or higher temperatures when the food is retorted. Different materials have different solvents and conditions for extraction of stimulants into solvents to pass the criteria of being used as a material for thermoform containers (Gopal et al. 2007).
Physical properties: The containers should be heat sealable, retain its shape and dimensions after retorting. It should not loose the material inertness and barrier properties which were originally present in the container.

All plastics, apart from the basic polymeric resin, usually contain several components (additives or adjuvants) either present as impurities or deliberately added for, in ppm to several percent. The final processed plastics is a somewhat different material compared to the virgin polymer and it is only natural to expect that it is the finished plastic material that needs to be evaluated by end tests. To minimise the risk factor due to transfer of polymer additives and also to restrict the ingress of non-nutritive substances into the food, the need for the formulation of guidelines for proper use of plastics for food packaging applications has been realized all over the world, and in view of the increasing use of plastics in food contact applications, guidelines are necessary to curb the indiscriminate use or abuse of plastics. Basically, regulations on food packaging materials comprise:

- Regulations for adjuvants (antioxidants, colourants, plasticisers etc.) used in food packaging materials.
- Specification for the basic polymeric resin used.
- Extractive limits for the final food contact article.

Therefore, a plastic material intended for food contact application must be of food grade, which means that only resins conforming to relevant specifications and only permitted adjuvants must be used in the manufacture of packaging material. For testing the maximum estimated daily intake, ideally, migration tests for adjuvant transfer into foods should be conducted with each type of food in a given package under normal conditions used for
an expected contact of time. However, apart from being economically prohibitive, this type of evaluation with actual foods is analytically difficult because of their complex nature. Further, the duration involved makes long-term tests with foodstuffs impractical. Accordingly, special extracting liquids, called food-simulating liquids have been recommended to be used in place of actual foodstuffs. Extraction experiments are conducted which are known as migration tests. Global migration considers the total amount of the adjuvants migrating while specific migration is concerned with specific adjuvant. The global migration tests are mandatorily prescribed in the specifications of all countries in food packaging materials. Global migration tests are important to test the compliance of a food packaging material to the extractive limits called Global Migration Limits in relevant specification. All plastic materials intended for food contact applications need to be first evaluated by migration tests before subjecting to shelf life studies etc. The global migration limits should be 60 ppm or 10 mg/dm² as prescribed by Bureau of Indian Standards (BIS, India), British Plastic Federation (BPF, UK) and 50 ppm in case of Food and Drug Administration (FDA, USA) standards for all polymers for which specifications are available.