AENG252 **2 (1+1)**

Greenhouses and Post Harvest Technology

Lecture No.1

Introduction to green houses - history, definition, greenhouse effect, advantages of green houses.

After the advent of green revolution, more emphasis is laid on the quality of the product along with the quantity of production to meet the ever- growing food requirements. Both these demands can be met when the environment for the plant growth is suitably controlled. The need to protect the crops against unfavourable environmental conditions led to the development of protected agriculture. Greenhouse is the most practical method of achieving the objectives of protected agriculture, where the natural environment is modified by using sound engineering principles to achieve optimum plant growth and yields.

1.1 History

A greenhouse is a framed or an inflated structure covered with a transparent or translucent material in which crops could be grown under the conditions of at least partially controlled environment and which is large enough to permit persons to work within it to carry out cultural operations.

The growing of off - season cucumbers under transparent stone for Emperor Tiberius in the 1st century, is the earliest reported protected agriculture. The technology was rarely employed during the next 1500 years. In the 16th century, glass lanterns, bell jars and hot beds covered with glass were used to protect horticultural crops against cold. In the 17th century, low portable wooden frames covered with an oiled translucent paper were used to warm the plant environment.

In Japan, primitive methods using oil -paper and straw mats to protect crops from the severe natural environment were used as long ago the early 1960s. Greenhouses in France and England during the same century were heated by manure and covered with glass panes. The first greenhouse in the 1700s used glass on one side only as a sloping roof. Later in the century, glass was used on both sides. Glasshouses were used for fruit crops such as melons, grapes, peaches and strawberries, and rarely for vegetable production.

Protected agriculture was fully established with the introduction of polyethylene after the World war II. The first use of polyethylene as a greenhouse cover was in 1948, when professor Emery Myers Emmert, at the University of Kentucky, used the less expensive material in place of more expensive glass.

The total area of glasshouses in the world (1987) was estimated to be 30,000 ha and most of these were found in North- Western Europe. In contrast to glasshouses, more than half of the world area of plastic green houses is in Asia, in which China has the largest area. According to 1999 estimates, an area of 6, 82,050 ha were under plastic greenhouses (Table 1.1). In most of the countries, green houses are made of plastic and glass; the majority is plastic.

Glasshouses and rigid plastic houses are longer-life structures, and therefore are most located in cold regions where these structures can be used throughout the year. In Japan, year-round use of greenhouses is becoming predominant, but in moderate and warm climate regions, they are still provisional and are only used in winter.

In India, the cultivation in the plastic greenhouses is of recent origin. As per 1994-95 estimates, approximately 100 ha of India are under greenhouse cultivation.

Table 1. Estimated world use of plastic greenhouses (1999)

Region	Area (ha)
Europe	1,80,000
Africa and the Middle East	55,000
America	22,350
Asia China - 3,80,000 Japan – 51,042 Korea – 2,200	4,50,000
World Total	**6,82,050**

Since 1960, the greenhouse has evolved into more than a plant protector. It is now better understood as a system of controlled environment agriculture (CEA), with precise control of air and root temperature, water, humidity, plant nutrition, carbon dioxide and light. The greenhouses of today can be considered as plant or vegetable factories. Almost every aspect of the production system is automated, with the artificial environment and growing system under nearly total computer control.

1.2 Greenhouse Effect

In general, the percentage of carbon dioxide in the atmosphere is 0.035% (345 ppm). But, due to the emission of pollutants and exhaust gases into the atmosphere, the percentage of carbon dioxide increases which forms a blanket in the outer atmosphere. This causes the entrapping of the reflected solar radiation from the earth surface. Due to this, the atmospheric temperature increases, causing global warming, melting of ice caps and rise in the ocean levels which result in the submergence of coastal lines. This phenomenon of increase in the ambient temperature, due to the formation of the blanket of carbon dioxide is known as **greenhouse effect**.

The greenhouse covering material acts in a similar way, as it is transparent to shorter wave radiation and opaque to long wave radiation.

During the daytime, the shorter wave radiation enters into the greenhouse and gets reflected from the ground surface. This reflected radiation becomes long wave radiation and is entrapped inside the greenhouse by the covering material. This causes the increase in the greenhouse temperature. It is desirable effect from point of view of crop growth in the cold regions.

1.3 Advantages of Greenhouses

The following are the different advantages of using the green house for growing crops under controlled environment:

1. Throughout the year four to five crops can be grown in a green house due to availability of required plant environmental conditions.
2. The productivity of the crop is increased considerably.
3. Superior quality produce can be obtained as they are grown under suitably controlled environment.
4. Gadgets for efficient use of various inputs like water, fertilizers, seeds and plant protection chemicals can be well maintained in a green house.
5. Effective control of pests and diseases is possible as the growing area is enclosed.
6. Percentage of germination of seeds is high in greenhouses.
7. The acclimatization of plantlets of tissue culture technique can be carried out in a green house.
8. Agricultural and horticultural crop production schedules can be planned to take advantage of the market needs.
9. Different types of growing medium like peat mass, vermiculate, rice hulls and compost that are used in intensive agriculture can be effectively utilized in the greenhouse.
10. Export quality produce of international standards can be produced in a green house.
11. When the crops are not grown, drying and related operations of the harvested produce can be taken up utilizing the entrapped heat.
12. Greenhouses are suitable for automation of irrigation, application of other inputs and environmental controls by using computers and artificial intelligence techniques.
13. Self-employment for educated youth on farm can be increased.

Lecture No.2

Brief description of types of green houses - greenhouses based on shape, utility, construction, covering materials and cost, shade nets.

Greenhouse structures of various types are used successfully for crop production. Although there are advantages in each type for a particular application, in general there is no single type greenhouse, which can be considered as the best. Different types of greenhouses are designed to meet the specific needs.

2.1 Greenhouse type based on shape

Greenhouses can be classified based on their shape or style. For the purpose of classification, the uniqueness of the cross section of the greenhouses can be considered as a factor. As the longitudinal section tend to be approximately the same for all types, the longitudinal section of the greenhouse cannot be used for classification. The cross sections depict the width and height of the structure and the length is perpendicular to the plane of cross section. Also, the cross section provides information on the overall shape of the structural members, such as truss or hoop, which will be repeated on every day.

The commonly followed types of greenhouse based on shape are lean-to, even span, uneven span, ridge and furrow, saw tooth and quonset.

2.1.1 Lean-to type greenhouse

A lean-to design is used when a greenhouse is placed against the side of an existing building. It is built against a building, using the existing structure for one or more of its sides (Fig.1). It is usually attached to a house, but may be attached to other buildings. The roof of the building is extended with appropriate greenhouse covering material and the area is properly enclosed. It is typically facing south side. The lean-to type greenhouse is limited to single or double-row plant benches with a total width of 7 to 12 feet. It can be as long as the building it is attached to. It should face the best direction for adequate sun exposure.

The advantage of the lean-to type greenhouse is that, it usually is close to available electricity, water, and heat. It is a least expensive structure. This design makes the best use of sunlight and minimizes the requirement of roof supports. It has the following disadvantages: limited space, limited light, limited ventilation and temperature control. The height of the supporting wall limits the potential size of the design. Temperature control is more difficult because the wall that the greenhouse is built on, may collect the sun's heat while the translucent cover of the greenhouse may lose heat rapidly. It is a half greenhouse, split along the peak of the roof.

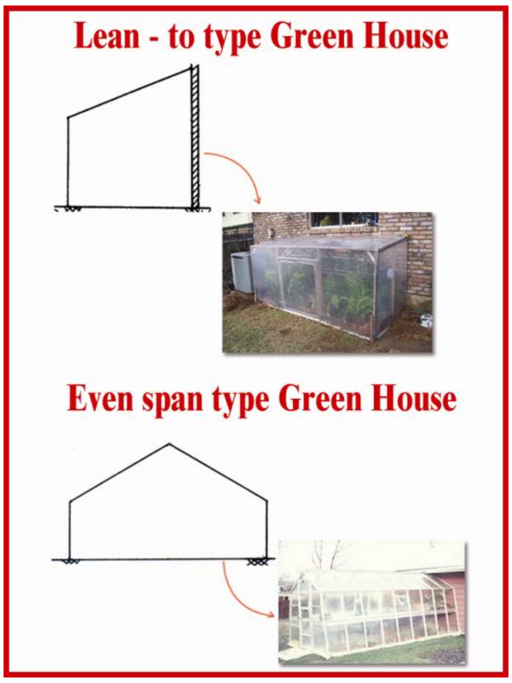


Fig. 1. Lean-to-type and Even span type greenhouses

2.1.2 Even span type greenhouse

The even-span is the standard type and full-size structure, the two roof slopes are of equal pitch and width (Fig.1). This design is used for the greenhouse of small size, and it is constructed on level ground. It is attached to a house at one gable end. It can accommodate 2 or 3 rows of plant benches. The cost of an even-span greenhouse is more than the cost of a lean-to type, but it has greater flexibility in design and provides for more plants. Because of its size and greater amount of exposed glass area, the even-span will cost more to heat. The design has a better shape than a lean-to type for air circulation to maintain uniform temperatures during the winter heating season. A separate heating system is necessary unless the structure is very close to a heated building. It will house 2 side benches, 2 walks, and a wide center bench. Several single and multiple span types are available for use in various regions of India. For single span type the span in general, varies from 5 to 9 m, whereas the length is around 24 m. The height varies from 2.5 to 4.3 m.

2.1.3 Uneven span type greenhouse

This type of greenhouse is constructed on hilly terrain. The roofs are of unequal width; make the structure adaptable to the side slopes of hill (Fig. 2). This type of greenhouses is seldom used now-a-days as it is not adaptable for automation.

2.1.4 Ridge and furrow type greenhouse

Designs of this type use two or more A-frame greenhouses connected to one another along the length of the eave (Fig. 2). The eave serves as furrow or gutter to carry rain and melted snow away. The side wall is eliminated between the greenhouses, which results in a structure with a single large interior, Consolidation of interior space reduces labour, lowers the cost of automation, improves personal management and reduces fuel consumption as there is less exposed wall area through which heat escapes. The snow loads must be taken into the frame specifications of these greenhouses since the snow cannot slide off the roofs as in case of individual free standing greenhouses, but melts away. In spite of snow loads, ridge and furrow greenhouses are effectively used in northern countries of Europe and in Canada and are well suited to the Indian conditions.

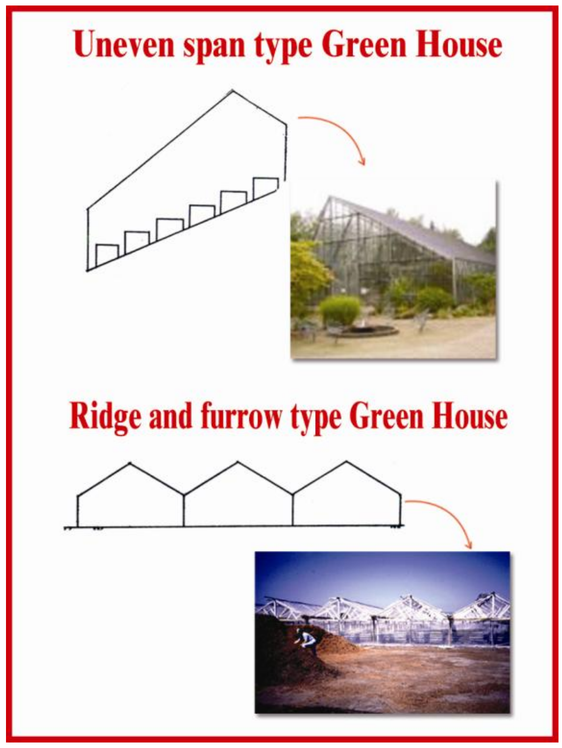


Fig. 2. Uneven and Ridge and furrow type greenhouses

2.1.5 Saw tooth type Greenhouse

These are also similar to ridge and furrow type greenhouses except that, there is provision for natural ventilation in this type. Specific natural ventilation flow path (Fig. 3) develops in a saw- tooth type greenhouse.

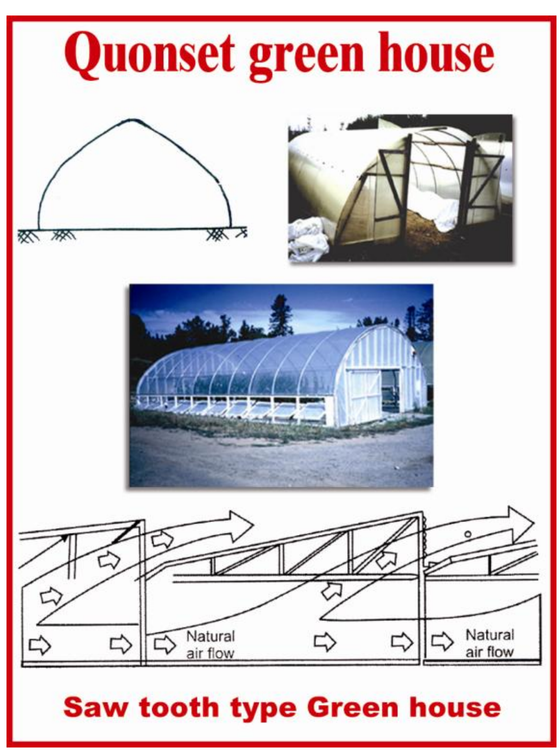


Fig. 3. Quonset and Saw tooth type greenhouses

2.1.6 Quonset greenhouse

This is a greenhouse, where the pipe arches or trusses are supported by pipe purling running along the length of the greenhouse (Fig 3). In general, the covering material used for this type of greenhouses is polyethylene. Such greenhouses are typically less expensive than the gutter connected greenhouses and are useful when a small isolated cultural area is required. These houses are connected either in free, standing style or arranged in an interlocking ridge and furrow.

In the interlocking type, truss members overlap sufficiently to allow a bed of plants to grow between the overlapping portions of adjacent houses. A single large cultural space thus exists for a set of houses in this type, an arrangement that is better adapted to the automation and movement of labour.

2.2 Greenhouse type based on utility

Classification of greenhouses can be made depending on the functions or utilities. Of the different utilities, artificial cooling and heating of the greenhouse are more expensive and elaborate. Hence based on the artificial cooling and heating, greenhouses are classified as green houses for active heating and active cooling system.

2.2.1 Greenhouses for active heating

During the night time, air temperature inside greenhouse decreases. To avoid the cold bite to plants due to freezing, some amount of heat has to be supplied. The requirements for heating greenhouse depend on the rate at which the heat is lost to the outside environment. Various methods are adopted to reduce the heat losses, viz., using double layer polyethylene, thermo pane glasses (Two layers of factory sealed glass with dead air space) or to use heating systems, such as unit heaters, central heat, radiant heat and solar heating system.

2.2.2 Greenhouses for active cooling

During summer season, it is desirable to reduce the temperatures of greenhouse than the ambient temperatures, for effective crop growth. Hence suitable modifications are made in the green house so that large volumes of cooled air is drawn into greenhouse, This type of greenhouse either consists of evaporative cooling pad with fan or fog cooling. This greenhouse is designed in such a way that it permits a roof opening of 40% and in some cases nearly 100%.

2.3 Greenhouse type based on construction

The type of construction is predominantly influenced by the structural material, though the covering material also influences the type. Span of the house inurn dictates the selection of structural members and their construction. Higher the span, stronger should be the material and more structural members are used to make sturdy truss type frames. For smaller spans, simpler designs like hoops can be followed. Therefore based on construction, greenhouses can be broadly classified as wooden framed, pipe framed and truss framed structures.

2.3.1 Wooden framed structures

In general, for the greenhouses with span less than 6 m, only wooden framed structures are used. Side posts and columns are constructed of wood without the use of a truss. Pine wood is commonly used as it is inexpensive and possesses the required strength. Timber locally available, with good strength, durability and machinability also can be used for the construction.

2.3.2 Pipe framed structures

Pipes are used for construction of greenhouses, when the clear span is around 12m (Fig. 4). In general, the side posts, columns, cross ties and purlins are constructed using pipes. In this type, the trusses are not used.

2.3.3 Truss framed structures

If the greenhouse span is greater than or equal to 15m, truss frames are used. Flat steel, tubular steel or angular iron is welded together to form a truss encompassing rafters, chords and struts (Fig. 4). Struts are support members under compression and chords are support members under tension. Angle iron purlins running throughout the length of greenhouse are bolted to each truss. Columns are used only in very wide truss frame houses of 21.3 m or more. Most of the glass houses are of truss frame type, as these frames are best suited for pre-fabrication.

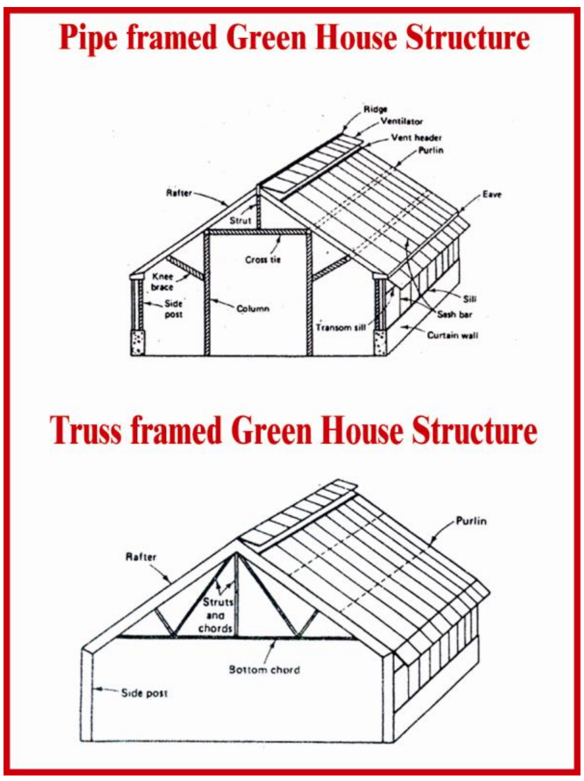


Fig. 4. Pipe and truss framed greenhouse structures

2.4 Greenhouse type based on covering materials

Covering materials are the major and important component of the greenhouse structure. Covering materials have direct influence on the greenhouse effect inside the structure and they alter the air temperature inside the house. The types of frames and method of fixing also varies with the covering material. Based on the type of covering materials, the greenhouses are classified as glass, plastic film and rigid panel greenhouses.

2. 4.1 Glass greenhouses

Only glass greenhouses with glass as the covering material existed prior to 1950. Glass as covering material has the advantage of greater interior light intensity. These greenhouses have higher air infiltration rate which leads to lower interior humidity and better disease prevention. Lean-to type, even span, ridge and furrow type of designs are used for construction of glass greenhouse.

2.4.2 Plastic film greenhouses

Flexible plastic films including polyethylene, polyester and polyvinyl chloride are used as covering material in this type of greenhouses. Plastics as covering material for greenhouses have become popular, as they are cheap and the cost of heating is less when compared to glass greenhouses. The main disadvantage with plastic films is its short life. For example, the best quality ultraviolet (UV) stabilized film can last for four years only. Quonset design as well as gutter-connected design is suitable for using this covering material.

2.4.3 Rigid panel greenhouses

Polyvinyl chloride rigid panels, fibre glass-reinforced plastic, acrylic and polycarbonate rigid panels are employed as the covering material in the quonset type frames or ridge and furrow type frame. This material is more resistant to breakage and the light intensity is uniform throughout the greenhouse when compared to glass or plastic. High grade panels have long life even up to 20 years. The main disadvantage is that these panels tend to collect dust as well as to harbor algae, which results in darkening of the panels and subsequent reduction in the light transmission. There is significant danger of fire hazard.

2.5 Shading nets

There are a great number of types and varieties of plants that grow naturally in the most diverse climate conditions that have been transferred by modern agriculture from their natural habitats to controlled crop conditions. Therefore, conditions similar to the natural ones must be created for each type and variety of plant. Each type of cultivated plant must be given the specific type of shade required for the diverse phases of its development. The shading nets fulfill the task of giving appropriate micro-climate conditions to the plants.

Shade nettings are designed to protect the crops and plants from UV radiation, but they also provide protection from climate conditions, such as temperature variation, intensive rain and winds. Better growth conditions can be achieved for the crop due to the controlled micro-climate conditions “created” in the covered area, with shade netting, which results in higher crop yields. All nettings are UV stabilized to fulfill expected lifetime at the area of exposure. They are characterized of high tear resistance, low weight for easy and quick installation with a 30-90% shade value range. A wide range of shading nets are available in the market which are defined on the basis of the percentage of shade they deliver to the plant growing under them.

Lecture No.3

Plant response to greenhouse environments - light, temperature, relative humidity, ventilation and carbon dioxide and environmental requirement of agriculture and horticulture crops inside green houses.

The productivity of a crop is influenced not only by its heredity but also by the microclimate around it. The components of crop microclimate are light, temperature, air compositions and the nature of the root medium. In open fields, only manipulation of nature of the root medium by tillage, irrigation and fertilizer application is possible. The closed boundaries in greenhouse permit control of any one or more of the components of the micro climate.

3.1 Light

The visible light of the solar radiation is a source of energy for plants. Light energy, carbon dioxide (Co_2) and water all enter in to the process of photosynthesis through which carbohydrates are formed. The production of carbohydrates from carbon dioxide and water in the presence of chlorophyll, using light energy is responsible for plant growth and reproduction. The rate of photosynthesis is governed by available fertilizer elements, water, carbon dioxide, light and temperature.

The photosynthesis reaction can be represented as follows

$$Co_2 + \text{water} + \text{light energy} \xrightarrow[\text{Plant nutrients}]{\text{Chlorophyll}} \text{carbohydrates} + \text{oxygen}$$

Considerable energy is required to reduce the carbon that is combined with oxygen in CO_2 gas to the state in which it exists in the carbohydrate. The light energy thus utilized is trapped in the carbohydrate. If the light intensity is diminished, photosynthesis slows down and hence the growth. If higher than optimal light intensities are provided, growth again slows down because of the injury to the chloroplasts.

The light intensity is measured by the international unit known as Lux. It is direct illumination on the surrounding surface that is one meter from a uniform point source of 1 international candle. Green house crops are subjected to light intensities varying from 129.6klux on clear summer days to 3.2 Klux on cloudy winter days. For most crops, neither condition is ideal. Many crops become light saturated, in other words, photosynthesis does not increase at light intensities higher than 32.2klux. Rose and carnation plants will grow well under summer light intensities. In general, for most other crops foliage is deeper green if the greenhouse is shaded to the extent of about 40% from mid spring (May) to mid fall (August and September). Thus, it is apparent that light intensity requirements of photosynthesis are vary considerably from crop to crop.

Light is classified according to its wave length in nanometers (nm). Not all light useful in photosynthesis process. UV light is available in the shorter wavelength range, i.e less than 400nm. Large of quantities of it is harmful to the plants. Glass screens are opaque to the most UV light and light below the range of 325nm. Visible and white light has wavelength of 400 to 700nm.Far red light (700 to 750nm) affects plants, besides causing photosynthesis. Infrared rays of longer wavelengths are not involved in the plant process. It is primarily, the visible spectrum of light that is used in photosynthesis. In the blue and red bands, the photosynthesis activity is higher, when the blue light (shorter wavelength) alone is supplied to plants, the growth is retarded, and the plant becomes hard and dark in colour. When the plants are grown under red light (longer wavelength), growth is soft and internodes are long, resulting in tall plants. Visible light of all wavelengths is readily utilized in photosynthesis.

3.2 Temperature

Temperature is a measure of level of the heat present. All crops have temperature range in which they can grow well. Below this range, the plant life process stop due to ice formation within the tissue and cells are possibly punctured by ice crystals. At the upper extreme, enzymes become inactive, and again process essential for life cease. Enzymes are biological reaction catalyst and are heat sensitive. All biochemical reactions in the plant are controlled by the enzymes. The rate of reactions controlled by the enzyme often double or triple for each rise of temperature by 10^0C, until optimum temperature is reached. Further, increase in temperature begins to suppress the reaction and finally stop it.

As a general rule, green house crops are grown at a day temperature, which are 3 to 6^0C higher than the night temperature on cloudy days and 8^0C higher on clear days. The night temperature of green house crops is generally in the range of 7 to 21^0C. Primula, mathiola incana and calceolaria grow best at 7^0C, carnation and cineraria at 10^0C, rose at 16^0C, chrysanthemum and poinsettia at 17 to 18^0C and African violet at 21 to 22^0C.

3.3 Relative humidity

As the green house is a closed space, the relative humidity of the green house air will be more when compared to the ambient air, due to the moisture added by the evapo-transpiration process. Some of this moisture is taken away by the air leaving from the green house due to ventilation. Sensible heat inputs also lower the relative humidity of the air to some extent. In order to maintain the desirable relative humidity levels in the green houses, processes like humidification or dehumidification are carried out. For most crops, the acceptable range of relative humidity is between 50 to 80%. However for plant propagation work, relative humidity up to 90% may be desirable.

In summer, due to sensible heat addition in the daytime, and in winters for increasing the night time temperatures of the green house air, more sensible heat is added causing a reduction in the relative humidity of the air. For this purpose, evaporative cooling pads and fogging system of humidification are employed. When the relative humidity is on the higher side, ventilators, chemical dehumidifiers and cooling coils are used for de- humidification.

3.4 Ventilation

A green house is ventilated for either reducing the temperature of the green house air or for replenishing carbon dioxide supply or for moderating the relative humidity of the air. Air temperatures above 35^0C are generally not suited for the crops in green house. It is quite possible to bring the green house air temperature below this upper limit during spring and autumn seasons simply by providing adequate ventilation to the green house. The ventilation in a green house can either be natural or forced. In case of small green houses (less than 6m wide) natural ventilation can be quite effective during spring and autumn seasons. However, fan ventilation is essential to have precise control over the air temperature, humidity and carbon dioxide levels.

3.5 Carbon dioxide

Carbon is an essential plant nutrient and is present in the plant in greater quantity than any other nutrient. About 40% of the dry matter of the plant is composed of carbon. Under normal conditions, carbon dioxide (CO_2) exits as a gas in the atmosphere slightly above 0.03% or 345ppm. During the day, when photosynthesis occurs under natural light, the plants in a green house draw down the level of Co_2 to below 200ppm. Under these circumstances, infiltration or ventilation increases **carbon dioxide levels,** when the outside air is brought in, to maintain the ambient levels of CO_2. If the level of CO_2 is less than ambient levels, CO_2 may retard the plant growth. In cold climates, maintaining ambient levels of CO_2 by providing ventilation may be un-economical, due to the necessity of heating the incoming air in order to maintain proper growing temperatures. In such regions, enrichment of the green house with CO2 is followed. The exact CO_2 level needed for a given crop will vary, since it must be correlated with other variables in greenhouse production such as light, temperature, nutrient levels, cultivar and degree of maturity. Most crops will respond favorably to Co_2 at 1000 to 1200 ppm.

Lecture No.4

Equipment required for controlling green house environment – summer cooling and winter cooling, natural ventilation, forced ventilation and computers.

Precise control of various parameters of green house environment is necessary to optimize energy inputs and thereby maximize the economic returns. Basically, the objective of environmental control is to maximize the plant growth. The control of green house environment means the control of temperature, light, air composition and nature of the root medium. A green house is essentially meant to permit at least partial control of microclimate within it. Obviously green houses with partial environmental control are more common and economical. From the origin of greenhouse to the present there has been a steady evolution of controls. Five stages in this evolution include manual controls, thermostats, step-controllers, dedicated micro processors and computers. This chain of evolution has brought about a reduction in control labour and an improvement in the conformity of green house environments to their set points. The benefits achieved from green house environmental uniformity are better timing and good quality of crops, disease control and conservation of energy.

4.1 Active summer cooling systems

Active summer cooling is achieved by evaporative cooling process .The evaporative cooling systems developed are to reduce the problem of excess heat in green house. In this process cooling takes place when the heat required for moisture evaporation is derived from the surrounding environment causing a depression in its temperature. The two active summer cooling systems in use presently are fan-and pad and fog systems. In the evaporative cooling process the cooling is possible only up to the wet bulb temperature of the incoming air.

4.1.1 Fan-and Pad cooling system

The fan and pad evaporative cooling system has been available since 1954 and is still the most common summer cooling system in green houses (Fig.5). Along one wall of the green house, water is passed through a pad that is usually placed vertically in the wall. Traditionally, the pad was composed of excelsior (**wood shreds**), but today it is commonly made of a **cross-fluted-cellulose material** some what similar in appearance to corrugated card board. Exhaust fans are placed on the opposite wall. Warm outside air is drawn in through the pad. The supplied water in the pad, through the process of evaporation, absorbs heat from the air passing through the pad as well as from surroundings of the pad and frame, thus causing the cooling effect. Khus-khus grass mats can also be used as cooling pads.

4.1.2 Fog cooling system

The fog evaporative cooling system, introduced **in** green houses in 1980, operates on the same cooling principle as the fan and pad cooling system but uses quite different arrangement (Fig.5). A high pressure pumping apparatus generates fog containing water droplets with a mean size of less than 10 microns using suitable nozzles. These droplets are sufficiently small to stay suspended in air while they are evaporating. Fog is dispersed throughout the green house, cooling the air everywhere. As this system does not wet the foliage, there is less scope for disease and pest attack. The plants stay dry throughout the process. This system is equally useful for seed germination and propagation since it eliminates the need for a mist system.

Both types of summer evaporative cooling system can reduce the greenhouse air temperature. The fan-and pad system can lower the temperature of incoming air by about 80% of the difference between the dry and wet bulb temperatures while the fog cooling system can lower the temperature by nearly 100% difference. This is, due to the fact that complete evaporation of the water is not taking place because of bigger droplet size in fad and pad, whereas in the fog cooling system, there will be complete evaporation because of the minute size of the water droplets. Thus lesser the dryness of the air, greater evaporative cooling is possible.

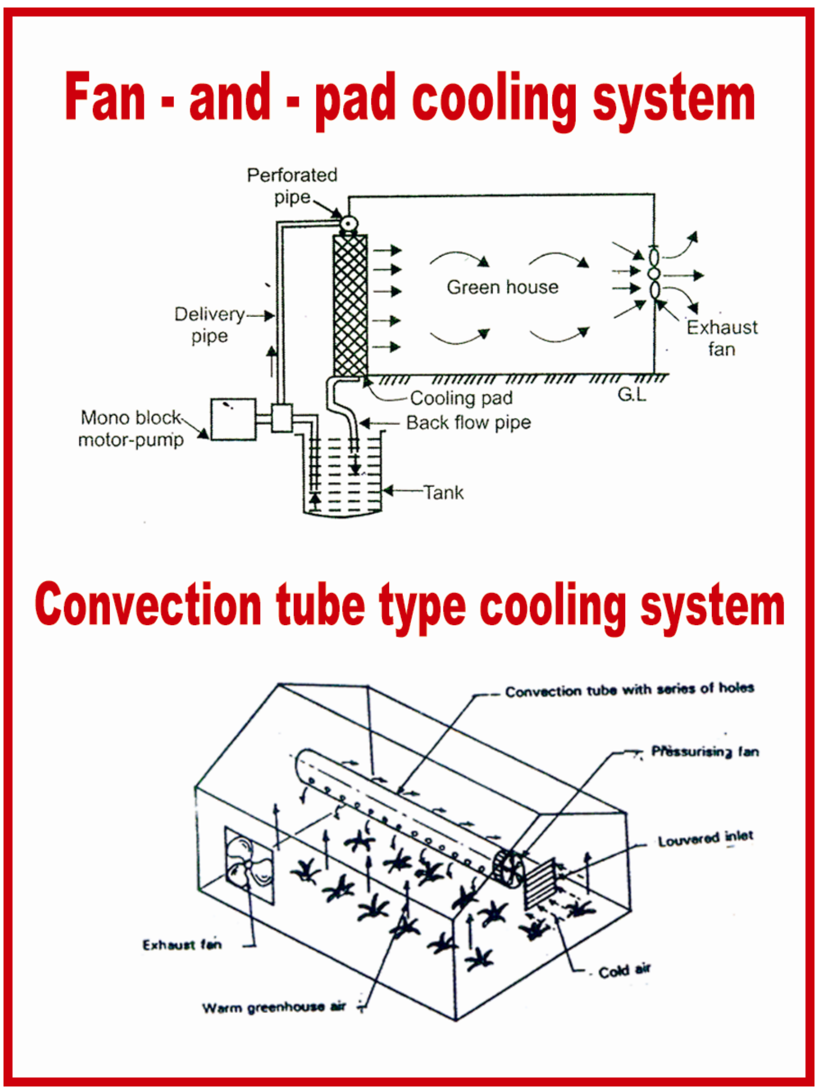


Fig. 5. Components of fan-and-pad and fog cooling systems in a greenhouse

4.2 Active winter cooling systems

Excess heat can be a problem during the winter. In the winter, the ambient temperature will be below the desired temperature inside the green house. Owing to the green house effect the entrapment of solar heat can rise the temperature to an injurious level if the green house is not ventilated. The actual process in winter cooling is tempering the excessively cold ambient air before it reaches the plant zone. Otherwise, hot and cold spots in the green house will lead to uneven crop timing and quality .This mixing of low temperature ambient air with the warm inside air cools the green house in the winter. Two active winter cooling systems commonly employed are convection tube cooling and horizontal air flow (HAF) fan cooling systems.

4.2.1 Convection tube cooling

The general components of convection tube are the louvered air inlet, a polyethylene convection tube with air distribution holes, a pressurizing fan to direct air in to the tube under pressure, and an exhaust fan to create vacuum. When the air temperature inside the green house exceeds the set point, the exhaust fan starts functioning thus creating vacuum inside the green house. The louver of the inlet in the gable is then opened through which cold air enters due to the vacuum. The pressurizing fan at the end of the clear polyethylene convection tube, operates to pick up the cool air entering the louver. A proper gap is available for the air entry, as the end of the convection tube is separated from the louvered inlet by 0.3 to 0.6m and the other end of the tube is sealed. Round holes of 5 to 8 cm in diameter are provided in pairs at opposite sides of the tube spaced at 0.5 to 1m along the length of the tube.

Cold air under pressure in the convection tube shoots out of holes on either side of the tube in turbulent jets. In this system, the cold air mixes with the warm greenhouse air well above the plant height. The cool mixed air, being heavier gently flows down to the floor level, effects the complete cooling of the plant area. The pressurizing fan forcing the incoming cold air in to the convection tube must be capable of moving at least the same volume of air as that of the exhaust fan, thereby avoiding the development of cold spots in the house. When cooling is not required, the inlet louver closes and the pressurizing fan continues to circulate the air within the greenhouse. The process minimizes the temperature gradient at difference levels. The circulation of air using convection tube consumes more power than a circulation system.

4.2.2 Horizontal air flow cooling

HAF cooling system uses small horizontal fans for moving the air mass and is considered to be an alternative to convection tube for the air distribution. In this method the green house may be visualized as a large box containing air and the fans located strategically moves the air in a circular pattern. This system should move air at 0.6 to 0.9 $m^3/min/m^2$ of the green house floor area. Fractional horse power of fans is 31 to 62 W (1/30 to 1/15hp) with a blade diameter of 41cm are sufficient for operation. The fans should be arranged in such a way that air flows are directed along the length of the greenhouse and parallel to the ground. The fans are placed at 0.6 to 0.9m above plant height and at intervals of 15m.They are arranged such that the air flow is directed by one row of the fans along the length of the greenhouse down one side to the opposite end and then back along the other side by another row of fans (Fig. 6). Greenhouses of larger widths may require more number of rows of fans along its length.

Temperatures at plant height are more uniform with HAF system than with convection tube system. The HAF system makes use of the same exhaust fans, inlet louvers and controls as the convection tube system. The only difference is the use of HAF fans in the place of convection tubes for the air distribution. Cold air entering through the louvers located at the higher level in the gables of the green house is drawn by the air circulation created by the net work of HAF fans and to complete the cycle, proper quantity of air is let out through the exhaust fans. The combined action of louvered inlet, HAF fans and the exhaust fans distribute the cold air throughout the greenhouse.

Similarly to the convection tubes, the HAF fans can be used to distribute heat in the green house When neither cooling nor heating is required, the HAF fans or convection tube can be used to bring warm air down from the upper level of the gable and to provide uniform temperature in the plant zone. It is possible to integrate summer and winter cooling systems with heating arrangements inside a green house for the complete temperature control requirements for certain days of the season.

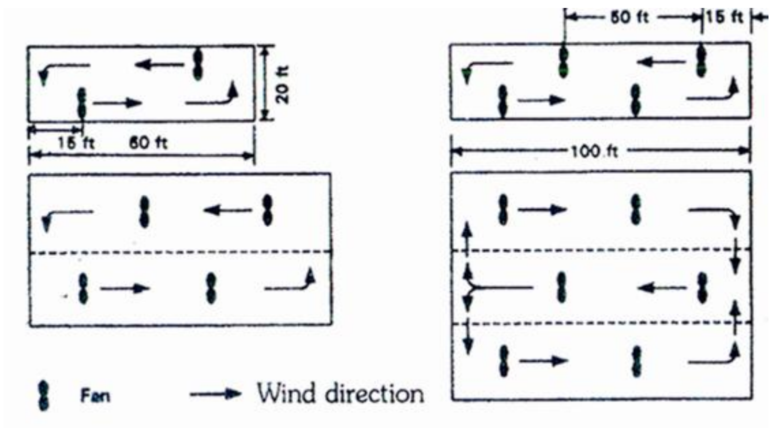


Fig. 6. HAF system in different sizes of greenhouses

4.3 Green house ventilation

Ventilation is the process of allowing the fresh air to enter in to the enclosed area by driving out the air with undesirable properties. In the green house context, ventilation is essential for reducing temperature, replenishing COo_2 and controlling relative humidity. Ventilation requirements for green houses vary greatly, depending on the crop grown and the season of production. The ventilation system can be either a passive system (natural Ventilation) or an active system (forced ventilation) using fans. Usually green houses that are used seasonally employ natural ventilation only. The plant response to specific environment factor is related to the physiological processes and hence the latter affects the yield and quality. Hence, controlling of environment is of great importance to realize the complete benefit of CEA. Manual maintenance of uniform environmental condition inside the green house is very difficult and cumbersome. A poor maintenance results in less crop production, low quality and low income. For effective control of automatic control systems like micro processor and computer are used presently to maintain the environment.

4.3.1 Natural ventilation

In the tropics, the sides of greenhouse structures are often left open for natural ventilation. Tropical greenhouse is primarily a rain shelter, a cover of polyethylene over the crop to prevent rainfall from entering the growing area. This mitigates the problem of foliage diseases. Ventilators were located on both roof slopes adjacent to the ridge and also on both side walls of the greenhouse. The ventilators on the roof as well as those on the side wall accounts, each about

10% of the total roof area. During winter cooling phase, the south roof ventilator was opened in stages to meet cooling needs. When greater cooling was required, the north ventilator was opened in addition to the south ventilator. In summer cooling phase, the south ventilator was opened first, followed by the north ventilator. As the incoming air moved across the greenhouse, it was warmed by sunlight and by mixing with the warmer greenhouse air. With the increase in temperature, the incoming air becomes lighter and rises up and flows out through the roof ventilators. This sets up a chimney effect (Fig. 7), which in turn draws in more air from the side ventilators creating a continuous cycle. This system did not adequately cool the greenhouse. On hot days, the interior walls and floor were frequently injected with water to help cooling.

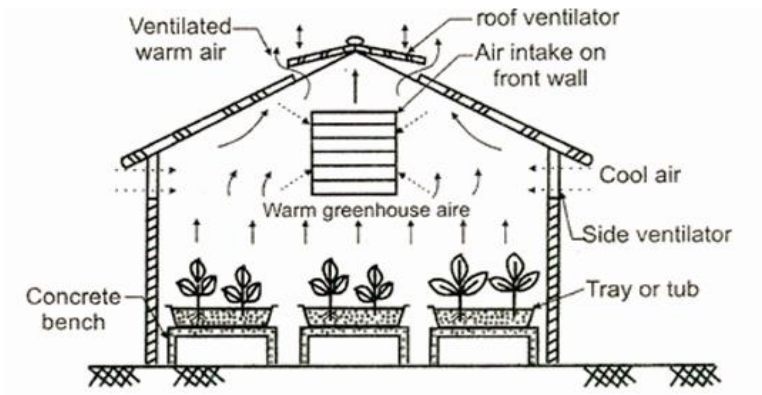


Fig. 7. **Chimney effect in general passive ventilation**

4.3.1.1 Roll up side passive ventilation in poly houses

In roll up method of ventilation, allowing the air to flow across the plants. The amount of ventilation on one side, or both sides, may be easily adjusted in response to temperature, prevailing wind and rain (Fig.8). During the periods of excessive heat, it may be necessary to roll the sides up almost to the top. Passive ventilation can also be accomplished by manually raising or parting the polyethylene sheet. The open vent areas must be covered with screens to prevent virus diseases. The holes must be large enough to permit free flow of air. Screens with small holes blocks air movement and cause a build up of dust. Rollup side passive ventilation on plastic greenhouses is only effective on free standing greenhouses and not on gutter connected greenhouses.

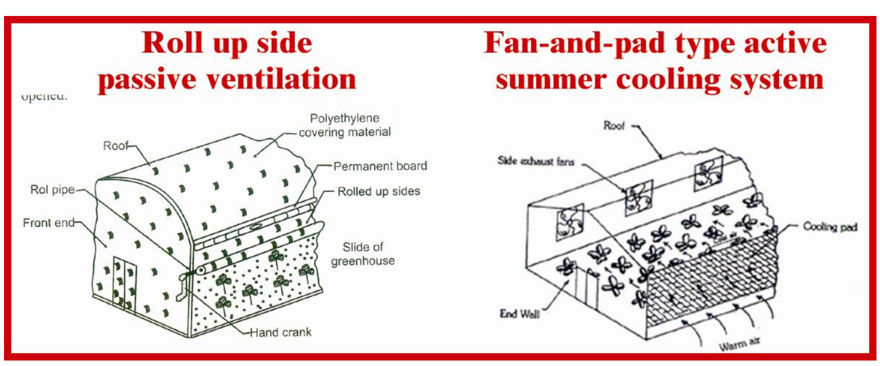


Fig. 8. Roll up side passive ventilation and fan-and-pad cooling system

4.3.2 Forced Ventilation

In forced or active ventilation, mechanical devices such as fans are used to expel the air. This type of ventilation can achieve uniform cooling. These include summer fan-and-pad and fog cooling systems and the winter convection tube and horizontal airflow systems. For mechanical ventilation, low pressure, medium volume propeller blade fans, both directly connected and belt driven are used for greenhouse ventilation. They are placed at the end of the green house opposite to the air intake, which is normally covered by gravity or motorized louvers. The fans vents, or louvers, should be motorized, with their action controlled by fan operation. Motorized louvers prevent the wind from opening the louvers, especially when heat is being supplied to the green house. Wall vents should be placed continuously across the end of the greenhouse to avoid hot areas in the crop zone.

Evaporative cooling in combination with the fans is called as fan-and-pad cooling system. The fans and pads are usually arranged on opposite walls of the greenhouse (Fig.8). The common types of cooling pads are made of excelsior (wood fiber), aluminum fiber, glass fiber, plastic fiber and cross-fluted cellulose material. Evaporative cooling systems are especially efficient in low humidity environments. There is growing interest in building greenhouses combining both passive (natural) and active (forced) systems of ventilation. Passive ventilation is utilized as the first stage of cooling, and the fan-pad evaporative cooling takes over when the passive system is not providing the needed cooling. At this stage, the vents for natural ventilation are closed. When both options for cooling are designed in greenhouse construction, initial costs of installation will be more. But the operational costs are minimized in the long run, since natural ventilation will, most often meet the needed ventilation requirements.

Fogging systems is an alternative to evaporative pad cooling. They depend on absolutely clean water, Free of any soluble salts, in order to prevent plugging of the mist nozzles. Such cooling systems are not as common as evaporative cooling pads, but when they become more cost competitive, they will be adopted widely. Fogging systems are the second stage of cooling when passive systems are inadequate.

4.3.3 Microprocessors

Dedicated microprocessors can be considered as simple computers. A typical microprocessor will have a keypad and a two or three line liquid crystal display of, sometimes, 80-character length for programming. They generally do not have a floppy disk drive. They have more output connections and can control up to 20 devices. With this number of devices, it is cheaper to use a microprocessor. They can receive signals of several types, such as, temperature, light intensity, rain and wind speed. They permit integration of the diverse range of devices, which is not possible with thermostats. The accuracy of the microprocessor for temperature control is quite good. Unlike a thermostat, which is limited to a bimetallic strip or metallic tube for temperature sensing and its mechanical displacement for activation, the microprocessor often uses a thermistor. The bimetallic strip sensor has less reproducibility and a greater range between the ON and OFF steps. Microprocessors can be made to operate various devices, for instance, a microprocessor can operate the ventilators based on the information from the sensor for the wind direction and speed. Similarly a rain sensor can also activate the ventilators to prevent the moisture sensitive crop from getting wet. A microprocessor can be set to activate the CO_2 generator when the light intensity exceeds a given set point, a minimum level for photosynthesis.

4.3.4 Computers

Now-a-days, computer control systems are common in greenhouse installation throughout Europe, Japan and the United States. Computer systems can provide fully integrated control of temperature, humidity, irrigation and fertilization, CO_2, light and shade levels for virtually any size growing facility. Precise control over a growing operation enables growers to realize saving of 15 to 50% in energy, water, chemical and pesticide applications. Computer controls normally help to achieve greater plant consistency, on-schedule production, higher overall plant quality and environmental purity.

A computer can control hundreds of devices within a green house (vents, heaters, fans, hot water mixing valves, irrigation valves, curtains and lights) by utilizing dozens of input parameters, such as outside and inside temperatures, humidity, outside wind direction and velocity, CO_2 levels and even the time of the day or night. Computer systems receive signals from all sensors, evaluate all conditions and send appropriate commands every minute to each piece of equipment in the greenhouse range thus maintaining ideal conditions in each of the various independent greenhouse zones defined by the grower (Fig.9). Computers collect and record data provided by greenhouse production managers. Such a data acquisition system will enable the grower to gain a comprehensive knowledge of all factors affecting the quality and timeliness of the product. A computer produces graphs of past and current environmental conditions both inside and outside the greenhouse complex. Using a data printout option, growers can produce reports and summaries of environmental conditions such as temperature, humidity and the CO_2 status for the given day, or over a longer period of time for current or later use.

As more environmental factor in the greenhouse is controlled, there comes a stage when individual controls cannot be coordinated to prevent system overlap. An example is the greenhouse thermostat calling for heating while the exhaust fans are still running. With proper software program, which uses the environmental parameters as input from different sensors, can effectively coordinate all the equipment without overlap and precisely control all parameters affecting plant development as desired. Despite the attraction of the computer systems, it should be remembered that the success of any production system is totally dependent on the grower's knowledge of the system and the crop management. Computers can only assist by adding precision to the overall greenhouse production practice, and they are only as effective as the software it runs and the effectively of the operator. The advantages and disadvantages of computerized control system are as follows:

Advantages

1. The computer always knows what all systems are doing and, if programmed properly, can coordinate these systems without overlap to provide the optimum environment.

2. The computer can record the environmental data, which can be displayed to show current conditions or stored and processed ones to provide a history of the cropping period, and if desired it may also be displayed in table or graph form.

3. A high-speed computer with networking facility can control several remotely located greenhouses, by placing the computer in a central area and the results can be monitored frequently by the management.

4. With proper programming and sensing systems, the computer can anticipate weather changes and make adjustments in heating and ventilation systems, thus saving the energy.

5. The computer can be programmed to sound an alarm if conditions become unacceptable to and to detect sensor and equipment failure.

Disadvantages

1. High initial cost investment.
2. Requires qualified operators.
3. High maintenance, care and precautions are required.
4. Not economical for small scale and seasonal production.

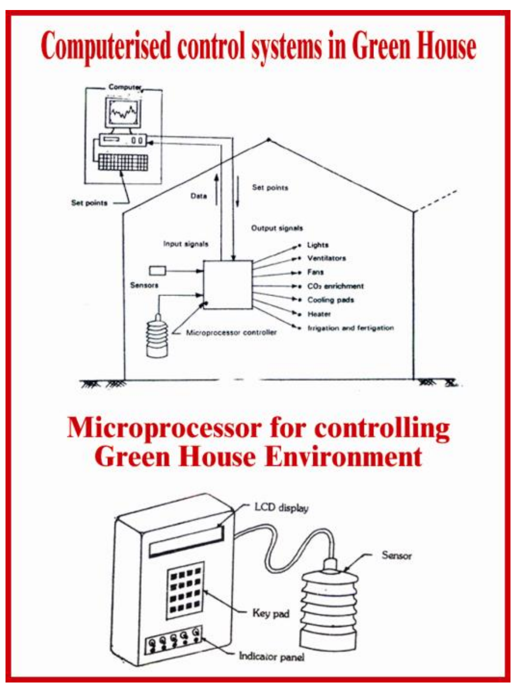


Fig. 9. Computerized control system and microprocessor for greenhouse

Lecture No.5

Planning of green house facility - site selection and orientation, structural design and covering materials.

A greenhouse, is basically the purpose of providing and maintaining a growing environment that will result in optimum production at maximum yield. The agriculture in the controlled environment is possible in all the regions irrespective of climate and weather.

It is an enclosing structure for growing plants, greenhouse must admit the visible light portion of solar radiation for the plant photosynthesis and, there fore, must be transparent. At the same time, to protect the plants, a greenhouse must be ventilated or cooled during the day because of the heat load from the radiation. The structure must also be heated or insulated during cold nights. A greenhouse acts as a barrier between the plant production areas and the external or the general environment.

5.1 Site selection and orientation

A greenhouse is designed to withstand local wind, snow and crop loads for a specific cropping activity. In this way, the structure becomes location and crop specific. The building site should be as level as possible to reduce the cost of grading, and the site should be well aerated and should receive good solar radiation. Provision of a drainage system is always possible. It is also advisable to select a site with a natural windbreak. In regions where snow is expected, trees should be 30.5 m away in order to keep drifts back from the greenhouses. To prevent shadows on the crop, trees located on the east, south, or west sides should be at a distance of 2.5 times their height.

5.2 Structural design

The most important function of the greenhouse structure and its covering is the protection of the crop against hostile weather conditions (low and high temperatures, snow, hail, rain and wind), diseases and pests. It is important to develop greenhouses with a maximum intensity of natural light inside. The structural parts that can cast shadows in the greenhouse should be minimized.

The different structural designs of greenhouse based on the types of frames are available. A straight side wall and an arched roof is possibly the most common shape for a greenhouse, but the gable roof is also widely used**.** Both structures can be free standing or gutter connected with the arch roof greenhouse. The arch roof and hoop style greenhouses are most often constructed of galvanized iron pipe. If tall growing crops are to be grown in a greenhouse or when benches are used, it is best to use a straight side wall structure rather than a hoop style house, this ensures the best operational use of the greenhouse. A hoop type greenhouse is suitable for low growing crops, such as lettuce, or for nursery stock which are housed throughout the winter in greenhouses located in extremely cold regions. A gothic arch frame structure can be designed to provide adequate side wall height without loss of strength to the structure (Fig.10).

Loads in designing the greenhouse structures include the weight of the structure itself and, if supported by the structure, loads of the equipment for the heating and ventilation and water lines. Greenhouse structures should be designed to resist a 130 km/h wind velocity. The actual load depends on wind angle, greenhouse shape and size, and the presence or absence of openings and wind breaks.

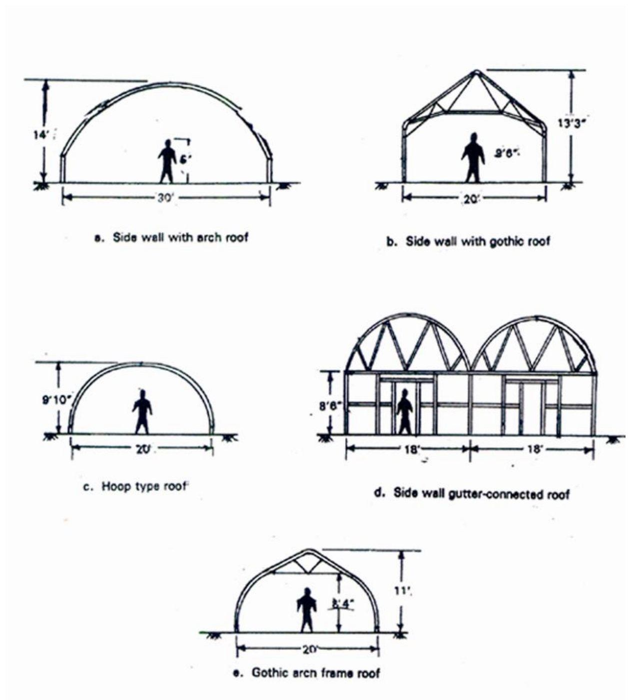


Fig.10. Structural designs of different greenhouse frameworks

The ultimate design of a greenhouse depends on the following aspects:

(i) The overall structural design and the properties of the individual structural components.

(ii) The specific mechanical and physical properties which determine the structural behaviour of the covering materials.

(iii) The specific sensitivity of the crop to light and temperature to be grown in the greenhouse.

(iv) The specific requirements relevant to the physical properties of the covering material.

(v) The agronomic requirements of the crop.

5.3 Covering materials

The following factors are to be considered while selecting the greenhouse covering material i.e., light, transmission, weight, resistant to impact, and durability to outdoor weathering and thermal stability over wide range of temperatures. Before selecting the covering material, two important points should be taken into consideration: the purpose for which greenhouse facility is intended and service life of material. In temperate regions where high temperatures are required, the covering material with high light transmission and far IR absorption must be selected. Also the loss of heat by conduction should be minimum.

Covering material	**Life span**
1. Glass and acrylic sheet	20 years
2. Polycarbonate and fiberglass-reinforced polyester sheet	5-12 years
3. Polyethylene	2-6 months
4. Polyethylene stabilized for UV rays	2-3 years

The ideal greenhouse selective covering material should have the following properties:

(i) It should transmit the visible light portion of the solar radiation which is utilized by plants for photosynthesis.

(ii) It should absorb the small amount of UV in the radiation and convert a portion of it to fluoresce into visible light, useful for plants.

(iii) It should reflect or absorb IR radiation which are not useful to plants and which causes greenhouse interiors to overheat.

(iv) Should be of minimum cost.

(v) Should have usable life of 10 to 20 years.

Lecture No.6

Materials for construction of green houses - wood, galvanized iron, glass, polyethylene film, poly vinyl chloride film, Tefzel T^2 film, fiberglass reinforced plastic rigid panel and acrylic and polycarbonate rigid panel.

The following materials commonly used to build frames for greenhouse are (i) Wood, (ii) Bamboo, (iii) Steel, (iv) Galvanized iron pipe, (v) Aluminum and (vi) Reinforced concrete (RCC). The selection of above materials was based on their Specific physical properties, requirements of design strength, life expectancy and cost of construction materials.

6.1 Wood

Wood and bamboo are generally used for low cost polyhouses. In low cost polyhouses, the wood is used for making frames consisting of side posts and columns, over which the polythene sheet is fixed. The commonly used woods are pine and casuarina, which are strong and less expensive. In pipe-framed polyhouses, wooden battens can be used as end frames for fixing the covering material. In tropical areas, bamboo is often used to form the gable roof of a greenhouse structure. Wood must be painted with white colour paint to improve light conditions within the greenhouse. Care should be taken to select a paint that will prevent the growth of mold. Wood must be treated for protection against decay. Chromated copper arsenate and ammonical copper arsenate are water based preservatives that are applied to the wood that may come into contact with the soil. Red wood or cypress (natural decay resistance woods) can be used in desert or tropical regions, but they are expensive.

6.2 Galvanised iron (GI), aluminum, steel and reinforced cement concrete

GI pipes, tubular steel and angle iron are generally used for side posts, columns and purlins in greenhouse structure, as wood is becoming scarce and more expensive. In galvanising operation, the surface of iron or steel is coated with a thin layer of zinc to protect it against corrosion. The commonly followed processes to protect against corrosion are:

(i) Hot dip galvanising (hot process) process: The cleaned member is dipped in molten zinc, which produces a skin of zinc alloy to the steel.

(ii) Electro-galvanising (cold process) process: The cleaned member is zinc plated similar to other forms of electro-plating

The galvanising process makes the iron rust proof, to eliminate the problem of rusting of structural members. Aluminum and hot dipped GI are comparatively maintenance free. In tropical areas, double dipping of steel is required, as single dip galvanising process does not give a complete cover of even thickness to the steel. Aluminum and steel must be protected by painting with bitumen tar**,** to protect these materials from corrosion, while these materials contact with the ground. Now-a-days, the greenhouse construction is of metal type, which is more permanent. RCC is generally limited to foundations and low walls. In permanent bigger greenhouses, floors and benches for growing the crops are made of concrete.

6.3 Glass

Glass has been traditional glazing material all over the world. Widely used glass for greenhouse are: (i) Single drawn or float glass and (ii) Hammered and tempered glass. Single drawn or float glass has the uniform thickness of 3 to 4 mm. Hammered and tempered glass has a thickness of 4 mm. Single drawn glass is made in the traditional way by simply pulling the molten glass either by hand or by mechanical equipment. Float glass is made in modern way by allowing the molten glass to float on the molten tin. Coating with metal oxide with a low emissivity is used for saving of energy with adequate light transmittance. Hammered glass is a cast glass with one face (exterior) smooth and the other one (interior) rough. It is designed to enhance light diffusion. This glass is not transparent, but translucent. Tempered glass is the glass, which is quickly cooled after manufacture, adopting a procedure similar to that used for steel. This kind of processing gives higher impact resistance to the glass, which is generally caused by hail. Glass used as a covering material of greenhouses, is expected to be subjected to rather severe wind loading, snow and hail loading conditions. The strength mainly depends on the length/width ratio of the panel and on the thickness of the panel, but the most widely used thickness is 4 mm.

6.4 Polyethylene film

Polyethylene is principally used today for two reasons- (i) Plastic film greenhouses with permanent metal frames cost less than glass greenhouses and (ii) Plastic film greenhouses are popular because the cost of heating them is approximately 40% lower compared to single-layer glass or fiberglass-reinforced plastic greenhouses. The disadvantages are **:** these covering materials are short lived compared to glass and plastic panels. UV light from the sun causes the plastic to darken, thereby lowering transmission of light, also making it brittle, which leads to its breakage due to wind. A thermal screen is installed inside a glass greenhouse that will lower the heat requirement to approximately that of a double-layer plastic film greenhouse, but this increases the cost of the glass greenhouse. Polyethylene film was developed in the late 1930s in England and spread around the middle of this century. Commonly used plastic for greenhouse coverings are thermoplastics. Basic characteristics of thermoplastics are: (i) thermoplastics consists of long chain molecules, soften with heating and harden with cooling and this process is reversible and (ii) thermoplastics constitute a group of material that are attractive to the designer for two main reasons: (a) Thermoplastics have the following specific physical properties- stiffness, robustness and resilience to resist loads and deformations imposed during normal use and (b) It can readily be processed using efficient mass production techniques, result in low labour charge.

The main reason to use polyethylene year round for greenhouse covering is due to presence of UV-inhibitor in it. Otherwise it lasts for only one heating season. UV-inhibited plastic cover may last for a period of 4 to 5 years. UV-grade polyethylene is available in widths up to 15.2 m in flat sheets and up to 7.6 m in tubes. Standard lengths include 30.5, 33.5, 45.7, 61 and 67 m. Some companies provide custom lengths upto a max. of 91.5 m. Condensation on ploythene film is a big problem. Condensation causes disease development, development of water logged condition and oxygen deficient inside the greenhouse. Condensation reduces light intensity within the greenhouse. To avoid this problem, anti-fog surfactant, which discourages condensation, is built into the film or panel. Warm objects, such as plants, the greenhouse frame and soil radiate IR energy to colder bodies at night, which result in loss of heat in greenhouse. Since polyethylene is a poor barrier to radiant heat, it is formulated with IR-blocking chemicals into it during manufacture, will stop about half of the radiant heat loss. On cold and clear nights, as much as 25% of the total heat loss of a greenhouse can be prevented in this way and on cloudy nights only 15% is prevented. UV-stabilised polyethylene, on an average, transmits about 87% of photosynthetically active radiation (PAR) into the greenhouse. IR absorbing polyethylene, reduces radiant heat loss, transmits about 82% of photosynthetically active radiation (PAR) into the greenhouse. The amount of light passing through two layers of a greenhouse covering is approximately the square of the decimal fraction of the amount passing through one layer. Eg. When 87% passes through one layer of UV-inhibited polyethylene, only 76% (0.87 x 0.87) passes through two layers**.** Similarlly, when 82% passes through one layer of IR-absorbing polyethylene, only 67% (0.82 x 0.82) passes through two layers.

6.5 Polyvinyl chloride film (PVC films)

PVC films are UV light resistant vinyl films of 0.2 to 0.3 mm and are guaranteed for 4 to 5 years respectively. The cost of 0.3 mm vinyl film is three times that of 0.15 mm polyethylene. Vinyl film is produced in rolls upto 1.27 m wide. Vinyl films tend to hold a static electrical charge, which attracts and holds dust. This in turn reduces light transmittance unless the dust is washed off. Vinyl films are seldom used in the United States. In Japan, 95% of greenhouses are covered with plastic film, out of which 90% are covered with vinyl film.

6.6 Tefzel T^2 film

The most recent addition of greenhouse film plastic covering is Tefzel T^2 film (ethylene tetrafluoroethylene). Earlier, this film was used as covering on solar collectors. Anticipated life expectancy is 20 years. The light transmission is 95% and is greater than that of any other greenhouse covering material. A double layer has a light transmission of 90% (0.95 x 0.95). Tefzel T^2 film is more transparent to IR radiation than other film plastics. Hence, less heat is trapped inside the greenhouse during hot weather. As a result, less cooling energy is required. Disadvantage is that, the film is available only in 1.27 m wide rolls. This requires clamping rails on the greenhouse for every 1.2 m. If reasonable width strips become available, the price is not a problem, because a double layer covering will still cost less than a polycarbonate panel covering with its aluminum extrusions, and will last longer, and will have much higher light intensity inside the greenhouse.

6.7 Polyvinyl chloride rigid-panel

Initially, PVC rigid panels showed much promise as an inexpensive covering material (almost 40% of cost of long lasting fiberglass reinforced plastics), has the life of 5 years. After commercial application, these panels indicated that the life expectancy was much shorter, less than 2 years. This is undesirable factor, because the cost of PVC panels was 4 to 5 times that of polyethylene film and they required much more time to install. Now-a-days, PVC rigid panels are not in use.

6.8 Fiberglass-reinforced plastic (FRP) rigid panel

FRP was more popular as a greenhouse covering material in the recent past. Advantage of FRP is that it is more resistant to breakage by factors, such as hail or vandals. Sunlight passing through FRP is scattered by the fibers in the panels, as a result the light intensity is rather uniform throughout the greenhouse in comparison with a glass covering. Disadvantages with these are the panels subjected to etching and pitting by dust abrasion and chemical pollution. Based on the grade, the usable life period of FRP panel varies. Some grades give 5 to 10 years, while better grades can last up to 20 years. FRP panels are flexible enough to conform to the shape of quonset greenhouses, which make FRP a very versatile covering material. FRP can be applied to the inexpensive frames of plastic film greenhouses or to the more elaborate frames of glass type greenhouses. The price of FRP greenhouse lies between that of a plastic film greenhouse and that of a glass greenhouse. But the cost is compensated by the elimination of the need for replacement of film plastic in every year or alternate years. Corrugated panels were used because of their greater strength. Flat panels are used occasionally for the end and side walls, where the load is not great. It is available in 1.3 m width, length up to 7.3 m and in a variety of colours. The total quantity of light transmitted through clear FRP is approximately equivalent to that transmitted through glass, but diminishes in relation its colour. For greenhouse crops in general, only clear FRP permits a satisfactory level of light transmission (88 to 90%). Coloured FRP has found a limited use in greenhouses intended for growing houseplants that require low light intensity and in display greenhouses for holding plants during the sales period. FRP has advantage over glass is that, it cools easily. FRP greenhouses require fewer structural members since sash bars are not needed.

6.9 Acrylic and polycarbonate rigid-panel

These panels have been available for about 15 years for greenhouse use. The panels have been used for glazing the side and end walls of plastic film greenhouses and retrofitting old glass greenhouse. Acrylic panels are highly inflammable, where as polycarbonate panels are non-flammable. Acrylic panels are popular due to their higher light transmission and longer life. Acrylic panels are available in thickness of 16 and 18 mm, and have 83% of PAR light transmission. Acrylic panels cannot be bent, but the thinner panels can be bent to fit curved-proof greenhouses. These panels are also available with a coating to prevent condensation drip. Polycarbonate panels are preferred for commercial greenhouses due to lower price, flame resistance and greater resistance to hail damage. Polycarbonate panels are available in thickness of 4,6, 8, 10 and 16 mm. These panels are also available with a coating to prevent condensation drip and also with an acrylic coating for extra protection from UV light.

Lecture No.7

Design criteria and constructional details of greenhouses - construction of pipe framed greenhouses, material requirement, preparation of materials and procedure of erection.

The term greenhouse refers to a structure covered with a transparent material for the purpose of admitting natural light for plant growth. Two or more greenhouses in one location are referred to as a greenhouse range. A building associated with the greenhouses that is used for storage or for operations in support of growing of plants, is referred to as a service building or head house.

7.1 Design criteria of construction

For locating the greenhouse, a piece of land larger than the grower's immediate need should be acquired. The ultimate size of the greenhouse range should be estimated. Area should then be added to this estimated figure to accommodate service buildings, storage, access drives and a parking lot. The floor area of service buildings required for small firms is about 13% of the greenhouse floor area, and it decreases with the increase in size of the firm. On an average, service buildings occupy 10% of the growing area. The service building is centrally located in a nearly square design of the firm, which minimizes distance of movement of plants and materials. Doors between the service buildings and the greenhouse should be wide enough to facilitate full use of the corridor width. Doors at least 3.1 m wide and 2.7 m high are common. It is good to have the greenhouse gutter at least 3.7 m above the floor to accommodate automation and thermal blanket and still leave the room for future innovations.

7.2 Construction of glass greenhouses

Glass greenhouses have an advantage of greater interior light intensity over plastic panel and film plastic covered greenhouses. Glass greenhouses tend to have a higher air infiltration rate, which leads to lower interior humidity, which is advantageous for disease prevention. On the other hand, glass greenhouses have a higher initial cost than double-layer film plastic greenhouses. While comparing the price of a glass greenhouse to a film plastic greenhouse, one needs to take into account the initial purchase price of each as well as the cost of re-covering the film plastic greenhouse every three to four years.

Several types of glass greenhouses are designed to meet specific needs. A lean-to-type design is used when a greenhouse is placed against the side of an existing building. This design makes the best use of sunlight and minimizes the requirements for roof supports. It is found mostly in the retail industry. An even-span greenhouse is one in which the two roof slopes are of equal pitch and width. By comparison, a un-even-span greenhouse has roofs of unequal width, which makes the structure adaptable to the side of a hill. This style is seldom used today because such greenhouses are not adaptable to automation. Finally, a ridge-and-furrow design uses, two or more A- frame greenhouses connected to one another along the length of the eave. The sidewall is eliminated between greenhouses, which results in a structure with a single large interior. Basically, three frame types are used in glass greenhouses, which are wood frames (6.1 m in width), pipe frames (12.2 m in width) and truss frames (15.2 m in width). Latest glass greenhouses are primarily of the truss frame type. Truss frame greenhouses are best suited for prefabrication.

All-metal greenhouses proved cheaper to maintain since they required no painting. At present, virtually all glass greenhouse construction is of the metal type. The structural members of the glass greenhouse cast shadows that reduce plant growth during the dark months of the year. Aluminum sash bars are stronger than wooden ones; hence wider panels of glass can be used with aluminum bars. The reduction in materials and the reflectance of aluminum have given these metal greenhouses a great advantage over wooden greenhouses in terms of higher interior light intensity.

Glass greenhouse construction of today can be categorized as high profile or low profile. The low profile greenhouse is most popular in the Netherlands and is known as the Venlo greenhouse. The low profile greenhouses uses single panels of glass extend from eave to ridge. The low profile greenhouse slightly reduces exposed surface area, thereby reducing the heating cost, but more expensive to cool. The high profile greenhouses require more than single panel to cover the eave to ridge. A problem with this design is the unsealed junction between pieces of glass in the inner layer. Moisture and dust may enter between the layers and reduce light transmission.

7.3 Construction of pipe framed greenhouses

The choice of construction of pipe framed greenhouses often favours low initial investment and relatively long life. Galvanized mild steel pipe as a structural member in association with wide width UV- stabilized low density polyethylene (LDPE) film is a common option of greenhouse designers.

7.3.1 Material requirement

The structural members of greenhouse are

(a) hoops

(b) foundation

(c) lateral supports

(d) polygrip assembly

(e) end frame

The following materials are required for a greenhouse having 4m × 20 m floor area:

(i) GI pipe class A (25 mm diameter, 85 cm long, 30 m total length)

(ii) GI pipe class B (15 mm diameter, 6.0 m long, 21 No.s)

(iii) GI sheet (20 gauge, size 90 ×24 cm, 4 sheets)

(iv) MS flat (25 × 3 mm size, 4 m length)

(v) Lateral support to end frames (10 mm diameter rod, 10 m length)

(vi) Cement concrete (1: 3: 6 mix, 1.0 m^3)

(vii) UV- stabilized LDPE film (single layer 800 gauge, 5.4 m^2/kg, 154 m^2)

(viii) Polygrip (channel 2000×3.5×4 cm, 2 No.s; Angle 2000×2×2 cm, 2 No.s; both made from the procured 20 gauge GI sheet, key 6 mm diameter, 56 mm length)

(ix) Wooden end frames (5 × 5 cm wood, 0.15 m^3)

(x) Nuts and bolts 9 6 mm diameter, 35 mm long, 70 sets)

(xi) Miscellaneous items like nails, hinges and latches as per requirement

7.3.2 Procedure of erection

(1) A 4m by 20m rectangular area is marked on the site, preferably orienting the longer dimension in east-west direction. This rectangle will act as the floor plan of the greenhouse (Fig.11).

(2). Mark four points on the four corners of the rectangle.

(3) Start from one corner point and move along the length of marked rectangle, marking a point every 1.25 m distance until reaching the other corner (16 bays; 17 points). The same procedure is repeated on the other side of the rectangle.

(4). Dig 10 cm diameter holes upto 70 cm depth on all marked points with the help of bucket auger (or) a crowbar. This way a total of 34 holes on both the parallel sides of the greenhouse floor is obtained.

(5) Polygrip sections formed according to the drawing into two 20m length.

(6). Fix the prefabricated polygrip channels to the foundation pipes on 1.25 m spacing with the help of 6 mm diameter bolts.

(7). Set these assemblies on temporary supports between the holes with the foundation pipes hanging vertically in the holes.

(8). Pour cement concrete mix of 1: 3 : 6 around foundation pipes in such a way that the lower 15 cm to 20 cm ends are covered in concrete. The concrete is compacted around the foundation pipes with the help of the crowbar and is allowed to cure for 2-3 days.

(9) After curing, fill the soil around the foundation pipes to the ground level and compact it well.

(10). Position end frames on the two ends. Mark the position of legs and dug holes for fixing of legs. Now install both the end frames.

(11). Put the ringside of lateral support members on adjacent foundation pipe to the corner, and other side is hooked to the end frame.

(12). Put all the hoops in the foundation pipes in such away that straight portion of hoop is inserted into the foundation and rests on the bolt used for fixing of polygrip channel .

(13). Take a 20 m long ridge line by spacing 15 mm diameter pipes together. Put the 20m long pipe at the ridge line of the hoops.

(14) Use cross connectors on the ridge line pipe, in such a way that one half of it remains on the one side of the hoop and the other half on the other side.

(15) Put two bolts of 6 mm diameter in the holes provided in the ends of cross-connector. Tie a few of them with the help of nuts.

(16) Repeat the same procedure for joining all the hoops with ridge line pipe.

(17) While forming cross-connectors, the distance between the cross-connectors or hoops should be maintained 1.25 m center to center. This poly grip mechanism will provide a firm grip of the ridge line pipe and hoops at right angles without allowing for slippage.

(18) Spread polyethylene film over the structure from one end to the other end without wrinkles and keeping the edges together.

(19) Place polyethylene film between the polygrip channel and right angle strip and secure them under pressure with the help of iron rods. The film is stretched gently and fixed on the other parallel side by polygrip. This way the polyethylene is secured on both the longer sides.

(20) On the other two remaining ends, polyethylene is nailed to the end frames using wooden battens and nails.

(21) The remaining portion of the end frames is covered with polyethylene film, which is secured with wooden battens and nails.

(22) Mechanical ventilation, heating and cooling equipment is installed on the frames as per the crop requirement.

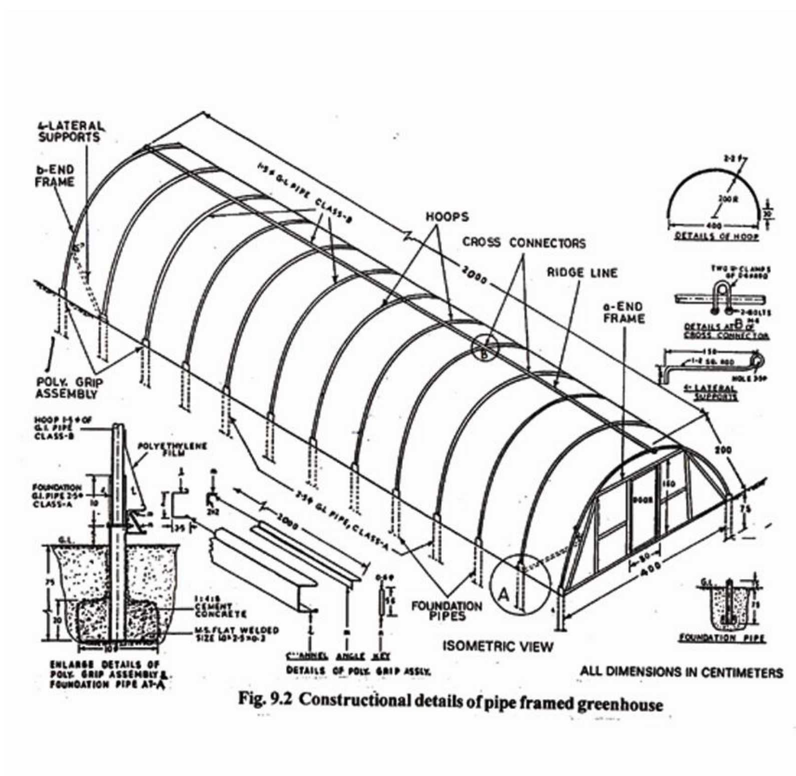


Fig.11.Constructional details of pipe framed greenhouse

Lecture No.8

Greenhouse heating and distribution systems. Greenhouse utilization - off-season drying of agricultural produce. Economic analysis of greenhouse production - capital requirement, economics of production and conditions influencing returns.

The northern parts of our country experience cold winters, where heating system need to be employed in the greenhouses along with cooling systems for summer. Whereas the southern region greenhouses need only cooling systems since the winter cold effect is not that severe. Greenhouse heating is required in cold weather conditions, if the entrapped heat is not sufficient during the nights. The heat is always lost from the greenhouse when the surroundings are relatively cooler. Heat must be supplied to a greenhouse at the same rate with which it is lost in order to maintain a desired temperature: Heat losses can occur in three different modes of heat transfer, namely conduction, convection, and radiation. Maintenance of desired higher temperature, compared with the surroundings needs heating systems and heat distribution systems. For the purpose of greenhouse heating, apart from conventional systems, solar energy can also be used and the heat can be stored using water and rock storage. Different heat conservation practices are available to effectively utilize the heat energy.

8.1 Modes of heat loss

The heating systems, in a continuous process, should supply the heat just enough to compensate which is lost. Most heat is lost by conduction through the covering materials of the greenhouse. Different materials, such as aluminum sash bars, glass polyethylene, and cement partition walls, vary in conduction according to the rate at which each conducts heat from the warm interior to the colder exterior. A good conductor of heat looses more heat in a shorter time than a bad conductor and vice versa. There are only limited ways of insulating the covering material without blocking the light transmission. A dead air space between two coverings appears to be the best system. A saving of 40% of the heat requirement can be achieved when a second covering in applied. For example greenhouse covered with one layer of polyethylene loses, 6.8 W of heat through each square meter of covering every hour when the outside temperature is 1^{oC} lower than the inside. When second layer of polyethylene is added, only 3.97 W/m^2 is lost (40% reduction).

A second mode of heat loss is that of convection (air infiltration). Spaces between panes of glass or FRP and ventilators and doors permit the passage of warm air outward and cold air inward. A general assumption holds that the volume of air held in a greenhouse can be lost as often as once very 60 minutes in a double layer film plastic or polycarbonate panel greenhouse, every 40 minutes in a FROP or a new glass greenhouse every 30 minutes in an old well maintained glass greenhouse, and every 15 minutes in an old poorly maintained glass greenhouse. About 10% of total heat loss from a structurally tight glass greenhouse occurs through infiltration loss.

A third mode of heat loss from a greenhouse is that of radiation. Warm objects emit radiant energy, which passes through air to colder objects without warming the air significantly. The colder objects become warmer. Glass, vinyl plastic, FRP, and water are relatively opaque to radiant energy, whereas polyethylene is not. Polyethylene, greenhouses can lose considerable amounts of heat through radiation to colder objects outside, unless a film of moisture forms on the polyethylene to provide a barrier.

8.2 Heating systems

The heating system must provide heat to the greenhouse at the same rate at which it is lost by co0nductin, infiltration, and radiation. There are three popular types of heating systems for greenhouses. The most common and least expensive is the unit heater system. In this system, warm air is blown from unit heaters that have self contained fireboxes. These heaters consist of three functional parts. Fuel is combusted in a firebox to provide heat. The heat is initially contained in the exhaust, which rises through the inside of a set of thin walled metal tubes on it way to the exhaust stack. The warm exhaust transfers heat to the cooler metal walls of the tubes. Much of the heat is removed from the exhaust by the time it reaches the stack through which it leaves the greenhouse. A fan in the back of the unit heater draws in greenhouse air, passing it over the exterior side of the tubes and then out from the heater to the greenhouse environment again. The cool air passing over hot metal tubes is warmed and the air is circulated.

A second type of system is central heating system, which consists of a central boiler than produces steam or hot water, plus a radiating mechanism in the greenhouse to dissipate the heat. A central heating system can be more efficient than unit heaters, especially in large greenhouse ranges. In this system, two or more large boilers are in a single location. Heat is transported in the form of hot water or steam through pipe mains to be growing area, and several arrangements of heating pipes in greenhouse is possible (Fig. 12.1). The heat is exchanged from the hot water in a pipe coil located across the greenhouse or an in-bed pipe coil located in the plant zone. Some greenhouses have a third pipe coil embedded in a concrete floor. A set of unit heaters can be used in the place of the overhead pipe coil, obtaining heat from hot water or steam from the central boiler.

The third type of system is radiation heating system. In this system, gas is burned within pipes suspended overhead in the greenhouse. The warm pipes supply heat to the plants. Low intensity infrared radiant heaters can save 30% or more, of fuel compared to conventional heaters. Several of these heaters are installed in tandem in the greenhouse. Lower air temperatures are possible since only the plants and root substrate are heated directly by this mode of heating.

The fourth possible type of system is the solar heating system, but it is still too expensive to be a viable option. Solar heating systems are found in hobby greenhouses and small commercial firms. Both water and rock energy storage systems are used in combination with solar energy. The high cost of solar heating systems discourages any significant use by the greenhouse industries.

8.2.1 Heat distribution systems

Heat is distributed from the unit heaters by one of two common methods. In the convection tube method, warm air from unit heaters are distributed through a transparent polyethylene tube running through the length of the greenhouse. Heat escapes from the tube through holes on either side of the tube in small jet streams, which rapidly mix with the surrounding air and set up a circulation pattern to minimize temperature gradients.

The second method of heat distribution is horizontal airflow. In this system, the greenhouse may be visualized as a large box containing air, and it uses small horizontal fans for moving the air mass. The fans are located above plant height and are spaced about 15 m (50 ft) apart in two rows. Their arrangement is tha, the heat originating at one corner of the greenhouse is directed from one side of the greenhouse to the opposite end and then back along the other side of the greenhouse. Proper arrangement of fans is necessary for effective distribution in horizontal airflow system for various greenhouse sizes. Both of these distribution systems can also be used for general circulation of air and for introducing cold outside air during winter cooling.

8.2.2 Solar heating system

Solar heating is often used as a partial or total alternative to fossil fuel heating systems. Few solar heating systems exist in greenhouses today. The general components of solar heating system (Fig. 12) are collector, heat storage facility, exchange to transfer the solar derived heat to the greenhouse air, backup heater to take over when solar heating does not suffice and set of controls.

Various solar heat collectors are in existence, but the flat plate collector has received greatest attention. This consists of a flat black plate (rigid plastic, film plastic, sheet metal, or board) for absorbing solar energy. The plate is covered on the sun side by two or more transparent glass or plastic layers and on the backside by insulation. The enclosing layers serve to hold the collected heat within the collector. Water or air is passed through the copper tubes placed over the black plate and absorb the entrapped heat and carry it to the storage facility. A greenhouse itself can be considered as a solar collector. Some of its collected heat is stored in the soil, plants, greenhouse frame, floor, and so on. The remaining heat is excessive for plant growth and is therefore vented to the outside. The excess vented heat could just as well be directed to a rock bed for storage and subsequent use during a period of heating. Collection of heat by flat-plate collection is most efficient when the collector is positioned perpendicular to the sun at solar noon. Based on the locations, the heat derived can provide 20 to 50% of the heat requirement.

8.3 Water and rock storage

Water and rocks are the two most common materials for the storage of heat in the greenhouse. One kg of water can hold 4.23 kJ of heat for each 1^{o}C rise in temperature. Rocks can store about 0.83 kJ for each 1^{o}C. To store equivalent amounts of heat, a rock bed would have to be three times as large as a water tank. A water storage system is well adapted to a water collector and a greenhouse heating system which consists of a pipe coil or a unit heater which contains a water coil. Heated water from the collector is pumped to the storage tank during the day. As and when heat is required, warm water is pumped form the storage tank to a hot water or steam boiler or into the hot water coil within a unit heater. Although the solar heated water will be cooler than the thermostat setting on the boiler, heat can be saved, since the temperature of this water need be raised as high as to reach the output temperature of water or steam from the boiler. A temperature rise of 17°C above the ambient condition is expected during the daytime in solar storage units. Each kilogram of water can supply 71.1 kJ of heat, and each kilogram of rock can supply14.2 kJ of heat, as it cools by 17°C.

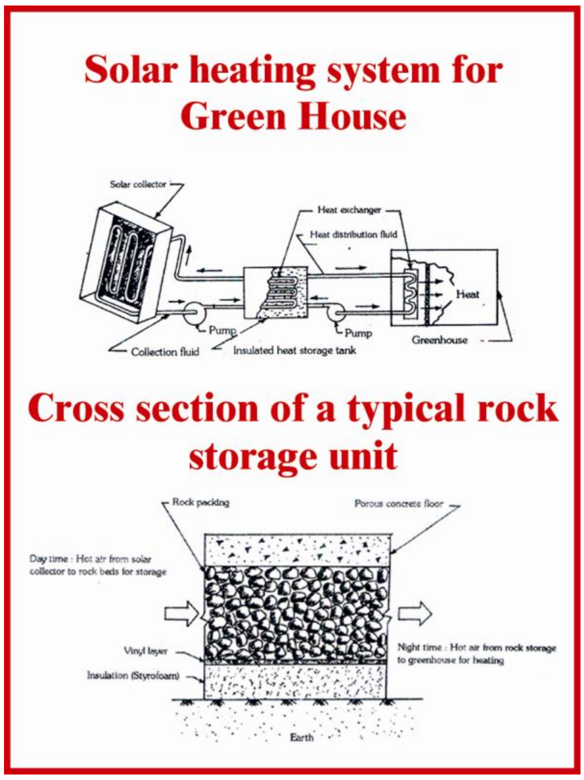


Fig.12. Solar heating system for greenhouse and cross section of a typical rock storage unit

A rock storage bed can be used with an air-collector and forced air heating system. In this case, heated air form the collector, along with air excessively heated inside the greenhouse during the day, is forced through a bed of rocks (Fig. 12). The rocks absorb much of the heat. The rock bed may be located beneath the floor of the greenhouse or outside the greenhouse, and it should be well insulated against heat loss. During the night, when heat is required in the greenhouse, cool air from inside the greenhouse is forced through the rocks, where it is warmed and the passed back into the greenhouse. A clear polyethylene tube with holes along either side serves well to distribute the warm air uniformly along the length of the greenhouse. Conventional convection tubes can be used for distributing solar heated air. The water or rock storage unit occupies a large amount of space and a considerable amount of insulation is provided if the unit is placed outside. Placing it inside the greenhouse offers an advantage in that escaping heat is beneficial during heating periods, but it is detrimental when heating is not required. Rock beds can pose a problem in that they must remain relatively dry. Water evaporating from these beds will remove considerable heat.

8.4 Economics of greenhouse production

Regardless of the type, protected agricultural systems are extremely expensive. The equipment and production cost may be more than compensated by the significantly higher productivity of protected agricultural systems as compared with open field agriculture. The cost and returns of protected agriculture vary greatly, depending on the system used, the location and the crop grown. By design, all protected agricultural systems of cropping are intensive in use of land, labour, and capital. Greenhouse agriculture is the most intensive system of all. The intensity of land use is greatly dependent upon the system of protected agriculture. Year-round greenhouse crop production is therefore much more intensive than seasonal use of mulches and row covers. Coinciding with intensity are yields, which are normally far greater per ha from year round than from seasonal systems. The normal benefit of higher yields of CEA over the open field agriculture depends on the system used and the region of production.

8.5 Capital requirements

The capital requirements differ greatly among the various systems of protected agriculture. Mulching is least expensive while greenhouses require the most capital per unit of land. Total cost involved in the production is the sum of fixed cost and operating cost (Fig.13). The fixed capital costs include land, fixed and mobile equipment, and structures like grading, packing and office. Fixed costs also include taxes and maintenance. The fixed capital costs for greenhouses clearly exceed those of other systems of protected agriculture, but vary in expense according to type of structure, and environmental control and growing systems. Operating costs include labour, fuel, utilities, farm chemicals and packaging materials. The operating or variable costs and fixed costs are annual expenditures and these can be substantial. Annual costs may correlate to some extent with capital investment. The flow diagram of capital requirements of production is shown in figure.

In estimating the capital requirements, the farmer must include the cost of the entire system as well as the mulch. While greenhouse production systems may be far more expensive than open field systems of equal land area, open field systems of protected agriculture are normally more expensive in field area than in greenhouse production. Greenhouses are expensive, especially if the environment is controlled by the use of heaters, fan and pad cooling systems and computer controls.

8.6 Economics of production

Production economics considers the various components of fixed and variable costs, compares them with the income and evaluates the net return, on unit area basis. On an average basis, wages account for approximately 85% of the total variable cost. Wages are the greatest expenditure in greenhouse production, followed by amortization costs and then energy costs, and energy expenditure, when heating is necessary. About two-fifths of the expenses are fixed costs and about three-fifths are variable costs. Depreciation and interest on investment accounts for most of the fixed costs.

8.6.1 Conditions Influencing Returns

A number of variables which may not show up in the yearly financial balance sheet influence the returns to green house operators, such as economics of scale, physical facilities, cropping patterns and government incentives. The size of any system of protected agriculture will depend on the market objectives of the farmer. Most protected agricultural endeavors are family operated. Often the products are retailed directly to the consumer through a road side market at the farm site. In the developed world, greenhouse operations tend to be a size that can be operated by one family (0.4 to 0.8 ha).A unit of 0.4 ha can be operated by two to three labourers, with additional help at periods of peak activity. The labour wages can usually be provided by the owner and his family. Moreover, the owner will pay close attention to management, which is the most important factor. Labour costs may rise significantly if it is necessary to recruit labour from outside the family. Green house owners who hire a highly qualified manager may have to operate a larger greenhouse than family size greenhouses in order to offset the additional salary paid.

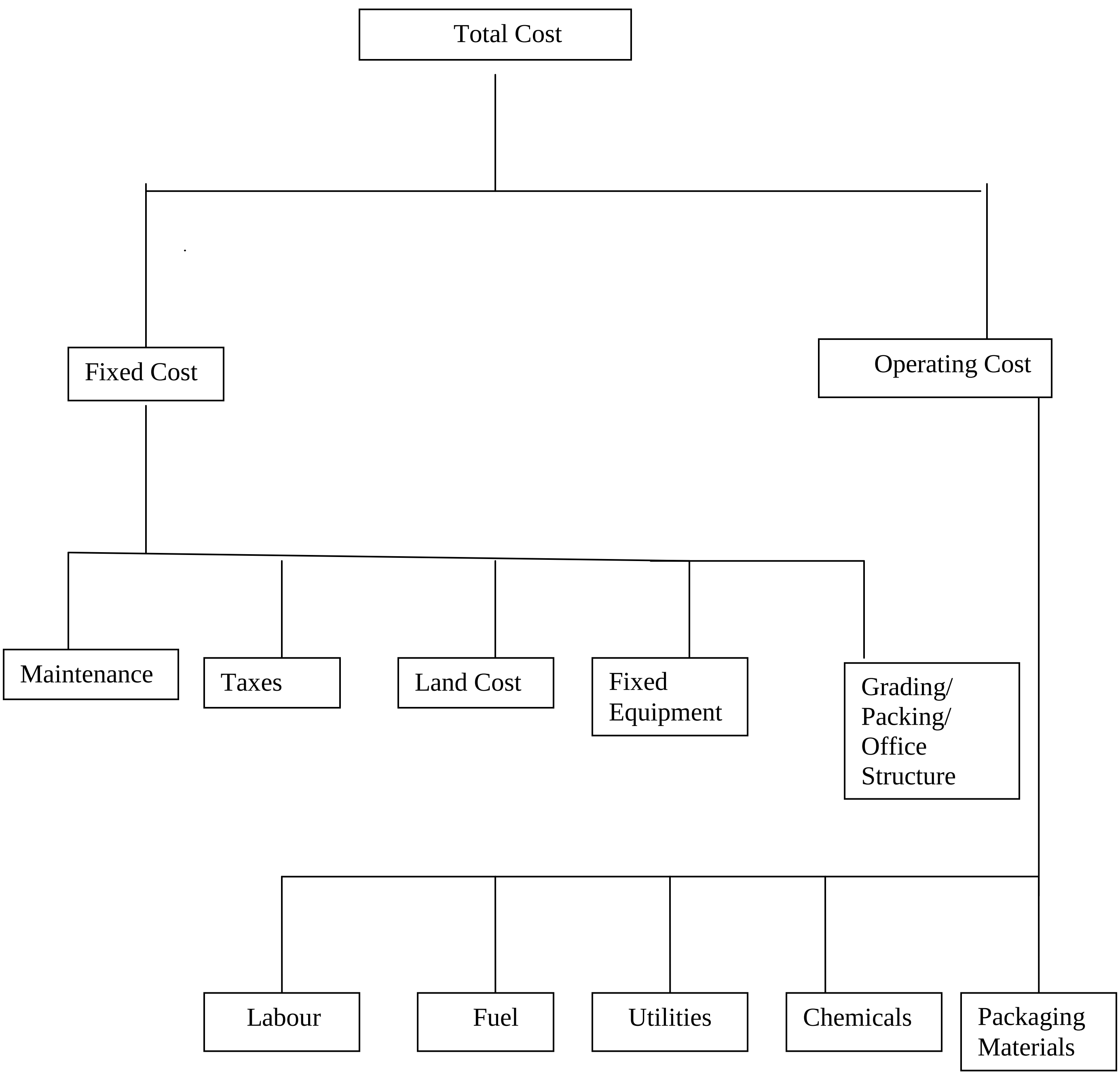


Fig. 13. Flow diagram of capital requirements of production

The green house system economy can be improved with increased size when:

1. There is a unique opportunity to mechanize certain operations.
2. Labour can be more efficiently utilized.
3. Low cost capital is available.
4. There are economics in the purchase of packaging materials and in marketing.
5. Some special management skills are available.

The physical facilities and location of the green house influence the economics. Another variable that influence the profits from the green house is intensity of production, which is determined by the structures with complete environmental control system facilities year round production and early harvest, thus enabling the grower to realize higher profits. Year –round production offers year round employment to the laborers. It is found that the environmentally controlled green house produced only one- third more revenue than high tunnel structure. With the improved transportation facilities, the new areas of production in combination with the following factors contribute to the lower costs.

1. High sun light intensity undiminished by air pollution.
2. Mild winter temperatures.
3. Infrequent violent weather conditions.
4. Low humidity during the summer for cooling.
5. Availability of water with low salinity levels.

Cropping pattern will have bearing on the green house structure. A high –tunnel structure or any structure not fitted with environmental controlled equipment for heating and cooling will be used only on a seasonal basis. It is common to switch over from green house vegetable production to flower production, especially in structures with more elaborate environmental control systems. Growers through out the world are currently experimenting with alternative crops, such as herbs. As eating habits change, with times and as the consumers are becoming increasingly conscious of diet and the nutritional value of fruits and vegetables, growers must continually look for alternative to existing cropping patterns. Government policies also influence the financial returns from the crops. Government may provide grants or low interest loans, subsidies towards construction costs, fuels, and use of plastics, such as drip irrigation systems, mulches, row covers and covering materials. Such incentives from the Government encourage the growers and stimulate the green house industry.

8.7 Greenhouse utilization in off-season

Drying is traditional method for preserving the food. It also helps in easy transport since the dried food becomes lighter because of moisture evaporation. Drying of seed prevents germination and growth of fungi and bacteria. The traditional practice of drying agricultural produce in the developing countries is sun drying, which is seasonal, intermittent, slow, and unhygienic. To overcome the problems of sun drying, mechanical drying is introduced with the following advantages: (i) fast drying, (ii) large volumes of produce can be handled (iii) drying parameters can be controlled and quality of the produce can be maintained. The energy demand of conventional mechanical dryers is met by electricity, fossil fuels, and firewood are becoming scarce. Solar energy can be an alternative source for drying of food and solar dryers are employed for the purpose. The use of the greenhouse as a dryer is the latest development. The drying capabilities of the greenhouse can be utilized for curing tobacco leaves, while guarding the harvest from rain damage.

8.7.1 Drying of agricultural produce

In an efficiently managed greenhouse CEA, there will not be any time gap between crops. However, for some other management reasons, if crops are not grown in a particular period, the greenhouse can be utilized as a solar dryer. A small amount of 15 to 30% of the incoming solar radiation is reflected back from the surface of the greenhouse, with the remainder is transmitted into the interior. Most of this transmitted radiation is absorbed by plants, soil and other internal surfaces, the rest being reflected. The usage of greenhouse for the purpose of the drying is of recent origin. Papadikas et al., (1981) investigated the usage of greenhouse type solar dryer for drying grapes. Khollieve et al., (1982) developed a greenhouse type fruit dryer cum hot house used as dryer in summer and as a hot house in winter. They were successful in advocating the year round utilization of the greenhouse facility and thus reducing the operation cost per unit output. In general, the produce is spread as thin layers in trays covering the greenhouse area. The trays can be fabricated with sheet metal and wire mesh. Trays should be arranged horizontally on existing growing benches or frames. For better operation, proper ventilation should be provided by either forced or natural ventilation, to remove the moisture liberating from the produce and to control the air temperature inside the greenhouse. The natural ventilation can be enhanced by using a black LDPE chimney connected to the greenhouse.

8.7.2 Curing of tobacco

Tobacco is an important foreign exchange earning commercial crop of India, which provides employment opportunities to lakhs of people. Curing of tobacco is a delicate and vital process in producing good quality leaves. Tobacco curing essentially refers to drying of the harvested fresh tobacco leaves under controlled temperature, humidity and ventilation in order to initiate the essential bio-chemical processes. The success of curing also depends on the condition of the harvested leaves and their degree of maturity. The usual curing methods are flue, air, pit, fire and sun curing. The open field sun curing is the cheapest method of curing. The drying capabilities of greenhouse can be successfully utilized for curing the tobacco. Different stages of tobacco curing require specific environmental conditions for the best product, which can be maintained easily in a greenhouse. The harvested tobacco leaves are made into bunches of few leaves by knots and arranged serially to form a string with free ends left for fixing it. Scaffoldings should be erected inside the greenhouse and the string of leaves is tied to them, for the tobacco curing process. To increase the capacity, the strings are tied with judicious gap between them and also put in tiers. As curing progresses, the leaves loose moisture and the string will become lighter and the initial sag in the strings can be corrected. For maintaining uniform product quality, the strings can be cycled among the tiers in a specified sequence. Humidity and temperature control by proper ventilation and frequent inspection is important in tobacco curing operations.

Lecture No.9

Irrigation system used in greenhouses-rules of watering, hand watering, perimeter watering, overhead sprinklers, boom watering and drip irrigation.

A well-designed irrigation system will supply the precise amount of water needed each day throughout the year. The quantity of water needed would depend on the growing area, the crop, weather conditions, the time of year and whether the heating or ventilation system is operating. Water needs are also dependent on the type of soil or soil mix and the size and type of the container or bed. Watering in the green house most frequently accounts for loss in crop quality. Though the operation appears to be the simple, proper decision should be taken on how, when and what quantity to be given to the plants after continuous inspection and assessment .Since under watering (less frequent) and over watering (more frequent) will be injurious to the crops, the rules of watering should be strictly adhered to. Several irrigation water application systems, such as hand writing, perimeter watering, overhead sprinklers, boom watering and drip irrigation, over sprinklers, boom watering and drip irrigation which are currently in use.

9.1 Rules of Watering

The following are the important rules of application of irrigation.

Rule 1: Use a well drained substrate with good structure

If the root substrate is not well drained and aerated, proper watering can not be achieved. Hence substrates with ample moisture retention along with good aeration are indispensable for proper growth of the plants. The desired combination of coarse texture and highly stable structure can be obtained from the formulated substrates and not from field soil alone.

Rule 2: Water thoroughly each time

Partial watering of the substrates should be avoided; the supplied water should flow from the bottom in case of containers, and the root zone is wetted thoroughly in case of beds. As a rule, 10 to 15% excess of water is supplied. In general, the water requirement for soil based substrates is at a rate of 20 l/m^2 of bench, 0.3 to 0.35 litres per 16.5 cm diameter pot.

Rule 3: Water just before initial moisture stress occurs

Since over watering reduces the aeration and root development, water should be applied just before the plant enters the early symptoms of water stress. The foliar symptoms, such as texture, colour and turbidity can be used to determine the moisture stress, but vary with crops. For crops that do not show any symptoms, colour, feel and weight of the substrates are used for assessment.

9.2 Hand watering

The most traditional method of irrigation is hand watering and in present days is uneconomical. Growers can afford hand watering only where a crop is still at a high density, such as in seed beds, or when they are watered at a few selected pots or areas that have dried sooner than others. In all cases, the labour saved will pay for the automatic system in less than one year. It soon will become apparent that this cost is too high. In addition to this deterrent to hand watering, there is great risk of applying too little water or of waiting too long between waterings. Hand watering requires considerable time and is very boring. It is usually performed by inexperienced employees, who may be tempted to speed up the job or put it off to another time. Automatic watering is rapid and easy and is performed by the grower it self. Where hand watering is practiced, a water breaker should be used on the end of the hose. Such a device breaks the force of the water, permitting a higher flow rate without washing the root substrate out of the bench or pot. It also lessens the risk of disrupting the structure of the substrate surface.

9.3 Perimeter watering

Perimeter watering system can be used for crop production in benches or beds. A typical system consists of a plastic pipe around the perimeter of a bench with nozzles that spray water over the substrate surface below the foliage (Fig.14).

Either polythene or PVC pipe can be used. While PVC pipe has the advantage of being very stationery, polythene pipe tends to roll if it is not anchored firmly to the side of the bench. This causes nozzles to rise or fall from proper orientation to the substrate surface. Nozzles are made of nylon or a hard plastic and are available to put out a spray are of 180°, 90° or 45°. Regardless of the types of nozzles used, they are staggered across the benches so that each nozzle projects out between two other nozzles on the opposite side. Perimeter watering systems with 180° nozzles require one water valve for benches up to 30.5 m in length.

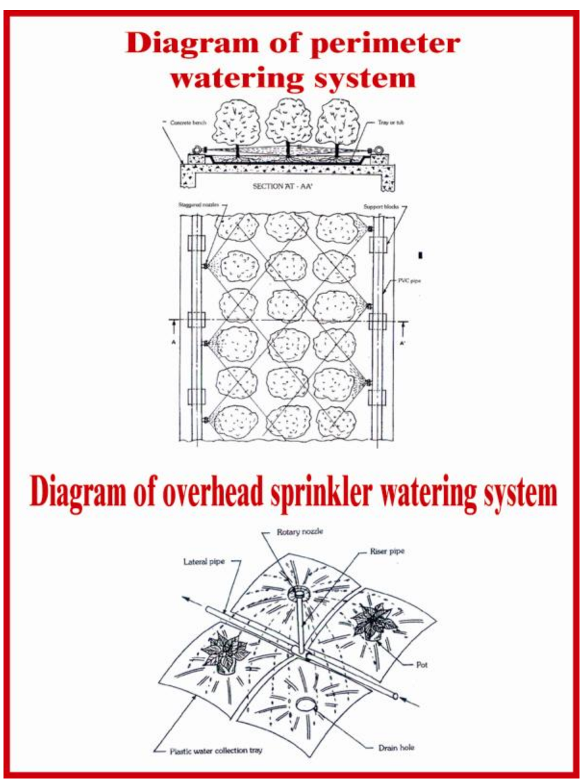


Fig. 14. Diagram of perimeter and overhead sprinkler watering system

9.4 Overhead sprinklers

While the foliage on the majority of crops should be kept dry for disease control purposes, a few crops do tolerate wet foliage. These few crops can most easily and cheaply be irrigated from overhead. Bedding plants, azalea liners, and some green plants are crops commonly watered from overhead. A pipe is installed along the middle of a bed. Riser pipes are installed periodically to a height well above the final height of the crop (Fig.14). A total height of 0.6 m is sufficient for bedding plants flats and 1.8 m for fresh flowers. A nozzle is installed at the top of each riser. Nozzles vary from those that throw a 360° pattern continuously to types that rotate around a 360° circle. Trays are sometimes placed under pots to collect water that would otherwise fall on the ground between pots and wasted. Each tray is square and meets the adjacent tray. In this way nearly all water is intercepted. Each tray has a depression to accommodate the pot and is then angled upward from the pot toward the tray perimeter. The trays also have drain holes, which allow drainage of excess water and store certain quantity, which is subsequently absorbed by the substrate.

9.5 Boom watering

Boom watering can function either as open or a closed system, and is used often for the production of seedlings grown in plug trays. Plug trays are plastic trays that have width and length dimensions of approximately 30 × 61 cm, a depth of 13 to 38 mm, and contain about 100 to 800 cells. Each seedling grown in its own individual cell. Precision of watering is extremely important during the 2 to 8 week production time of plug seedlings.

A boom watering system generally consists of a water pipe boom that extends from one side of a greenhouse bay to the other. The pipe is fitted with nozzles that can spray either water or fertilizer solution down onto the crop. The boom is attached at its center point to a carriage that rides along rails, often suspended above the centre walk of the greenhouse bay. In this way, the boom can pass from one end of the bay to the other. The boom is propelled by an electric motor. The quantity of water delivered per unit area of plants is adjusted by the speed at which the boom travels.

9.6 Drip Irrigation

Drip irrigation, often referred to as trickle irrigation, consists of laying plastic tubes of small diameter on the surface or subsurface of the field or greenhouse beside or beneath the plants. Water is delivered to the plants at frequent intervals through small holes or emitters located along the tube. Drip irrigation systems are commonly used in combination with protected agriculture, as an integral and essential part of the comprehensive design. When using plastic mulches, row covers, or greenhouses, drip irrigation is the only means of applying uniform water and fertilizer to the plants. Drip irrigation provides maximum control over environment variability; it assures optimum production with minimal use of water, while conserving soil and fertilizer nutrients; and controls water, fertilizer, labour and machinery costs. Drip irrigation is the best means of water conservation. In general, the application efficiency is 90 to 95%, compared with sprinkler at 70% and furrow irrigation at 60 to 80%, depending on soil type, level of field and how water is applied to the furrows. Drip irrigation is not only recommended for protected agriculture but also for open field crop production, especially in arid and semi-arid regions of the world. One of the disadvantages of drip irrigation is the initial cost of equipment per acre, which may be higher than other systems of irrigation. However, these costs must be evaluated through comparison with the expense of land preparation and maintenance often required by surface irrigation. Basic equipment for irrigation consists of a pump, a main line, delivery pipes, manifold, and drip tape laterals or emitters as shown in figure 15:

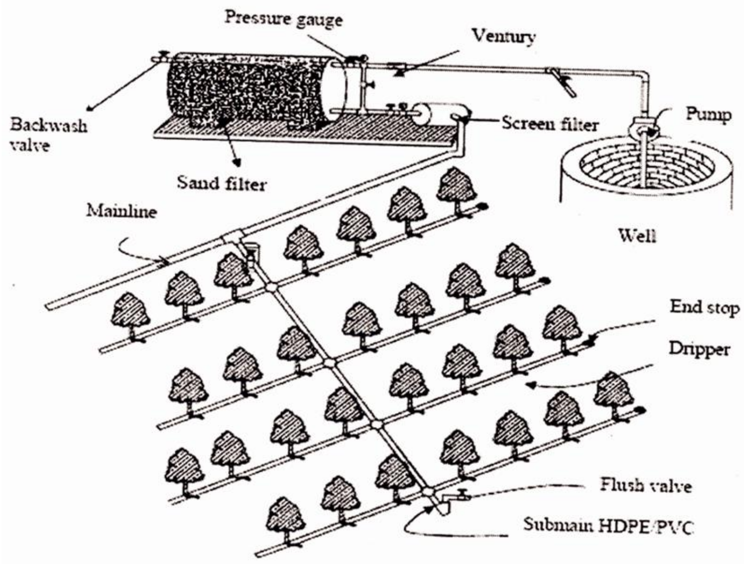


Fig.15. Diagram of drip irrigation system for greenhouse

The head, between the pump and the pipeline network, usually consists of control valves, couplings, filters, time clocks, fertilizer injectors, pressure regulators, flow meters, and gauges. Since the water passes through very small outlets in emitters, it is an absolute necessity that it should be screened, filtered, or both, before it is distributed in the pipe system. The initial field positioning and layout of a drip system is influenced by the topography of the land and the cost of various system configurations.

Lecture No.10

Threshing - types of threshers, parts, threshers for different crops, terminology, different types of cylinders used in threshers, care and maintenance.

Agricultural development has two major aspects: production and post harvest processing. Until now, we have concentrated on agricultural production and neglected processing of farm crops and animal products.

India is the world's second largest producer of food next to china. It is estimated that 10% of food grains produced in India are lost in processing and storage. Some estimates indicated that, in developing countries, as much as $1/4^{th}$ to $1/3^{rd}$ of total crop may be lost as a result of inefficient post harvest systems. About 11-12% in paddy, 8-9% in wheat, 10-11% in gram, 10-17% in rapeseed and mustard are lost during production in India due to usage of old and outdated methods of milling, improper and inefficient methods of storage, transportation and handling. An estimate of post harvest losses in paddy in South East Asia is given in Table 2:

Table 2. An estimate of post harvest losses in paddy in South East Asia

Operation	**Range of losses (%)**
Harvesting	1-3
Threshing	2-6
Drying	1-5
Handling	2-7
Milling	2-10
Storing	2-6
Total	**10-37**

Also, 10-30% of vegetables and fruits (approximately 20 crores worth) are lost every year due to lack of proper methods of processing and storage.

Post harvest processing technology or Post harvest technology of agricultural products refers to the processes and treatments carried out on agricultural products after it is harvested. It starts from the selection of proper harvest and ends with marketing. The following operations such as threshing, drying, storage, parboiling, milling, sorting, grading, oil extraction, juice extraction, ginning, cold storage, packing, transport, marketing etc., included under this term. The purpose of post harvest processing is to maintain or enhance quality of the products and make it marketable.

10.1 Post harvest technology and its importance

It is an inter-discipline "science and technique" applied to agricultural produce after harvest for its production, conservation, processing, packaging, distribution, marketing, and utilization to meet the food and nutritional requirement of the people in relation to their needs. It has the capability to meet food requirement of growing population by eliminating avoidable losses, making more nutritive food items from low grade raw commodity by proper processing and fortification, converting low grade food and organic waste into nutritive cattle feed. It has potential to create rural agro industries.

10.2 Threshing

Threshing is the process of removal of grain from the plant by striking, treading or rubbing. Common methods of threshing are threshing by manual labour, threshing by animals, and threshing by machines

10.2.1Threshing by manual labour

It is done either by treading the grain under the feet of men or striking the grains with stick or striking the plant against a hard object. It is a slow and labour consuming process. It is suitable for small quantity of harvests and output is 17-20 kg grains per hour.

10.2.2 Threshing by animals

Threshing by animals is very common method used in villages**.** In India, the indigenous method is **bullock treading** in which the crop is spread on threshing floor in a circle, and bullocks are made to walk on it in circular path. The repeated trampling under the bullock feet results separation of grains from straw. The trampling is continued till the grains are completely separated from straw. On an average, a pair of bullocks can thresh 140 kg grains per hour. With the advancement, farmers started the use of dragging devices like rollers, wooden planks, disc harrow and finally Olpad thresher.

10.2.3 Olpad thresher

It is a mainly a wheat thresher (Fig.16). It is said to have origin at a small place named **Olpad** in Gujarat state. It consists of 14 to 21 plain or serrated disks mounted on a rectangular wooden or iron frame in three axils with bearings, on which a seat and a platform are provided. It is operated by pair of bullocks. Output is 75 kgs of grains per hour and Rs. 3.00 to 3.50 per quintal cost of threshing, which is almost ½ the cost of bullock trampling. The thresher is useful for threshing wheat, barley, gram etc., on a threshing floor. This thresher has three to four wheels to facilitate its movement from one place to another place.

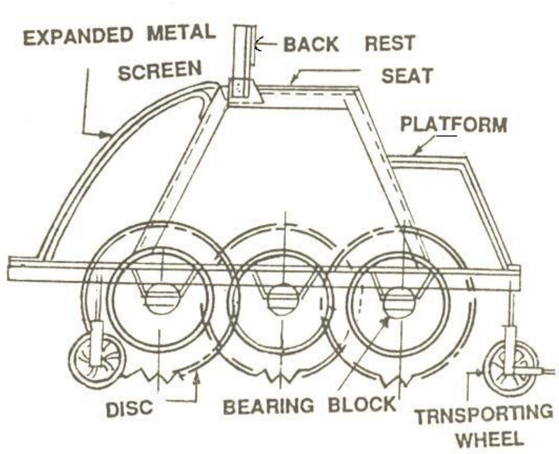


Fig.16. Diagram of Olpad thresher

10.2.4 Threshing by machines

If the farmers get busy in threshing crops manually, it will not be possible for them to spare time for timely preparation of land for the next crop. Delayed threshing will cause not only spoilage of grains, but also increase the broken rice percentage during milling. To meet this requirement, threshing either needs to be delayed or the farmers are bound to use power threshers. The delayed threshing accounts huge grain losses. Hence, the use of stationery thresher (a faster method of grain detachment) is a viable option. The machine used for the purpose of grain detachment and separation is called a thresher and was introduced in India during 1960. With the increase of mechanization in farms, many new threshing machines are getting popular day by day. Threshing can be achieved by three methods: rubbing action, impact and stripping.

Principles of threshing

Removal of grains from the plant stalk is done by rotating cylinders, whose threshing action depends primarily upon impact. “Hold-on” and “Throw-in” are the two major types of threshers are available in India.

“**Hold-On” thresher**: The plant stalks are held in bundles against the rotating cylinder and the grains are stripped off and collected. Eg. Pedal operated paddy thresher

“**Throw-in” thresher**: Plant stalks are fed into the machine continuously which produces grain and threshed straw in the respective outlets. Eg. Power thresher or all crop thresher.

10.2.5 Pedal operated paddy thresher

Pedal operated paddy thresher (Fig.17) is a manually driven medium size thresher for threshing paddy. The pedal operated paddy thresher consists mainly a well balanced threshing cylinder, driving mechanism and supporting frame.

Threshing cylinder

The cylinder is usually available in two sizes. One size is about **450 mm** in length when one man operates thresher. The other size is **700 mm** in length when it is to be operated by two persons. The threshing cylinder is made with iron or wood and suitably reinforced at its center for proper rigidity. The cylinder is usually made with wooden, to make the thresher light in weight. The cylinder is provided with a series of threshing teeth in the shape of loops fixed on wooden slats all round its circumference. The diameter of the cylinder used on common threshers is about 43 cm but its width may vary from 40 to 76 cm. The cylinder is supported by two ball bearings on the frame.

Drive mechanism

The drive of the pedal operated thresher is of eccentric type. Drive consists of a crank, one end of which is connected to a spur gear. The other end of the crank is connected suitably to the pedal frame fulcrum, which is welded to the pedal frame. The normal operating speed is about 400 revolutions per minute.

Gear housing

Gear housing made of cast iron. It consists of two spur gears provide an over-all ratio of 1:4 speed gain from a pedal, to achieve a cylinder speed of 400 rpm.

Crank : The crank is made of mild steel bar.

Pedal frame fulcrum: The fulcrum is made of either mild steel tube or a bar.

Pedal frame: It is made of mild steel flat.

Pedal board: The pedal board is made of wooden plank.

Supporting frame

The body frame of the thresher consists of the base, the side frame, the front grain shield and rear grain shield.

Base: The base is made of mild steel angle section or wood. It is suitably fixed to the side frame of the body.

Side frame**:** The side frames are made of mild steel angle section. The side frame support side boards, which are usually made of mild steel sheet.

Front grain shield**:** The front grain shield is made of wooden plank of about 12 mm thick and is fitted suitably to the side frame.

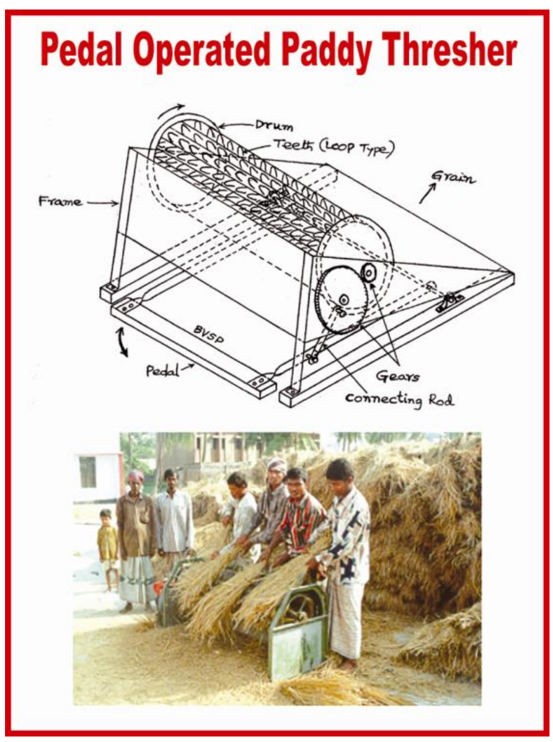


Fig.17. Diagram of Pedal operated thresher

10.2.5.1 Working Principle

Threshing of paddy crop is done by holding the bundle against the teeth of the threshing cylinder. While the cylinder is rotated at high speed, the paddy bundles of suitable size are held against the teeth. The grains are separated by the combing as well as by hammering action of the threshing teeth. The grains are thus separated or combed out easily. The direction of the cylinder is marked on it. If the mark is not there, the cylinder shall be operated in such a way that the grains are thrown away from the operator. The pedal is operated by one man. But, larger size machines operated by two men at a time are also common. This type of thresher has become very popular among small farmers. The capacity of the single man operated pedal operated thresher is about 1.5 to 1.9 quintals per day. The cost of threshing will be about Rs. 6/- per quintal of grain.

Lecture No.11

Terminology related to threshers, components, working, care and maintenance

It .is a machine operated by a prime mover such as electric motor, engine, tractor or power tiller, used for threshing.

It performs the following functions such as:

(i) To feed the harvest to the threshing cylinder,

(ii) To thresh the grain out of the ear head,

(iii)To separate the grain from the straw,

(iv)To clean the grain,

(v) To put the grain in a bag,

(vi)To make the chaff suitable for animal feeding.

Removal of grains from the ear heads is done by rotating cylinders, whose threshing action depends primarily upon **impact**. When a slow moving material comes in contact with the high speed cylinder, the heads or pods are shattered and the grains are separated from straw. Further threshing is done when the material passes through the restricted clearance space between the cylinder and the concave portion of the unit. Output is 200-500 kg grains per hour.

11.1 Components of power thresher

The main components are: (i) cylinder (ii) concave and (iii) cleaning unit.

11.1.1 Cylinder

It is the most important component of the thresher. It is cylindrical in shape and has projections or undulations on its surface arranged in regular array form, to meet the threshing requirement of different crops. It is a balanced rotating assembly, threshes the grain against the bars or teeth of the concave. The cylinders are made of either metal (steel) or well seasoned hard wood. There are five types of threshing cylinders commonly used in the country.

(i) Peg tooth or spike tooth cylinder

(ii) Rasp bar cylinder

(iii) Angle bar cylinder

(iv) Loop type cylinder

(v) Hammer mill type cylinder.

11.1.2 Peg tooth cylinder

The threshing cylinder has rows of projections in the form of short metal pegs. These peg tooth rows are also present on the concave. Teeth on the concave and cylinder are so arranged that, the cylinder teeth pass midway between the staggered teeth on the concave. The concave assembly is pivoted at the rear portion of the machine. Clearance space between the cylinder and concave can be adjusted according to the requirement by swinging the concave. As the stalks pass through the clearance space, the grains get separated from the ear heads due to impact and stripping action between the teeth. Peripheral speed of the cylinder is about 1500-1800 m^3/min (Fig.18).

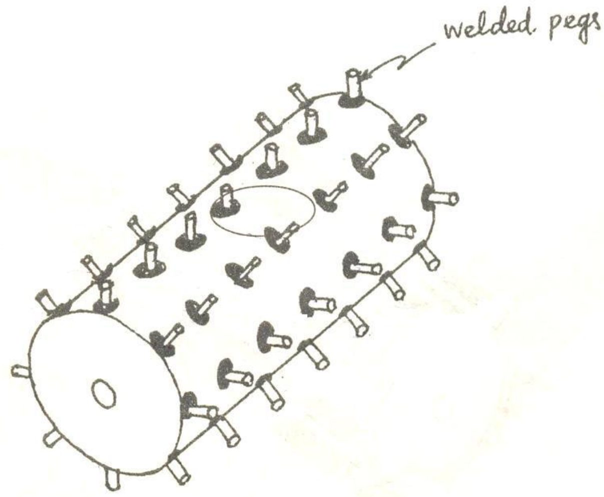


Fig.18. Peg tooth cylinder

11.1.3 Loop type cylinder

The cylinder is studded with a number of wire loops throughout its outer periphery. This is mostly used on paddy threshers. Thick wires are bent as loops and are arranged in rows on the cylinder surface. Smooth surface of the loops give gentle combing action, which does not damage the grains (Fig.19).

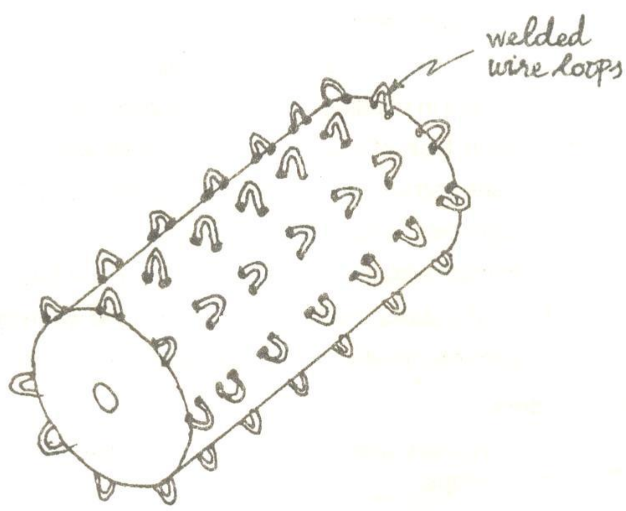


Fig.19. Loop type cylinder

11.1.4 Angle bar cylinder

Cylinders of this type are provided with angle iron bars, helically fitted on the cylinders. The bars provided with rubber pads on their faces. The concave unit is fitted with a rubber faced shelling plate and steel jacketed rubber bars. The clearance between the cylinder and concave unit at the entrance is from 13 to 19 mm and reduces to about 6 to 9 mm at the end. The threshing action caused by the straight bars is through sudden impact, where as threshing action caused by helical bars are smooth (Fig.20).

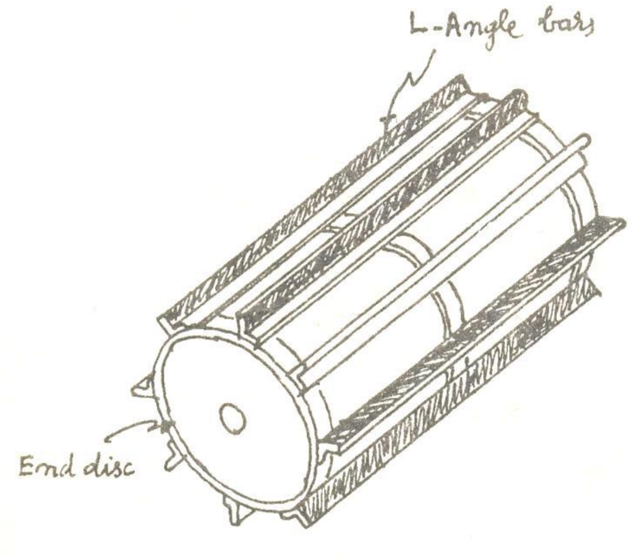


Fig. 20. Angle bar cylinder

11.1.5 Rasp bar cylinder

Rasp bars are thick cast flats with inclined ridges or serrations. The cylinder has corrugated rasp bars around it. Threshing is accomplished between corrugated cylinder bars and stationery bars of the concave portion. The rotating cylinder takes the grains out from the ear heads as it is drawn over the bars on the concave unit. Usually, 6 to 8 bars are fixed on the cylinder in straight or helical configuration. Rasp bars are generally used in all-crop threshers (Fig.21).

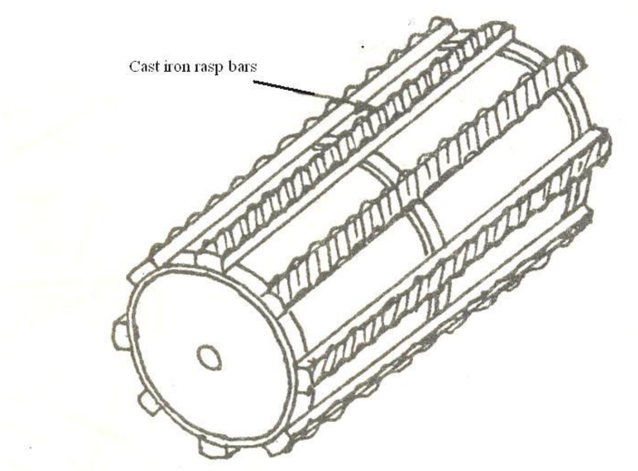


Fig. 21. Angle bar cylinder

11.1.6 Hammer mill cylinder

Beaters or hammers of the hammer mill cylinders are metal pieces hinged at one end so that it swings freely. The beaters are in the shape of hammers of a hammer mill. These are attached to the beater arm at the tip. Beater arms are rigidly fixed to a hub, which is mounted on main shaft. The hammer assembly is arranged inside a closed cylinder casing and concave. When the cylinder rotates, the swinging beaters fly away and become straight and stiff and perform the threshing. If the hammers come across heavy obstruction such as stone, the hammers swing back without damaging the concave and the cylinder elements (Fig.22).

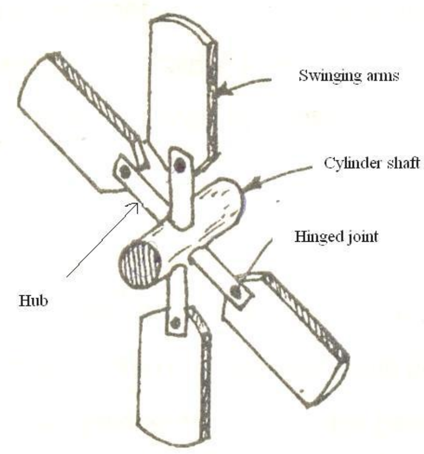


Fig. 22. Hammer mill cylinder

11.2 Concave

It is a concave shaped metal grating, partly surrounding the cylinder against which the cylinder rubs the grain from the plant or ear heads and through which the grains fall on the sieve.

11.3 Cleaning unit

The function of the cleaning unit is to separate and clean the threshed grain. The cleaning unit mainly consists of two or more oscillating sieves, a fan and an air sucking duct known as aspirator. The aspirator is used for cleaning the grain by drawing air through the grain mass. Usually it contains two ducts, one is primary duct and other is secondary duct. The function of the primary duct is to remove major portion of straw, dust and other foreign matter. The secondary duct is used for final cleaning of the grains.

11.4 All-crop thresher

The all-crop thresher (Fig.23) is a high capacity threshing machine, with a rasp bar cylinder and open grate concave. With proper adjustment of cylinder speed and cylinder-concave clearance, paddy, wheat, maize, jowar, bajra and other cereal grains can be threshed quickly and economically.

The various components of all-crop thresher are:

1. Feeding hopper
2. Threshing cylinder
3. Concave
4. Straw rack
5. Beaters
6. Blower
7. Sieve assembly

A 5 H.P. oil engine or electric motor or power tiller is required to drive the machine. A flat or V-belt drive can be used.

11.4.1 Threshing action

The crop is manually fed into the threshing cylinder. In the case of paddy and wheat, the entire crop is fed into the machine and only ear heads are fed in the case of bajra, maize and jowar. Much of the grain is removed from the ear heads, cobs or pods by impact, when slow moving material comes in contact with the high speed rotating cylinder rasp-bars. Further threshing occurs, by agitation and rubbing action, as the material passes through the space between the cylinder and concave bars.

11.4.2 Separation and winnowing

Threshed grain fall through the concave openings and onto the grain pan, which moves the grain to rear side to a position where it falls through the air blast from the aspirator and onto the sieve. Chaff is blown out to the rear side of the machine by the air blast.

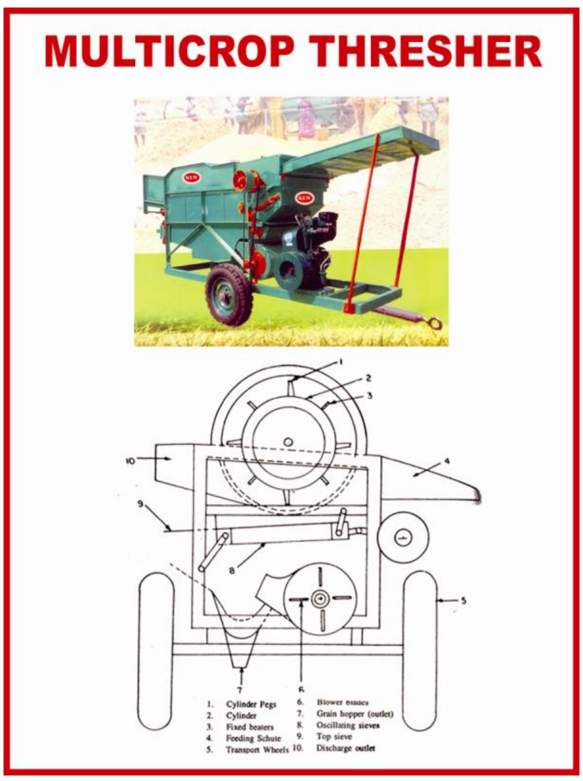


Fig. 23. All crop thresher

a) As threshing occurs, straw is stripped off from the cylinder by the beater, which aids in separating loose grains from the straw and directs the straw down onto the straw rack. Remaining loose grains are dropped through the openings in the straw rack, fall through the air blast and finally onto the sieve. The straw is carried out of the machine by the straw rack and dropped behind the machine. Sieve openings allow grain to pass through into the sieve pan while remaining straw or cobs, which are carried out to the rear side of the machine by the oscillating motion of the sieve. Cleaned grain is delivered from the grain outlet of the machine and bagged. Seed damage may occur due to cylinder - concave clearance being too small. Sieves can be changed for cleaning various crops. A 3/16 inch sieve opening is required for bajra, ragi and most of the varieties of jowar. A ¼ inch opening is best for wheat and short grain paddy varieties. Sieve openings of 3/8 inch are required for long grain paddy and ½ inch openings are necessary for maize. The following factors affecting threshing efficiency are: peripheral speed of the cylinder, cylinder-concave clearance, type of crop, moisture content of crop, weather condition and feed rate. Various crops can be threshed by changing the speed of the cylinder, are given in Table 3.

Table 3. Recommended speeds of threshing drum

Crop	Speed of drum	
	rpm	m/s
Paddy	675-1000	16 - 25
Wheat	550-1100	20 -30
Barley	740-1080	20-26
Gram	400-750	12-22
Jowar	400-675	12-20
Bajra	400-550	12-16
Peas	430-750	12-22

11.4.3 Adjustments

(i) The beater, straw rack and fan must be driven at a relatively constant speed regardless of cylinder rpm. Therefore, it is essential to change the V-belt drive pulley on the cylinder shaft for the crops requiring different cylinder speeds.

(ii) Cylinder concave clearance may be adjusted to raise or lower the cylinder and concave unit. Clearance should be as great as can be used with satisfactory threshing.

(iii) Cylinder speeds may be changed by changing sheaves and sprockets.

11.4.4 Precautions and care in operation of thresher

1. The machine should be installed at a leveled surface as far as possible.
2. The direction of the machine should be set inconsonance with the direction of the prevailing wind.
3. The machine should be fixed in the ground with the help of suitable pegs or by digging into the ground.
4. The thresher should be operated at the speed recommended by the manufacturer.
5. Suitable size of pulley should be should be provided on the thresher to operate the cylinder at recommended speed.
6. The feeding should be continuous and uniform.
7. Bearings and other working parts should always be properly greased and oiled.
8. Before starting the machine, the main pulley should be driven by hand to ensure that there is no obstruction inside the machine.
9. While feeding, care is to be taken that crop should be free from any wooden or iron pieces.
10. It is desirable to dry the crops before feeding, as far as possible.
10. The sieves should be inspected frequently and cleaned from time to time to avoid clogging.
11. While feeding, the operator should not insert his hand deep in the feeding trough.

12. After continuous working for 8 to 10 hours, the machine should be given some rest before it is put into operation again.
13. After threshing season, all the belts should be removed and the machine should be kept in a covered place.

11.4.5 Trouble shooting methods in threshers

Problem	Adjustment
1. Un threshed grain in ear heads	1. Increase cylinder speed 2. Reduce cylinder-concave clearance 3. Feeding should be uniform
2. Cracked or broken grains	1. Reduce cylinder speed 2. Increase cylinder-concave clearance
3. Paddy straw wrap around cylinder	1. Increase cylinder speed
4. Grains blows with straw	1. Decrease the fan speed 2. Clean the sieve holes
5. Straw is coming with grain	1. Adjust the fan speed 2. Use proper size of sieves 3. Clean the concave 4. Adjust the straw rack speed
6. Vibration in thresher	1. Install the thresher properly 2. Tighten the bearing

11.4.6 Preventive maintenance

1. Before operating the machine, all bolts and screws should be checked for tightness.
2. Bearing caps should be removed and bearings filled with grease gun after every 20 hours of operation. Wood and metal carriers for the straw rack, sieve and grain pan and crank shaft connecting rod bearings, should be oiled with waste oil.
3. Foreign matter (if any) in the crop should be removed.
4. Threads on the concave adjustment and bolts should be oiled or greased occasionally.
5. Damaged and bent parts to be checked and repaired.
6. Sieves to be checked and cleaned if necessary.

11.4.7 Terminology connected with power thresher

Clean grain: It is the threshed grain, free from foreign matter and broken grain.

Cleaning efficiency: It is the cleaned grain received at main grain outlet (s) with respect to the total grain mixture received at main grain outlet (s) expressed as percentage by mass.

Concave clearance: It is the clearance between beater or cylinder tip and concave.

Feed rate: It is the quantity of crop fed into the inlet of thresher per unit time.

Threshing efficiency : The threshed grain received from all outlets with respect to total grain input expressed as percentage by mass.

Blower loss: The percentage of grains blown by blower along with bhusa with respect to total grain input in the thresher by weight is called blower loss.

Sieve loss: The percentage of healthy grains, dropped from sieve with respect to healthy grains, received from main outlet by weight is known as sieve loss.

Cylinder loss: The percentage of un-threshed grains from all outlets with respect to total grain input in the thresher by weight is called cylinder loss.

Visible damage loss: The percentage of broken or cracked grains from all outlets with respect to total grain input in the thresher by weight is known as visible damage loss.

Lecture No.12

Winnowing - manual and power operated winnowers, care and maintenance.

Winnowing is the process of separating grain from a mixture of grain, chaff and other impurities in an air stream from a natural or artificial source. The winnowing operation is very common in India. It is done on the threshing floor where the entire harvested crop is threshed. Usually one or more persons pour the threshed material with a basket from slightly above their own height. For more effective cleaning, they shake the basket while pouring the mixture against the effective direction of air stream. Before the winnowing is started, the threshing floor is thoroughly cleaned and sometimes plastered with cow dung, so that the soil may not mixed with the grain. Winnowing of crops like paddy, in which chaff is very small fraction is accomplished in one operation only. But the second winnowing becomes necessary for cops like wheat, barely, gram etc, in which bhusa (chaff) constitutes about 1/2 to 2/3 of the total weight of the mixture.

12.1 Principle of winnowing

Separation is achieved by allowing the air stream to pass through the mixture falling vertically down, Density difference of the components of mixture, namely, heavier grain, lighter chaff and bhusa, is responsible for separation when suspended grain is in air steam. The grain being the heavier material gets deposited almost at the place of dropping, whereas the lighter material (chaff) is blown away to a greater distance.

12.2 Winnowing devices

The following devices are commonly adopted for winnowing process:

1. Winnowing basket
2. Winnowing fan
3. Winnower

12.2.1 Winnowing basket

The use of winnowing basket is the oldest and common method of winnowing in India. It makes use of the natural wind, which is very frequent and effective at the time of harvesting. For this purpose, a convenient place is selected, high enough from the general field level. The thresher grain is collected near the winnowing platform. One man stands on the platform with the basket full of grain to be winnowed. Keeping his hand up and continuously stirring the basket, very slowly, he drops the grain. As the grain falls, the broken straw and chaff, being lighter than the seed, are taken at a far distance by the blowing wind. The grain being heavier than the straw, falls very near to the platform. Thus two heaps are formed, one of grain and the other of straw, which are collected separately.

12.2.2 Winnowing Fans

When the natural wind velocity is not adequate, artificial means are used to create a sufficiently strong air blast. Winnowing fans either manually operated or mechanically operated, are mostly used. Manually, operated fans of various types are available for use in India. Most often, the hand operated or pedal operated winnowing fans are used by farmers. In either case, the fan blades create a steady blast of air at the front side of the fan. One or more workers standing on the front side can drop the threshed material for effective separation. The distance where the threshed material is poured on the front side of the fan has the most important effect in winnowing. Some of the experiments performed with a pedal operated winnowing fan at about 1.8 m distance from the fan, along its central line. It was found that, the most effective cleaning can be obtained in that zone.

Various type of hand operated and pedal operated winnowing fans are being manufactured by many firms in India (Fig.24). The number of blades on their impellers is either three or four. The diameter of the impellers varies from about 0.90 to 1.25 m. Mostly, the blades are made of mild steel sheet and their frames are made of either wood or welded steel or a combination of the two. In order to increase the rotational speed, various driving mechanisms are employed, namely sprocket and chain, V-belt pulleys and single or double reduction gears. All these fans are without casing around the impeller and they are expected to be operated in the speed range of 200-350 rpm.

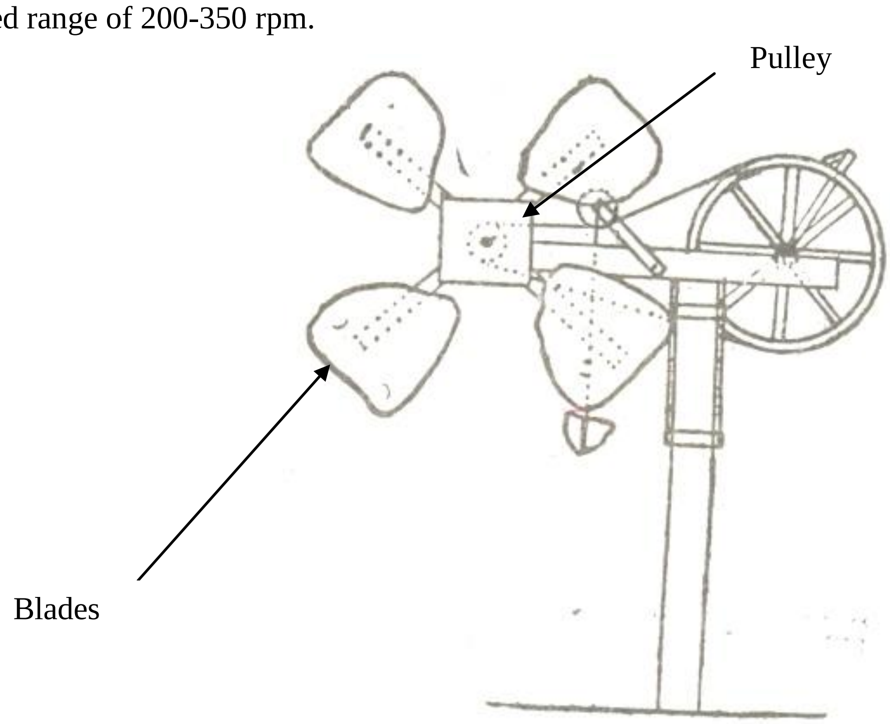


Fig. 24. Winnowing fan

12.2.3 Winnower

The winnower consists of wooden or angle iron frame, housing, blower, feed hopper, feed and purity adjustment mechanisms, grain outlet, immature grain outlet, chaff and dust outlets and blower hand wheel with gears and pulley arrangement (Fig.25). Walls of the feed hopper taper towards inside from all sides and ensures gravity flow. Flow of the mixture is regulated by the feed rate adjustment mechanism, which makes the mixture to fall as a thin stream perpendicular to the air current, is essentially a gate obstructing the flow below the feed hopper. Blower consists of four curved blades mounted horizontally on a shaft with two ball bearings. The shaft carries a small gear (pinion) at its one end that meshes with a bigger gear. The bigger gear is rotated by handle provided at its periphery. On the other end of the shaft, a V-belt pulley is attached for possible mechanized operation and also it acts as a flywheel. Ring gear has 66 teeth and the pinion has 20 teeth giving a speed ratio of 3.3: 1 or 4:1 i.e., the diameter of big gear is 3.3 or 4 times bigger than the pinion. For one revolution of bigger gear will give four revolutions to the blower. Thus, if the handle is turned at a speed of 50 revolutions per minute (rpm) , the blower will rotate at a speed of 165 or 200 rpm. The sieve is placed in front of the fan at the lower end of the winnower. A set of sieves are supplied with machine to suit the different sizes of grains. These sieves have holes of 12, 8, 6, 4, 3 and 2 mm diameter. The sieve is reciprocated by an eccentric roller which gets its motion from the axle of the blower. The reciprocating action of the sieve permits the grains and dirt particles to fall down, while the straw is blown out.

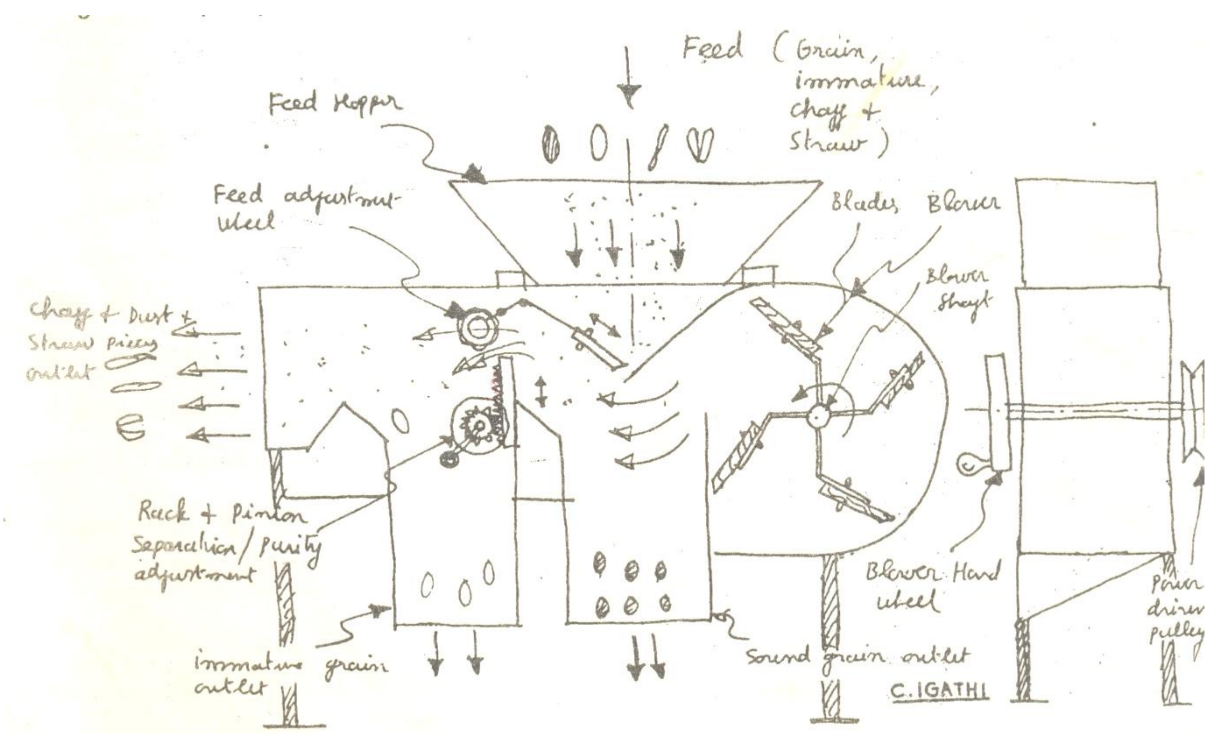


Fig. 25. Winnower

12.2.3.1 Working of winnower

As the mixture falls into the air current, the lighter materials and chaff are blown through the opening for chaff and husk outlet by the air blast, while the good grains being heavier fall directly below and guided out by the grain outlet. Immature grains that are relatively lighter will be carried by the blast a little away from the good grain outlet and collected by the immature grain outlet. Purity adjustment mechanism is a wooden plank kept in between the grain and immature grain outlets in the air flowing path and is raised or lowered by a rack and pinion arrangement. It diverts major portion of the immature grains to the good grain outlet when lowered and immature grains are also collected; when raised the free flowing air will carry some quantity of good grains also to the immature grain outlet but improves the purity of grains in the good grain outlet. Proper rpm of the blower and feed rate and purity adjustments are essential for efficient winnowing of the grains from the other lighter fractions.

Lecture No.13

Groundnut decorticators - hand and power operated decorticators, principle of working, care and maintenance.

Groundnut is the 13th most important food crop of the world. It is the world's 4th most important source of edible oil and 3rd most important source of vegetable protein. Groundnut seeds contain high quality edible oil (50%), easily digestible protein (25%) and carbohydrates (20%). It is grown on 26.4 million ha worldwide with a total production of 36.1 million metric tons, and an average productivity of 1.4 metric tons/ ha (FAO, 2004). Groundnut is grown in nearly 100 countries. Major groundnut producers in the world are: China, India, Nigeria, USA, Indonesia and Sudan. In India, groundnut is grown on 5.7 million ha with a production of 4.7 million metric tons, with an average productivity of 0.8 metric tons/ ha during the rainy season and in the post-rainy season it is grown on 0.9 million ha with a production of 1.5 million metric ton, and an average productivity of 1.6 metric tons/ ha.

In Andhra Pradesh, it is grown on 1.6 million ha during the rainy season with a production of 1.6 million tons, and during the post rainy season it is grown on 0.3 million ha with an production of 0.4 million tons. Anantapur district in the state is the largest producer of groundnut with 0.74 million ha of area under cultivation. Globally, 50% of groundnut produce is used for oil extraction, 37% for confectionery use and 12 % for seed purpose. In India, 80% of the total produce is used for oil extraction, 11% as seed, 8% for direct food uses and 1% is exported. Groundnut is one of the major farm crop of the Southern and Western states of India. However, with the establishment of “Technical Mission on Oil” seeds in India, the spread of groundnut has reached in the non traditional regions namely Orissa, Bihar, Assam and U.P. also. It is number one oil seed crop of the country.

Both digging and shelling of groundnuts present a great problem in making the product ready for market. The process of obtaining kernels from the stripped groundnut pods is known as decortication. Mostly decortication is usually done by breaking the shell by hand pressure under the thumb. Manual decortication by hand is laborious, expensive and less productive. But now, the commercial hand and power operated groundnut decorticators are being used in the country. Both these machines work on the same principles. The main difference lies in their capabilities. After decortication, separation of grain from a mixture of grain and split shells is done in an air stream. The separation is achieved by allowing the air stream created artificially or naturally and passing the mixture vertically down, perpendicular to the air blast. The grain being heavier gets collected almost at the place of dropping, whereas the lighter material (split shells) is blown away to a greater distance. The hand operated one has a capacity of about 200 kg/h and the mechanical decorticator has 500 kg/h capacity.

The Groundnut decorticator performs essentially 3 operations namely 1) Feeding groundnut to the shelling unit, 2) Shelling groundnuts and separating nuts from the shell and 3) Cleaning the nuts from the mixture.

13.1 Types of decorticators

The groundnut decorticators are classified into two types based on principle of operation:

(1) Rotary decorticators

(2) Rocking decorticators

13.1.1 Rotary decorticator

It consists of a rotating shelling cylinder which is mounted on a shaft and a grate. Shelling of pods is effected by the crushing action between the cylinder and the grate.

13.1.2 Rocking decorticator

It consists of a number of detachable rectangular beaters having conical studs made of cast iron in a slotted or perforated trough. The pods struck between the beater and the trough is crushed and broken. The shell and nut mixture pass down through the slots of the trough.

The groundnut decorticators are classified into two types based on source of power:

(1) Manual type

(2) Power operated

Manual type groundnut decorticators are further classified into:

(a) Hand operated rotary decorticator

(b) Pedal operated rotary decorticator.

(c) Hand operated ’’ rocking type’’ decorticator.

13.1.3 Hand operated rotary type decorticator

It consists of a wooden or cast iron shelling drum and a steel grate. Shelling of the nuts is accomplished in the clearance between the drum and the grate. The output of the machine is 0.4 to 0.6 quintals of pods/hour.

13.1.4 Pedal operated rotary type decorticator

It is operated by foot. The motion from the foot pedal is transmitted to the cylinder through a connecting rod and a set of spur gears. This machine provided with a fan. The fan is operated by means of pulley mounted on the cylinder shaft. The kernels are separated from the shell by the winnowing fan.

13.1.5 Hand operated ’’rocking type” decorticator

It consists of the following parts: (a) angle iron frame, (b) trough of radius 28 cm (c) steel handle, and (d) beaters. The beaters are fixed to the handle at the bottom and operate in to and fro motion. The pods are put into the trough and the handle is operated to and fro to decorticate the pods. The decorated pods are collected beneath the through. It requires two persons to operate and can shell **1 to 1.25** quintals of pods/hour. It can also be run by a small 1.5 Hp engine (Fig.26).

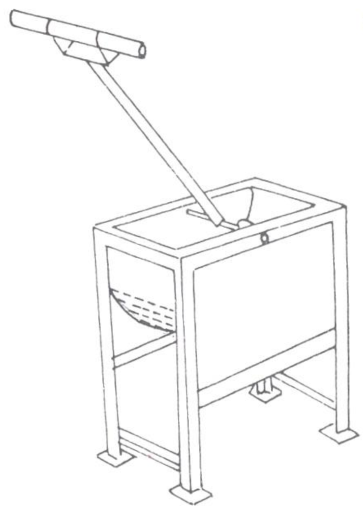


Fig. 26. Hand operated rocking type decorticator

13.1.6 Power operated rocking type decorticator

A power operated groundnut decorticator require 8 hp engine to shell about 75 to 80 bags (1875 to 2000 kg) of groundnut per hour (Fig.27). The machine has to perform the following functions: (a) Feeding of groundnuts to the shelling unit, (b) Shelling of groundnuts and separating nuts from the shell and (c) Cleaning the nut from the mixture. It consists of the following main parts: Feeder mechanism, Shelling unit and Crushing section. **The feeder mechanism** consists of a hopper, feeder shaft and pawl and ratchet wheel to drive the shaft. Groundnuts are fed to the machine at a uniform rate. Feed rate can be varied by adjusting the stroke of the pawl. **The shelling unit** is provided with two main parts, namely crushing plate and a grate. The crushing plates are made of close grained semi steel. Six small externally grooved channels are mounted on radial arms of the main rotor shaft which rotates at about 110 rpm. As the main rotor shaft is operated, the external grooved surface channels, roll and shell groundnuts. The crushing plates are bolted to the externally grooved channels and mounted at an angle resulting in unequal gaps on both ends between the plates and the grate. The minimum uniform gap of 2.5 to 3.2 cm between the lower edge of the plates and inner surface of the grate gives satisfactory operation. The grate is composed of a flat steel bars placed horizontally on their edges with a small space between the bars can be done by changing the thickness of the washers used on them, to suit any size of pods. A fan, which is operated at **450 rpm** by the main rotor shaft, is the basic part of the **cleaning section.** The blades of the fan are made of iron sheets bolted to angle iron arms on both sides**.** The blast of air created by the fan is strong enough to blow away the broken empty shell, so that the heavy nuts fall into the bottom pan by gravity.

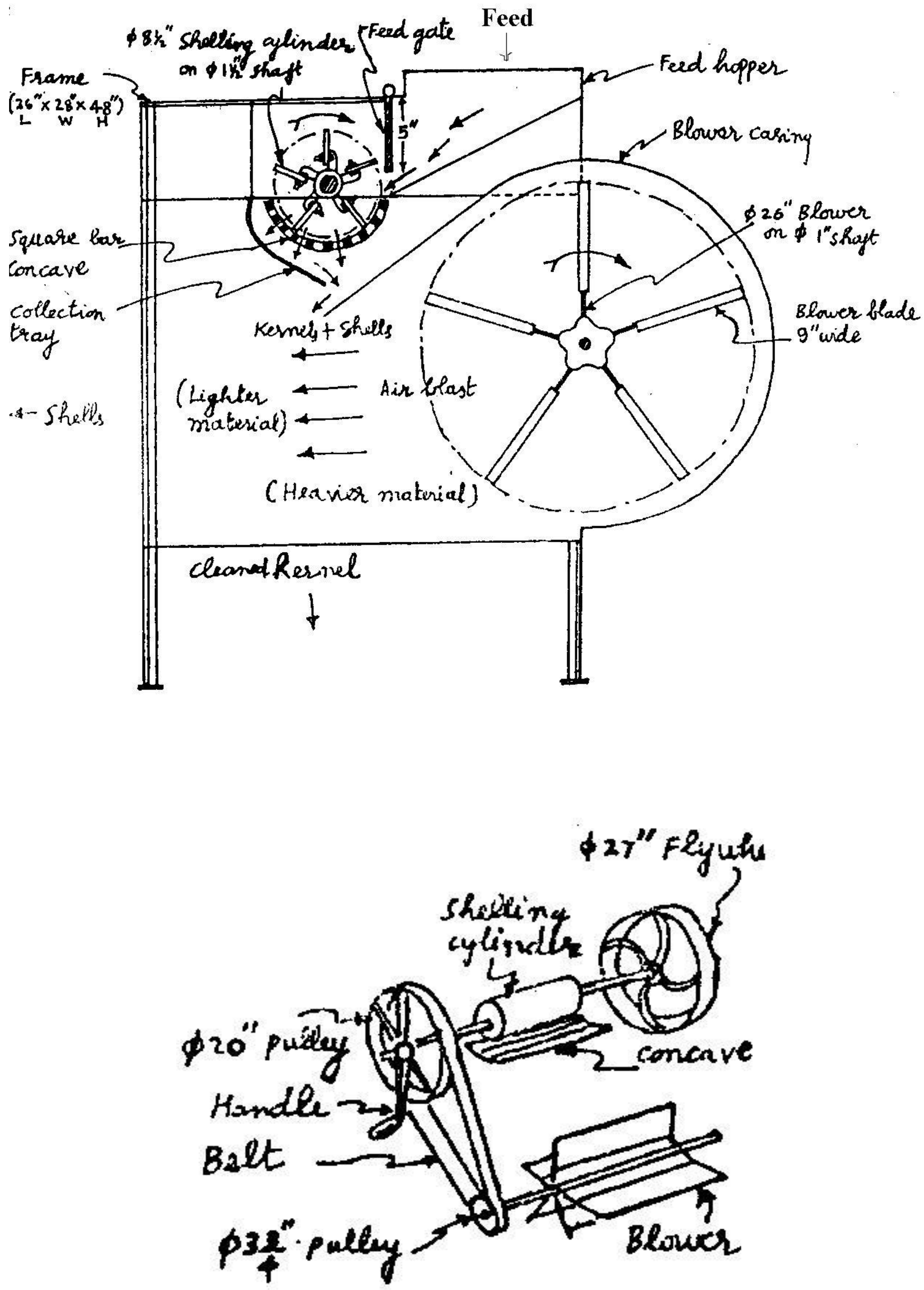


Fig. 27. Power operated rocking type decorticator

Lecture No.14

Castor and maize shelling - manual and power operated shellers, principle of working, care and maintenance.

Shelling operation usually follows threshing of harvested crops. In shelling, the beans or kernels are extracted from the protective coat known as shell, hull or husk. Though the operations are known by different names such as shelling, dehusking, milling and decortication, they are thought to be synonymous and are specific to the crop handled. These operations essentially produce the same out put, which can be directly utilized or processed further. In shelling, the input to the machine being the whole pods and the output is the kernels, whereas in threshing the input is whole crop. For shelling of some crops, the principle of threshing can be used but for others a variety of mechanisms are to be sorted for, based on the crop characteristics. It is a common practice to dry the input material on an appropriate level for a efficient shelling. The output obtained from sheller is cleaned by winnowing or aspiration methods.

14.1 ANGRAU castor sheller

This castor sheller was developed at farm implements and machinery (FIM) Scheme, ANGRAU, Hyderabad (Fig.28). The machine can be operated by two persons and has a working capacity of 100 kg/h. Cleaning of the shelled kernels should be done separately. A power operated unit has also been developed. The breakage of beans in hand operated sheller is less than 2.0%.

14.1.1 Working principle

The chief component of the sheller is the wooden ribbed cylinder or drum of 320 mm length and 380 mm diameter. The other parts are concave, cylinder cover, feeding chute, discharge chute, drive mechanism and crank. The clearance between the cylinder and concave can be adjusted to shell different sizes of castor beans. Since the force required to break the shell and release the seed is moderate, wooden ribbed cylinder is the proper choice, which produces lesser broken seeds and also reduces the overall weight of the machine. Shelling cylinder is operated by crank through a gear unit which increases the speed of the cylinder. The dried pots fed to the inlet chute will be gradually fed to the clearance and shelling takes place due to crushing and rubbing action between the cylinder and concave. Shelled output is nothing but the seeds and broken hull pieces, which can easily be separated by a manual cleaning process of winnowing. While the unit is in operation, one person operates the sheller by cranking and another is required to feed, collect and clean the materials.

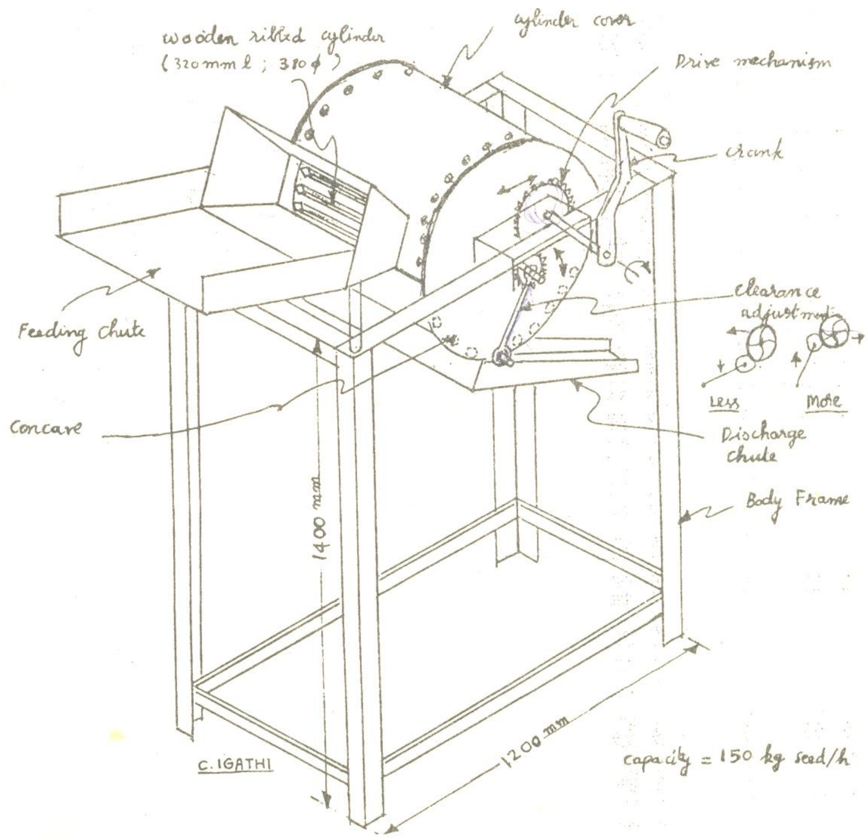


Fig. 28. hand operated castor sheller

14.2 Tubular hand maize sheller

Maize being an important crop of India, mechanical shellers are in great demand by the growers. Even small and marginal farmers need manually operated **(hand held**) or table mounted maize shellers. The traditional method of separating kernels from cobs by pressing with fingers or with sickle is tedious operation. The simple hand tools developed can be successfully used by the growers of this crop in small plots yielding small quantity of grain. The three models shown in the above figures are made of **G.I.** pipe at a minimum cost. The capacity of these shellers ranges between **25** and **50** k g of grain per hour.. Maize sheller is used to remove corn pearls from the cobs. Tubular hand maize sheller is a simple metal pipe of diameter 65 mm and length 70 mm with four tapering blades or vanes welded on the inner surface of the pipe equally spaced.

Shelling action of vanes is similar to the operation done by the fingers. The pipe is made of 1 mm thick mild steel sheet. The sheet is rolled over a cylindrical mandrel (to form the cylindrical shape) and is welded at the ends. The vanes are 55 mm in length and are tapered from a width of 27 to 22 mm. These vanes are bent in ‘L’ shape and bottom portion of vane is welded to the inner surface of the cylinder. One leg of the vane will be supported by the inner cylindrical face and the other will project radially towards the centre and acts as the shelling element. These four vanes are placed at an equal interval of 90 degrees (Fig.29).

14.2.1 Working Principle

The cob is pressed at the input end of the tube and sheller is rotated and simultaneously pushed forward. After shelling on same length, the shelled cob is pulled out from the output end with rotation. The corn should be at matured stage at the time of shelling. If immature cob is used, it results in heavy breakage of the pearls. When the size of the cobs vary widely, then a single tubular maize sheller may not work for all cobs. The sheller has a maximum working space at feeding end is 40 mm diameter and outlet end is 30 mm diameter, which means that cobs more than 40 mm stalk diameter will get choked during operation and cobs less than 30mm diameter will come out without getting shelled.

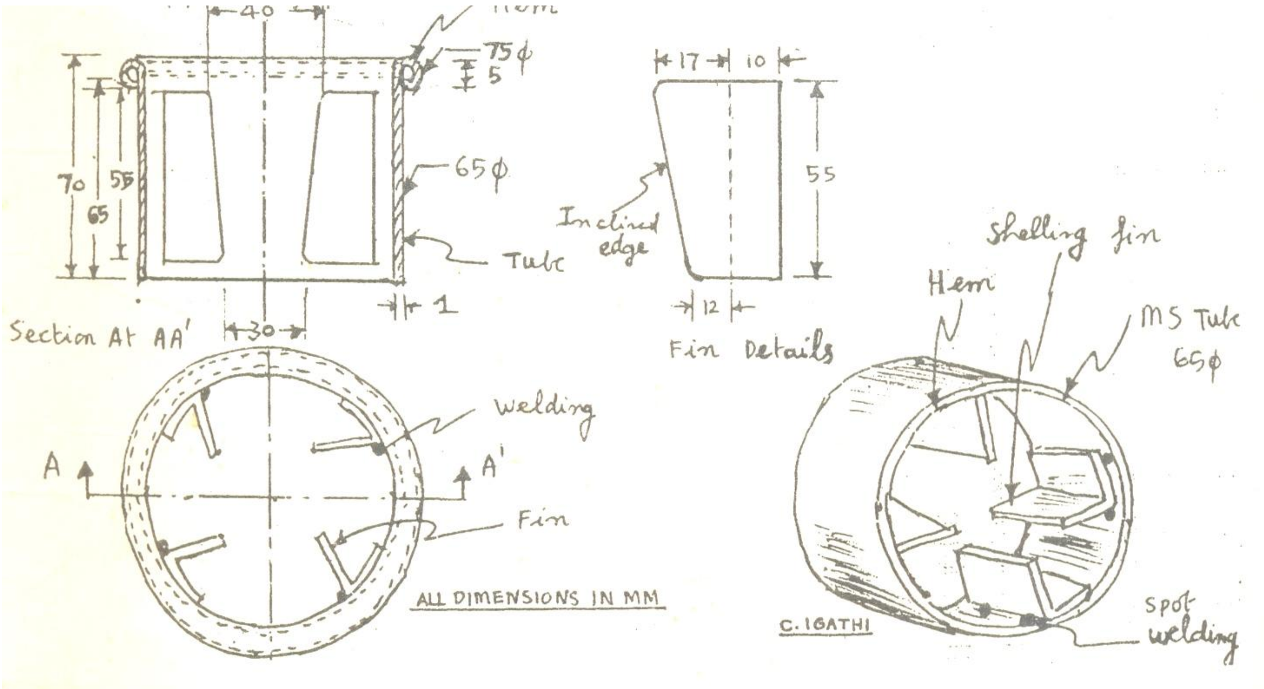


Fig. 29. Construction details of tubular hand maize shellers

Lecture No.15

Drying – types, grain dryers.

Drying is the universal method of conditioning grain by removing moisture to a moisture content level that is in equilibrium with normal atmospheric air in order to preserve its quality and nutritive value for food and feed and its viability for seed. Generally, drying refers to the removal of relatively small amount of moisture from a solid or nearly solid material by evaporation. Therefore, drying involves both heat and mass transfer operations simultaneously. Two major moisture removal methods are **drying** (or dehydration) to produce a solid product and **evaporation** to produce a more concentrated liquid. **Drying** refers to removal of moisture from grains and other products to a predetermined level, whereas **dehydration** means removal of moisture to very low levels usually to bone dry condition.

15.1 Moisture content

All agricultural products are hygroscopic in nature and contain some percent of moisture. This moisture content of substance is usually expressed in percentage by weight. Two methods are used to express this moisture content. These methods are wet basis (*m*) and dry basis (*M*).

Moisture content, wet basis

Moisture content is usually expressed is percentage by weight on wet basis as

$$m = \frac{W_m}{W_m + W_d} * 100 \ldots\ldots\ldots\ldots(1)$$

W_m = Weight of moisture

W_d = Weight of bone dry material

Moisture content, dry basis

$$M = \frac{W_m}{W_d} * 100 = \frac{m}{100 - m} * 100 \ldots\ldots\ldots\ldots\ldots(2)$$

The moisture content on dry basis is more simple to use in calculation as the quantity of moisture present at any time is directly proportional to the moisture content on dry basis. Use of the wet basis measurement is common in the grain industry. However, use of the wet basis has one clear disadvantage is that, the total mass changes as moisture is removed. Since the total mass is the reference base for the moisture content, the reference condition is changing as the moisture content changes. On the other hand, the amount of dry matter does not change. For a given product, the moisture content dry basis is always higher than the wet basis moisture content.

Problem : The moisture content of grain is 25% on w.b. and is equal to -----% on d.b.

M= 25/75= 33.3 % d.b.

15.2 Moisture measurement

Moisture content can be determined by direct and indirect methods. Direct method includes air-oven drying method (130±2^{0}C) and distillation method. Direct methods are simple and accurate but time consuming, where as indirect methods are convenient and quick but less accurate.

Direct method: Grind the sample (2 to3 g), keep the sample in oven for about 1 hour at 130±2^{0}C and place the sample in desiccator and then weigh.

Distillation method: 100 g grain + 150 ml mineral oil is heated in a flask at 200˚C for 30-40 minutes. Moisture condenses in a measuring cylinder.

15.3 Methods of drying grains

Drying of grains can be done in different ways depending upon the source of heat utilized for the purpose. The most common methods are based on the **mode of heat transfer:** Conduction drying: (i) conduction drying, (ii) convection drying, and (iii) radiation drying. The other methods of drying are: dielectric drying, chemical drying, vacuum drying and freeze drying. Convection drying is commonly used for drying of all types of grain and conduction drying can be employed for drying of parboiled grain.

15.3.1 Conduction drying

When the heat for drying is transferred to the wet solid mainly by conduction through a solid surface (usually metallic), the phenomenon is known as conduction or contact drying.

15.3.2 Convection drying

The drying agent (hot gases) in contact with the wet solid, is used to supply heat and carry away the vapourized moisture. The heat is transferred to the wet solid mainly by convection. Convection drying is most popular in grain drying. Fuel consumption per kg of moisture evaporated is always higher than that of conduction drying.

15.3.3 Radiation drying

It is based on the absorption of radiant energy of the sun and its transformation into heat energy by the grain. Sun drying is an example of radiation drying.

15.4 Classification of grain drying

Grain drying is classified based on two principles: (i) Thin layer drying and (ii) deep bed drying.

15.4.1 Thin layer drying

Thin layer drying refers to the grain drying process in which all grains are fully exposed to the drying air under constant drying conditions, i.e., at constant temperature, and humidity. Generally, up to 20 cm thickness of grain bed is taken as thin layer. All commercial flow dryers are designed on thin layer drying principle. The features of thin layer method of grain drying are

a) Limited to 20 cm of grain depth

b) Drying rate is independent of air velocity

c) At a given RH and moisture content, the drying rate is proportional to the difference between the dry bulb temperatures of air in equilibrium with the grain.

d) The rate of drying is proportional to the difference between the vapour pressure of moisture in the grain and vapour pressure of moisture in the drying air.

15.4.2 Deep bed drying

Deep bed drying process refers to the heterogeneous drying of grain in deep layer (more than 20 cm deep) where drying is faster at the inlet end of drying chamber than at the exhaust end.

The drying of grain in a deep bin (Fig 30.) can be taken as the sum of several thin layers of grain arranged one above another. The rate of moisture removal is maximum for the bottom layer and decreased exponentially for subsequent layers. Dry air becomes cooler and moister as it moves up in the grain bed. Actually, all grains in the drying chamber may be considered to be in 3 zones: (a) dried zone; (b) the drying zone; (c) the wet zone. The dried zone will gradually move upward as drying proceeds in the direction of air movement. The air passes through the dried zone and picks up moisture in the drying zone until it reaches equilibrium moisture content (EMC) in the case of very wet grain. In this way, as the air moves, its drying capacity goes on decreasing. Drying will cease as soon as the product comes in equilibrium with the air. The upper edge of the drying zone at the interface with the wet zone is called the drying front. The drying front indicates the level of grains in the bin at which, the grain have just started loosing moisture to the drying air. The volume of drying zone varies with the temperature and humidity of entering air, the moisture content of the grain and velocity of air movement.

The drying rate in a bin varies from layer to layer from time to time and depends upon the characters of grains and the air used for drying.

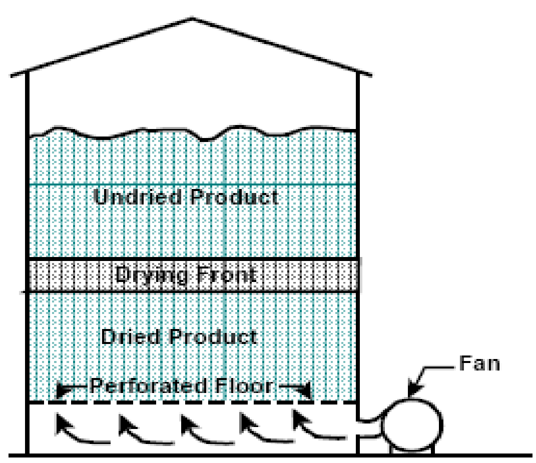


Fig.30. Drying process in deep bin

15.5 Sun drying

This is a traditional method of drying of crops and grains. Sun drying involves using the energy of the sun to remove moisture from the product. Major portion of crops is left in the field and threshing yard for drying under sun. A major quantity of grain is still dried by the sun in most of the developing countries. The advantages of sun drying are:

1. No fuel or mechanical energy is required.
2. Operation is very simple

3. Viability, germination, baking qualities are fully preserved.
4. Microbial activity and insect/pest infestation are reduced.
5. No pollution
6. Low capital requirement
7. Operating costs are considerable.

The disadvantages of the sun drying are:
1. Uncontrolled and non-uniform drying, results in sun checks or cracks in kernels.
2. Completely dependent on weather.
3. Not possible round the clock and round the year.
4. Excessive losses occur due to shattering, birds, rodents etc. It is usually 0.1 to 0.4%.
5. Require specially constructed large drying floor.
6. The entire process is unhygienic.
7. Unsuitable for handling large quantity of grain within a short period of time.
8. Require large number of unskilled labour.

15.6 **Mechanical drying**

This process utilizes mechanical means to circulate heated air at constant temperature and humidity, through the grain mass to accomplish the removal of excess moisture from the grain. Its features are: (a) the rate of drying can be controlled by adjusting the temperature of hot air circulating through the grain mass. Therefore, increase in milling quality with possible reduction in development of cracks in the grain. (b) Grains can be dried irrespective of weather condition, day or night; the process does not depend on any natural sources like sun energy. (c) The process is automatic and requires unskilled labour, except a trained person to operate the dryer. (d) there are practically no losses due to birds, rodents and insects. (e) The entire process is hygienic. (f) Possible round the clock and round the year and (g) Suitable for handling of large quantity of grain with in a short period of harvest. Mechanical drying requires very little space for operation. Mechanical drying, in conjunction with early harvest, improves the milling quality of paddy considerably. The disadvantages of mechanical drying are: the process requires fuel and electrical or mechanical power to drive the blower, elevators etc. Therefore, cost of drying is relatively higher compared to sun-drying for commercial drying.

15.6.1 **Mechanical dryers**

The mechanical dryers are classified as:

(a) Sack driers (storage layer driers, batch driers or bin driers).

(b) Rotary driers (batch or continuous)

(c) Continuous flow dryers

Non-mixing type - Recirculatory batch dryer

Mixing type - LSU type dryer & Baffle dryer

15.6.1.1 Sack drier

A sack drier (Fig. 31) consists of a large floor in a building with openings over which the sacks of grain are placed. The openings are covered with a perforated material to support the sacks. A blower is connected to an air chamber beneath the floor to supply the air. A sack dryer is best suited for drying a small quantity of grain. It eliminates the problem of mixing various paddy varieties. This type of dryer requires high labour cost. Usually air temperature of 45^0C is used with air flow rate of 4 m^3/min per bag of 60 kg for fast drying. The sacks are turned over once during the drying operation.

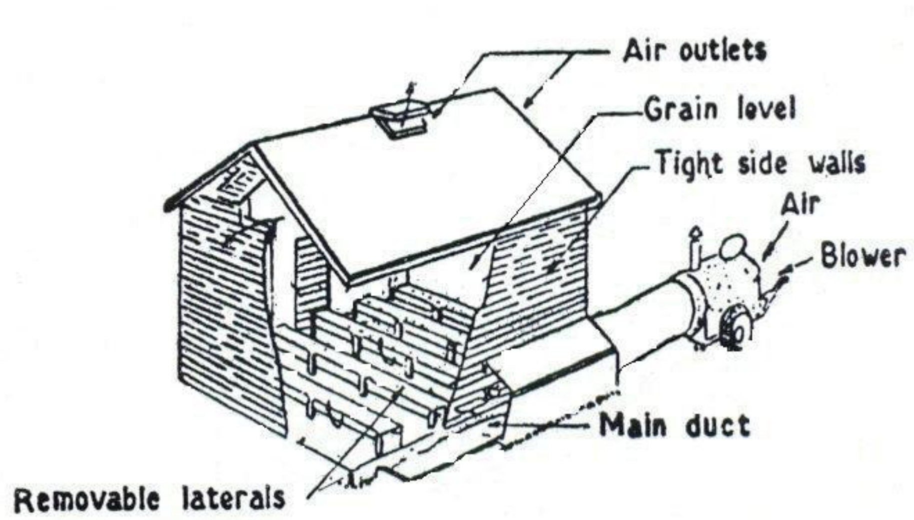


Fig. 31. Sack dryer

15.6.1.2 **Batch/Bin dryer**

This dryer dries a relatively small amount of batch of grain in sacks or in bulk. The grain is normally remaining static during the drying process. These batch dryers can be different shapes. The holding capacity ranges from one ton to several tons of grain. If the capacity is small they are called batch dryers otherwise they are called “bin dryers” and the process is bin drying. These bins could be circular, square, rectangular or hexagonal. If they are small, they could be portable. Drying in these bins is called deep bed drying. In a simple batch dryer, the grain is placed in a bin and heated air is forced through it until the desired moisture content is reached. The drying of the grain in the bin takes place following the deep bed drying principle (Fig. 32).

The normal air temperature recommended for batch or bin drying is 45ºC to 50 ºC. The recommended maximum depth of paddy grain is 200 to 250 cm and the minimum air flow rate is 3 to 4 m^3/min/cu.m of paddy.

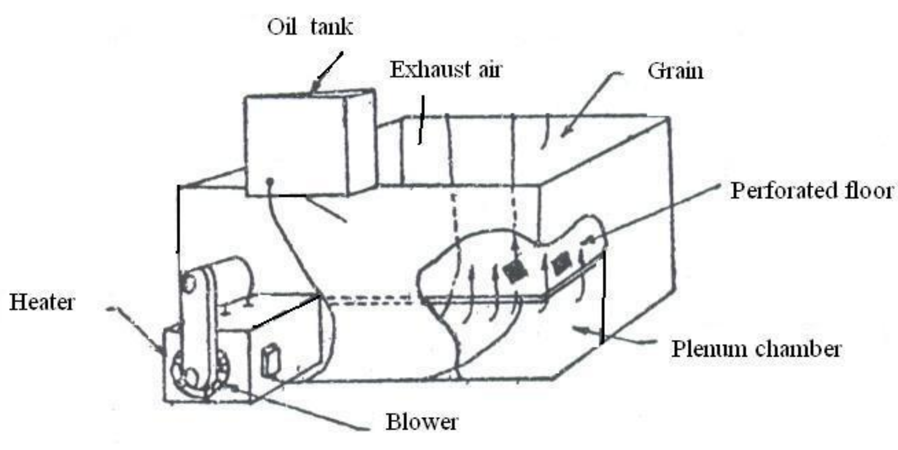


Fig. 32. Bin dryer

15.6.1.3 Rotary dryer

This dryer could be a batch or a continuous type. It is also called rotating drum dryer as it consists of a large drum 2m in diameter and 3 to 6 m in length, placed on a slight incline (Fig.33). Grain is fed into the upper end and as the unit rotates the grain move downwards and mixes with the air flowing around the grain and finally drops down on the lower end (grain and the air move in the same direction). This provides a continuous mixing of the grain with the drying air until the grain leaves the dryer at the lower end of the drum. Heated air acts here mainly as a carrier of moisture from the dryer. While traveling the grain from feed end to discharge end of the dryer, the parboiled paddy comes into contact with the steam heated pipes for a very short time in each rotation and is gradually dried. As parboiled paddy can stand high temperature without significant increase of cracks in grains, these dryers can be employed for rapid drying of parboiled paddy using temperatures as high as 100 to 110ºC. The cylindrical shell of the dryer is rotated at 2 to 6 rpm by a motor through speed reduction gear, pulley and belt drive system. In India, the Jadavpur university, Calcutta introduced a rotary dryer of 1 tonne/hour capacity for the drying of parboiled paddy.

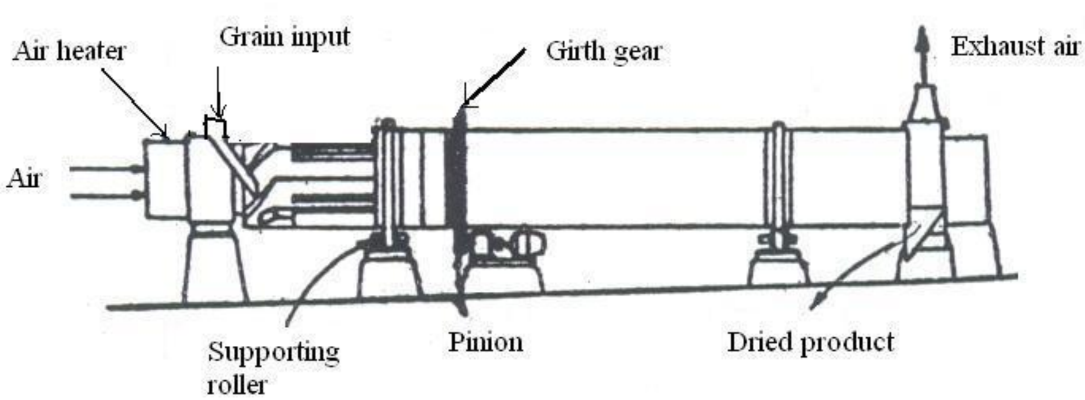


Fig. 33. Rotary dryer

15.6.1.4 Recirculatory batch dryer (RPEC dryer)

This is continuous flow **non-mixing** type of dryer**.** This dryer was developed at Rice Processing Engineering Centre (RPEC), IIT, Khargpur. It consists of two concentric circular cylinders made of perforated sheets of 20 gauge (Fig.34). The cylinders are set about 20 cm apart, to move the grain downward. These two cylinders are supported on four channel sections. A bucket elevator of suitable capacity is provided to feed and recirculate the grain into the dryer. A centrifugal blower blows the hot air into the inner cylinder which acts as a plenum. The hot air from the plenum passing the grain moving downward by gravity and comes out of the perforated cylinder. A torch burner is employed to supply the necessary heat with kerosene oil as fuel. RPEC dryers are made for half, one and two tones holding capacities.

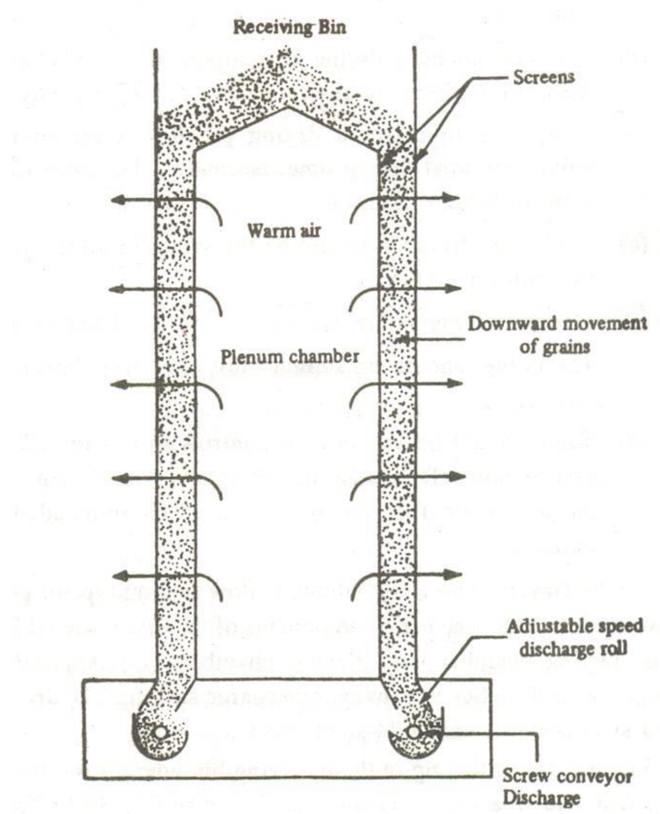


Fig. 34. Longitudinal section of a RPEC dryer (Non-mixing type dryer)

15.6.1.5 Continuous flow mixing type dryers

There are several types of continuous flow mixing type dryers. The most popular type in India and USA is the LSU type. The main advantages of continuous flow dryers are:

1. A shorter drying period, which is necessary with less danger of spoilage during wet season.
2. Larger volumes of paddy can be dried in less time.
3. Drying losses are less
4. Drying is more uniform as there is mixing of grain with air
5. The milling quality of paddy is better
6. Higher air flow rates could be obtained
7. The drying parameters can be controlled and therefore, also the drying rate.

15.6.1.5.1 Baffle dryer

This is a continuous flow **mixing type** of grain dryer. The main advantage with the dryer is uniformly dried product is obtained.

Construction

The baffle dryer consists of; (1) grain receiving bin, (2) drying chamber fitted with baffles, (3) plenum fitted with hot air inlet, (4) grain discharge control devices and (5) hopper bottom. A number of baffles are fitted with the drying chamber to divert the flow and affect certain degree of mixing of grain. The dryer is made of mild steel sheets.

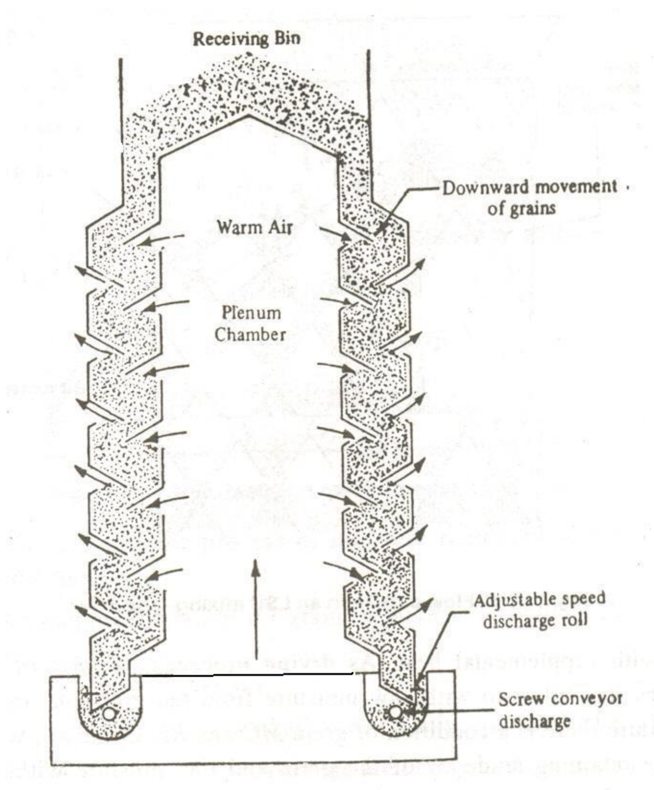


Fig. 35. Baffle dryer

Operation

Grain is fed at the top receiving bin and allowed to move downward in a zigzag path through the drying chamber where it encounters a cross flow of hot air. A bucket elevator can recirculate the grain till it is dried to the desired moisture level. This design helps in mixing of dried and undried grains.

15.6.1.5.2 Louisiana state university (LSU) dryer

This is a continuous flow-mixing type of grain dryer which is popular in India and the U.S.A. It was developed at Louisiana State University Baton Rouge, USA in 1949.

Construction:

It consists of :(1) a rectangular drying chamber fitted with air ports and the holding bin, (2) an air blower with duct, (3) grain discharging mechanism with a hopper bottom, and (4) an air heating system (Fig.36).

(1) **Rectangular bin**: Usually the following top square sections of the bin are used for the design of LSU dryers:

(i) 1.2m x 1.2 m, (ii) 1.5 m x 1.5 m,

(iii) 1.8 m x 1.8 m and (iv) 2.1 m x 2.1 m.

The rectangular bin can be divided into two sections, namely, top holding bin and bottom drying chamber.

(2) Air Distribution system: Layers of inverted trough or V- shaped channels (called inverted V-ports) are installed in the drying chamber.

Alternate rows of these ports are opened on the blower and closed on the exhaust end. These are called inlet ports Hot air enters the drying chamber through these ports. The other

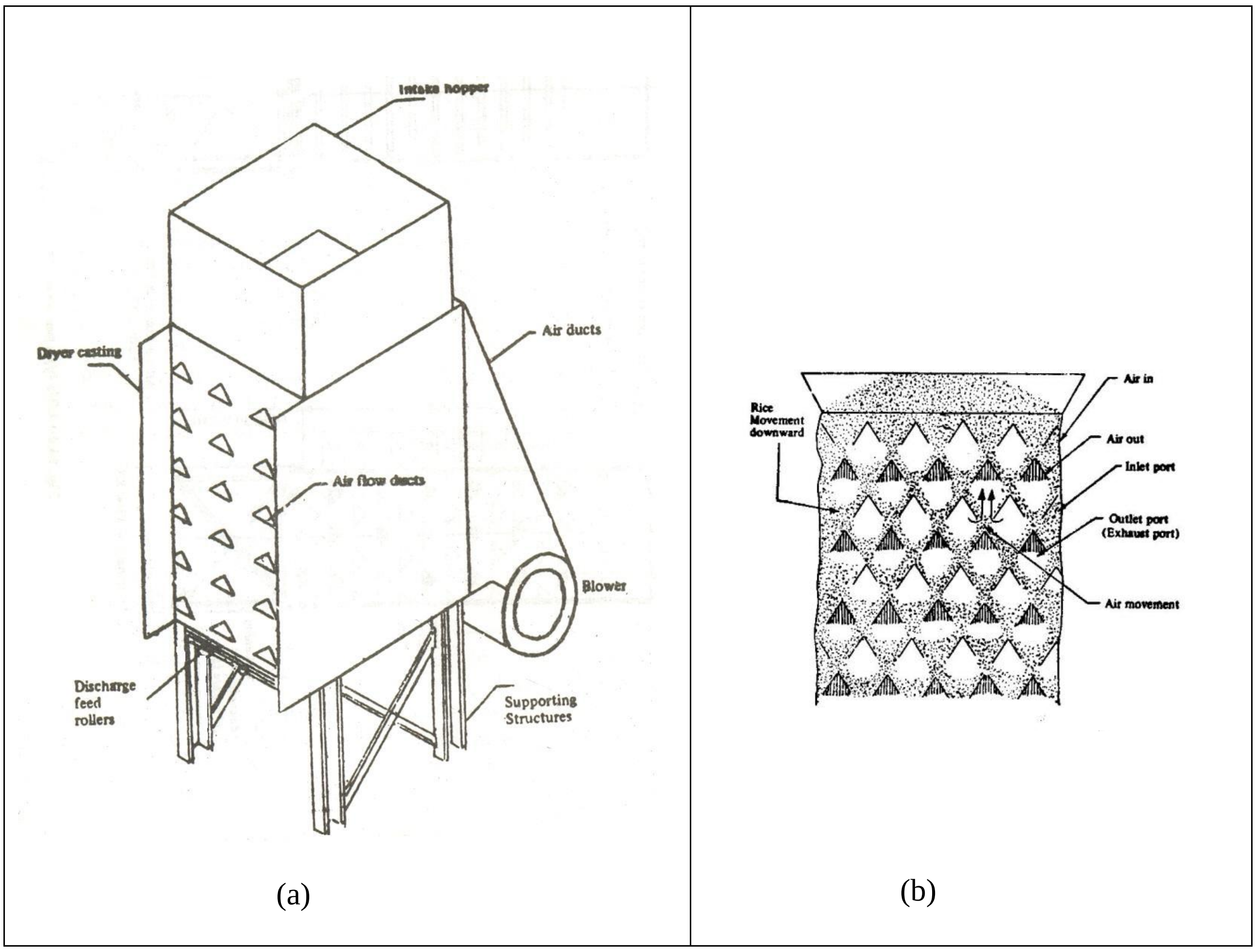


Fig. 36. (a) LSU type dryer and (b) flow pattern in LSU dryer

alternative rows of ports are closed on the blower end and are opened on the exhaust end. These are called outlet or exhaust ports as the drying air goes out through these ports. The inlet and outlet ports are of uniform sizes and equal in number with equal spacing in between them. Usually the inlet ports are given in 3 columns and outlet ports in 4 columns (2 column of full size ports and 2 columns of half-size ports). The number of ports containing a dryer varies widely depending on the size of the dryer. The inlet and outlet ports are arranged one below the other in a zig-zag path, so that when paddy flows down between these ports, it takes a zig-zag path. Hot air enters the inlet ports from the blower end. Since these ports are closed on exhaust end, the hot air from these channels or ports flows down through the paddy and enter the outlet ports and leave the drying chamber through exhaust side. Some degree of mixing of hot air and paddy occurs in this chamber while air is flowing across it in zig-zag path and paddy flowing downwards. Three fluted rolls are attached at the bottom, which are rotated at a slow speed. The discharge of the paddy is regulated with these fluted rolls. To provide hot air for drying, fuel is burnt to raise the ambient air temperature. Heat may be supplied by the direct fired burners or direct or indirect heat exchangers.

In general, the capacity of the dryer varies from 2 to 12 tonnes of grain, but sometimes dryers of higher capacities are also installed. Accordingly power requirement varies widely. Recommended air flow rate is 70 m^3/min/tonne of dry paddy and optimum air temperatures are 60-70^O C and 85^O C for raw and parboiled paddy respectively. A series of dryers can also be installed. In continuous flow dryers, drying air temperature may be as high as 70^{0}C, where as for batch dryers, this temperature seldom exceeds 45^{0}C. Following are some recommendations for the drying operation with particular reference to the operation of an LSU Dryer:

a) A drying cycle chart in the control room will be a great help and to guide the operator.

b) The dryer should not be operated until it is filled completely with grain.

c) The recommended drying air temperature is 60^O C and the air flow rate is 70 cu m/min./ ton of holding capacity of dryer.

d) Tempering in between drying process is recommended to reduce the total drying time. Normally, this tempering period is of 8 hour duration.

e) Feed roll clearance should be the same for all the fluted rolls for uniform drying.

f) The grain temperature during drying should not exceed 40^O C.

g) The burner should be started only after the blower has been started.

h) There should be appropriate controls to put the flame off in case of blower failure due to either power or mechanical failure. An automatic fuel cut-off valve is recommended for this purpose.

Lecture No.16

Storage - grain storage, types, bag storage, cylindrical grain bin, metal bin, rectangular grain bin, pusa bin.

There has been a spectacular increase in food grain production in India. The annual production was 208.6 million tones in 2005-06. However, there has only been a marginal increase in the structure for grain storage. This has resulted in losses both in quality and quantity of the harvested grain.

The qualitative loss may be due to chemical changes in the protein, carbohydrate and fat and by the contamination of micotoxins, pesticide residues, insect fragments, excreta of rodents and birds and their bodies. The quantitative loss in storage may be on account of the activities of the birds, rodent, insects, enzyme activity of micro organisms etc. The losses in quantity also occur in threshing yards, processing plants and during handling.

It is roughly estimated that about 2/3rd of the total grain produced is retained by the farmers for their food and seeds. The remaining 1/3rd quantity is considered as marketable surplus. The total storage capacity available with various agencies of the Government is of the order of about 10 per cent. It is obviously quite in adequate and needs to be increased considerably in order to reduce losses.

The main factors responsible for the losses in quality and quantity of grain are insects, rodents and dampness. Damage by insect pests results in the food grain becoming weevilled, causing losses not only in weight but also in food value. Leakage of water through roof, and dampness in the structure through floors and side walls make the grain deteriorate in many ways. One of the several effects is excessive oxidation which causes a rise in temperature of the grain, including its heating and cake formation. Moisture also encourages fungus, mould and termite growth, at times rendering the entire grain stock unfit for human consumption. Beside this, rats cause serious loss by eating or breaking the grains into pieces.

16.1 Requirement of good storage structures

A good storage structure should satisfy the following requirements:

(1) It should provide adequate protection from rodents, birds, insects, mites etc.

(2) It should permit aeration and fumigation when required.

(3) It should prevent losses due to moisture and temperature etc.

(4) It should permit easy inspection.

(5) It should facilitate proper cleaning and should be self cleaning if it is silo.

(6) It should be economical on unit storage cost basis.

16.2 Grain Storage Methods

(i)Keeping in bags in a house (Farmers level)

(ii) Keeping in bags on platform and covering them with polyethylene (CAP Storage)

(iii)Keeping in bags in godowns

(iv)Keeping in indigenous storage structures and traditional devices (Farmers level)

16.2.1 **Bag storage**

It is, therefore, essential that grain be stored in structures of standard types, after careful study, have been found suitable for different regions in the country. Grain is generally stored either in bags or in bulk. A combined system of bag-cum-bulk storage is also practiced in some parts of the country. In villages, the bulk storage system is more common than the storage in bags which is considered to be a practicable method of storing grain in the government godowns as well as in trade. The size of a bag used for grain storage is large enough to contain about 93 kg of grain. These bags are made of jute fibers and are commonly known as gunny bags.

16.2.2 Improved bag storage structure

These structures are generally used for the storage of 25 to 500 tonnes of grain. The length of the structure is about twice the width or greater than that. The structure should be large enough to store the required capacity and make the sides, floor and roof, moisture proof. Each of the structures are provided with two large size doors of 2.4 x 2.4 m and top ventilators. Each door is provided with a light over-hanging hood of 3.6 m, long and 2.4 m wide. A ground ventilator having an opening of 30 x 30 cm is provided below each corresponding top ventilators. The top of the ventilator is kept at a height of 60 cm above the floor level. It is also provided with iron rods, wire netting and a shutter. Besides this, a sun shade is provided on both the top and the ground ventilators (Fig. 37).

In order to ensure that the floor is damp-proof, it is made of different materials in six layers as stated below (Fig.37):

1. 15 cm thick layer of gravel and sand, well rammed at the bottom.
2. 12.5 cm thick layer of stone or brick ballast or double layer brick.
3. 10 cm thick layer of cement concrete (1:4:8) mixed with broken glass.
4. 1.25 cm thick layer of bitumen mixed with sand.
5. 4 cm thick layer of cement concrete (1:2:4).
6. 2.5 cm thick layer of cement concrete (1: $1^{1}/2$:3).

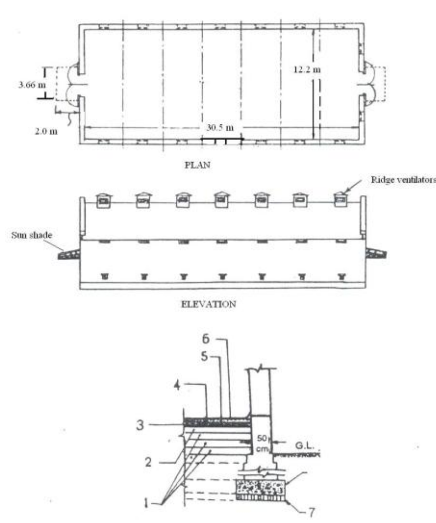


Fig. 37 . Construction details of bag storage system

The walls are made of bricks or stones laid either in lime mortar (1:2) or cement mortar (1:6). The wall thickness is restricted to a minimum of 37.5 cm or maximum of 45 cm. The roof is either gabled or flat. The gable roof is covered with corrugated metal sheet with maximum precautions taken to make it leak proof. However, a flat roof is more durable as it is made of either reinforced brick or reinforced concrete of about 10 to 12.5 cm thickness. The terracing on the roof is made of brick ballast, *surkhi* and lime in the proportion of $3^{1/2}$:1:1 respectively. Before putting up the terracing, a thin layer of bitumen is applied over the concrete roof.

16.2.3 Cylindrical grain bin

Cylindrical bulk storage structures are being used for storing different varieties of grain. Depending upon the size, the capacity may vary from 10 to 40 tonnes. The complete structure including its foundation is made of reinforced concrete. The minimum height of the bottom edge of spout should be about 1.2 m above the ground level. The entire structure rests on supporting columns. There are two openings provided in the structure for filling the grain and for taking it out. The top hole is made large enough to let a man enter for cleaning purposes. The size of the outlet is comparatively smaller. The outlet is placed at a point where the slope from all sides of the floor converges. It should have a hinged cap shutter with a locking device. The manhole at the top is also provided with a water tight steel lid. The roof on the top is provided with enough slope on all the sides and it overhangs to the extent of about 30 cm (Fig. 38).

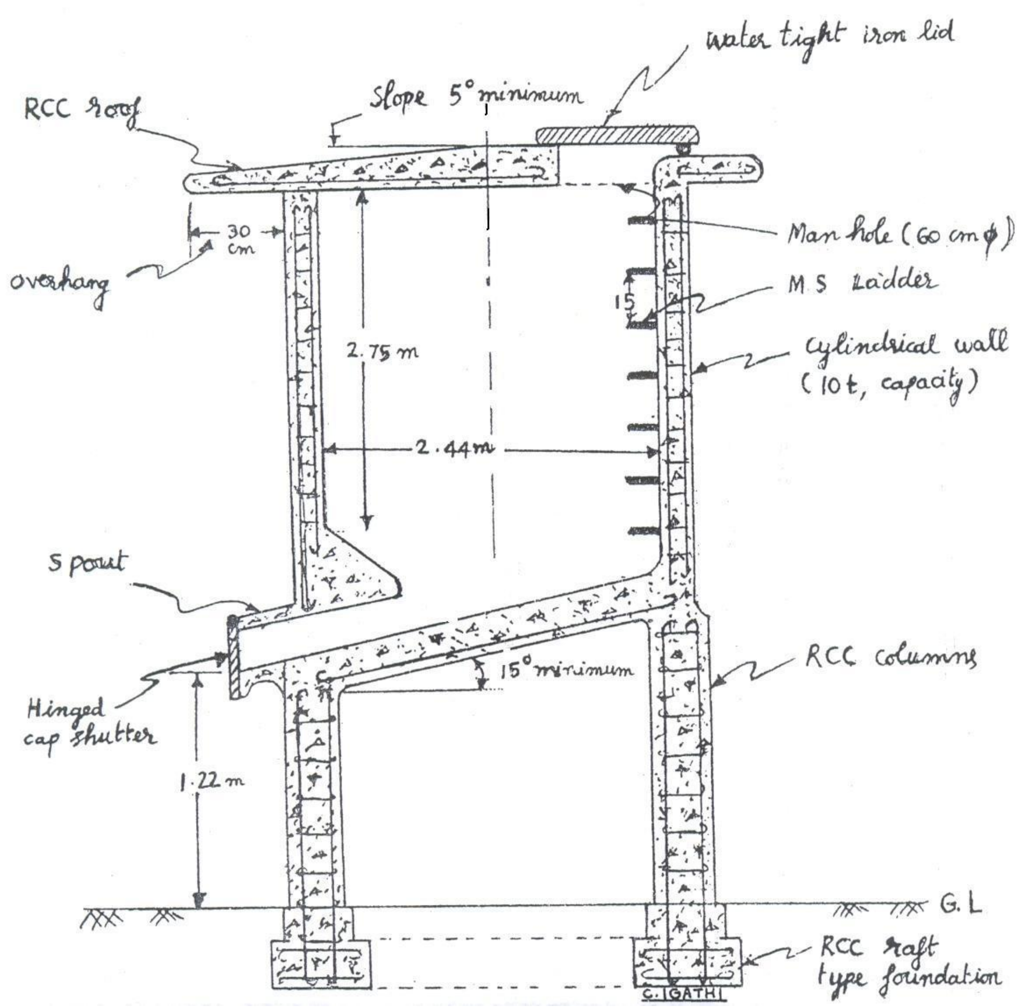


Fig. 38. Construction details of cylindrical grain bin

16.2.4 Rectangular grain bins

On a farm, where several grain crops are raised, different grain bins are made under the same shed to store all varieties of grain separately. The size of the bin is determined on the basis of expected average yield of the crop from the total area under the particular crop.

The bin walls are made 11.5 cm thick laid in cement mortar of 1:3 ratio. The bin walls are kept 2.4 m high near the outer wall, dropping down to 1.6 m in front. The front wall is provided with a rectangular hole on the floor level for taking out the grain. The hole can be closed or partially opened from the inside of the bin by a wooden board. A wooden plank of size 60 x 45 cm is large enough to close a hole of 45 x 40 cm size. The height of the bin wall is made low so that workmen may drop the head load of grain directly into the bins (Fig. 39).

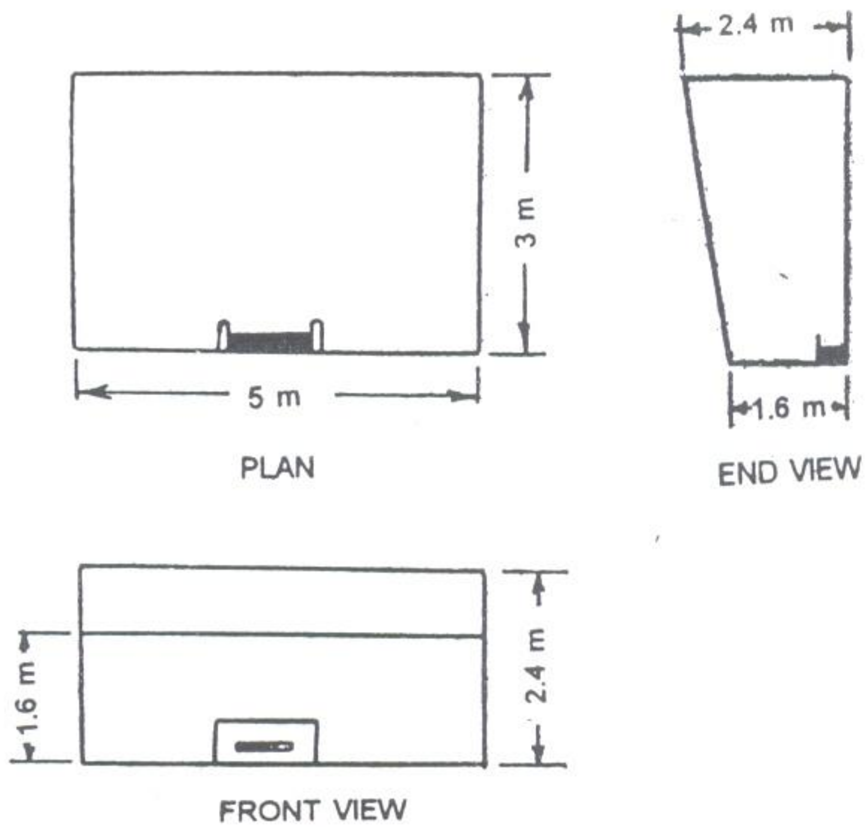


Fig. 39. Construction details of rectangular grain bin

16.2.5 Pusa grain bin

The Pusa bin was developed by Indian Agricultural Research Institute (IARI), New Delhi. It is a scientific storage bin in which LDPE film is sandwiched between two layers of inner and outer mud storage structure. This bin is popularly known as Pusa bin. The LDPE film prevents moisture entering the bin and the mud walls keep the stored grain free from the effects of temperature changes.

Constructional features

A platform of suitable size is made with un-burnt bricks on the hard floor (Fig. 40).

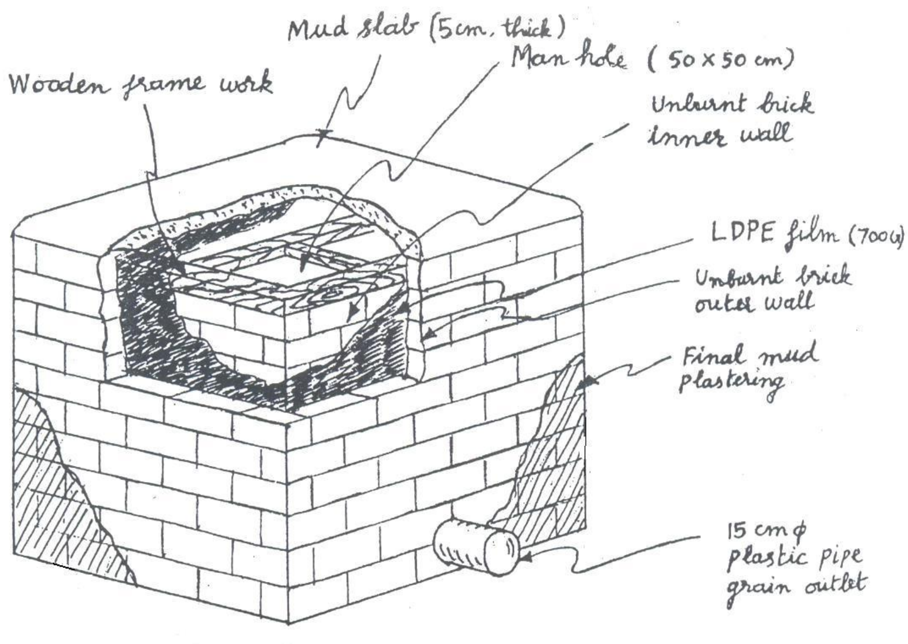


Fig. 40. Construction details of pusa bin

A black LDPE film of 700 gauge is spread over the platform with at least 6 inch extension on all the four sides of the platform. Above the polyethylene film, another platform of the same size is made with un-burnt bricks. Later the wall is constructed on all the four sides to the required height. The wall inside is mud plastered. A wooden frame with arrangement for manhole (50 × 50 cm) is made and put on the top of the walls to act as support to the roof of the bin. By using the similar LDPE sheet, a cover in the form of mosquito net is made, which is sufficient to cover upto bottom of the walls and put on the walls. Later, it is heat sealed from all sides and laid on the floor layers of the bricks. The LDPE sheet, at the place of manhole is cut to the size and removed. A round hole of about 15 cm diameter is left at the bottom of the front wall for withdrawing the grain. Finally, an outer wall with single layer of bricks is constructed on all the sides in such a way that the polythene film put on the inner walls is sandwiched between the two walls. A mud slab of 5 cm thick is placed on the top, leaving out the portion of the manhole. The structure is plastered on the top as well as on all the four sides and allowed to dry well before use. Dried and cooled grain is loaded into the bin for storage. For better performance, it is necessary that the bin is completely filled with grain or with minimum unfilled space. In the event of shortage of grain, it is advised to fill the space above the grain with straw or bhusa. Finally, the bin is sealed at the manhole and also at the outlet hole. After the storage period, the manhole is opened to draw the stored grain for use.

Problem: Design a bag storage structure for storing 250 T of paddy. Assume reasonable data wherever necessary.

Solution:

Assumptions:

(i) Standard capacity of bag = 75 kg

(ii) Dimensions of 75 kg capacity bag are: 100 cm× 60 cm × 30 cm

(iii) Stack consists of 12 bags in length, 10 bags in width and 10 bags in height.

(iv) Distance between stack to stack = 2 m

(v) Distance between end of wall to stack = 0.8 m

No. of bags in bag storage structure (or godown) = $\frac{250000}{75}$ = 3333.33

No. of stacks in godown = $\frac{3333.33}{12 \times 10 \times 10}$ = 2.77 $\cong$ **3**

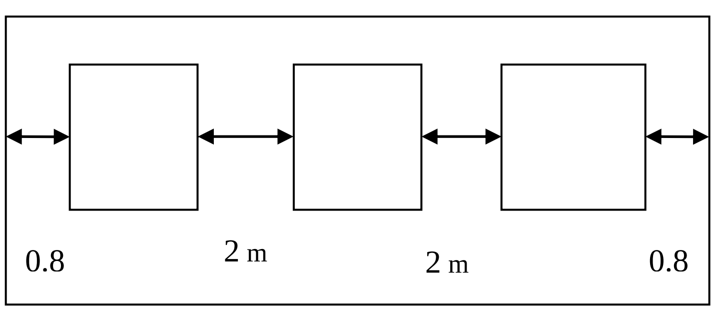
Stack dimensions:

Stack length = 12 ×100 = 1200 = 12.0 m

Stack width = 10 × 60 = 600 = 6.0 m

Stack length = 10 × 30 = 300 = 3.0 m

Godown dimensions:



Length = 0.8 + 6 + 2 + 6 + 2 + 6 + 0.8 = 23.6 m

Width = 0.8 + 10+ 0.8 = 11.6 m

Height = 0.8 + 3+ 0.8 = 4.6 m

The dimensions of 250 T capacity bag storage structure are: 23.6 m × 11.6 m× 4.6 m

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