In recent years, the technological trends in pulp and paper industry in general have been directed towards developing & adopting cleaner production technologies / techniques for resource conservation and to reduce the pollution loads at source so as to make the paper industry environmentally friendly & sustainable.

2.1 CLEANER PRODUCTION TECHNIQUES & TECHNOLOGIES

Cleaner Production concept is basically targeted towards achieving the following objectives either individually or collectively i.e.:

- Resource conservation
- Energy conservation
- Water conservation
- Reduction in pollution load (liquid, air & solid)
- Minimization of adverse environmental impact
- Reduced production costs
- Improved quality of paper products

The main application areas of cleaner production technologies can be:

- At source reduction
- End of pipe treatment
- Recycling/reuse
- Product Modification
The performance of the mill in context with cleaner production can be evaluated by the help of cleaner production indicators. These include:

- Process/ technology employed
- Efficiency of the unit operations
- Specific water consumption
- Specific energy consumption
- Specific pollution load
- System Closure

The above parameters help in inter & intra mill comparative analysis of its environmental status. In last few years the major cleaner production technological developments have been directed towards reducing pollutional parameters specially Colour & AOX through pulping & bleaching modifications, improved pulp washing as well as end of pipe treatment methods. In air emissions the major focus has been on reduction/ elimination of non condensable gases to reduce odor problem associated with kraft pulping process. With likelihood of ban on land filling of solid wastes, options are being explored for its incineration or utilization.

### 2.2 ADSORBABLE ORGANIC HALIDES (AOX) & COLOUR – REDUCTION & ELIMINATION

The formation of chlorinated phenolic compounds primarily depends on the nature and quantity of organic compounds particularly, lignin and its derivatives present in the pulp. Variety of chlorinated phenolics, dioxins and furans are formed during bleaching of pulp with chlorine based chemicals. Efforts made in recent past include developments to reduce the demand of bleaching chemicals by decreasing the kappa number of unbleached pulp and to minimise the carry over of black liquor along with pulp before bleaching process. Most of the pulp mills in developed countries have adopted modified pulping and bleaching technologies.
and the elemental chlorine has been almost replaced / substituted with chlorine dioxide to a large extent. As a result pulp mills in developed countries have achieved AOX level well below 1.0 kg / t paper and also dioxins and furans below detection limit in the effluents.

The application of these new technological developments is accomplished by various modern fiber line technologies which include:

- Extended delignification during pulping,
- Oxygen delignification,
- Improved pulp washing to minimize carryover of black liquor
- TCF & ECF Bleaching

Fig 2.1 indicates the trends in development of new fiber line including pulping & bleaching technologies for reducing the AOX.

2.2.1 Extended Delignification

The extended delignification process includes RDH modified batch cooking, super batch, modified continuous cooking (MCC) etc. These processes are energy efficient and produce pulp of low kappa number with better pulp yield and quality. However, these processes are capital intensive and their economics are dictated by the scale of operation.

The investment cost for adoption of extended delignification process for a pulp mill of capacity more than 1.0 lac tonnes of pulp per annum (say 300 tpd) works out to be around Rs 5000-6000 per tonnes of pulp annually which is approximately equivalent to Rs. 50- 60 crores (based on figures collected from literature and mills).
2.2.2 Oxygen Delignification

The oxygen delignification is now a well established technology. Almost all the pulp mills in developed countries are using oxygen delignification process to further reduce the kappa number of washed unbleached pulp before bleaching stage. The process reduces the kappa number by 40-50%, chlorine consumption by 50-60% and AOX generation by 60-70%. Some of the mills in developed countries have even adopted two stage oxygen delignification to reduce the kappa number to lowest possible extent and the spent liquor from oxygen stage is taken to chemical recovery along with black liquor. The efforts are continued to reduce kappa number further below 10 in order to improve the process efficiency and environmental compatibility. One of the requirements of the process is a special pressure vessel to maintain the desired treatment conditions. Based on information available in the literature, for a mill of pulping capacity around 1.0 lac tonnes per annum, the estimated capital investment works out to be about Rs. 20-25 crores. The application of above mentioned modified technology are limited to wood based industries of capacity above 1.0 lac tonne pulp per annum.

2.2.3 Chlorine dioxide Bleaching

Most of the pulp mills abroad have switched over to the use of chlorine dioxide bleaching in view of its advantages related to substantial reduction in formation of dioxins, furans and AOX related compounds. One of the main requirements for induction of chlorine dioxide stage is to completely changeover to special grades of alloyed stainless steel system to prevent corrosion. This calls for heavy investments and scrapping the entire system in bleaching including washing system.

2.2.4 Improved Pulp Washing

Washing of pulp has significant role in influencing not only the process economy through recovery of chemicals used in cooking of raw materials and reduced
bleaching costs but also minimize the carryover of organic & inorganic substances along with pulp to bleaching section and ultimately reduce the environmental impact associated with the discharge of toxic chlorinated phenolic compounds.

In view of improving the washing process, new generation of pulp washing equipments have been introduced in last decade which have minimized water requirement, washing losses and carryover of organic substances along with pulp to bleach plant. Some of the examples are:

- Pressure diffuser washer
- Horizontal belt washer
- Compact washer
- Drum displacer washer
- Screw press in combination with rotary drum washers.

The major highlights/ advantages of these modern pulp washing systems are summarized as under:

| Pressure diffusion washer | • An integral part of the continuous digester system
|                         | • Also being used for post oxygen delignification washing.
|                         | • Only washer which does not require knot separation and dilution ahead of the equipment.
|                         | • Eliminates air entrainment into the stock and the high operating temperature, give the pressure diffuser washer high displacement efficiency, resulting in better pulp washing.
| Horizontal belt washer  | • A very versatile pulp washer, which operates on dilution factors as low as 1.0
|                         | • Extremely efficient for the washing of the slow draining agricultural residues.
|                         | • Belt washer accepts a feed consistency higher than that of rotary vacuum drum filter and the good pulp mat formation is assured by a head box which evenly distributes the pulp suspension.
| **Compact washer:** | • A hood, which totally encloses the pulp mat, reduces the air circulation in the system.  
| | • Consecutive displacement stages without intermediate dilution, and overflow weir type showers allow a single unit of this belt washer to perform better than a vacuum drum washing system |
| **Drum displacer washer** | • The compact washer can be either a pro-feed washer or a compaction baffle filter.  
| | • Both these types use submerged displacement washing, to increase washing capacity and efficiency.  
| | • The pulp mat is pressed to a high consistency to remove black liquor with higher solids concentration |
| **Screw Press in combination with Rotary Drum Washers:** | • The drum displacer washer incorporates all the washing stages on a single rotary drum.  
| | • This unit allows four stage washing to be done in one drum, and thus not more than one filtrate tank is needed.  
| | • Less energy consumption (~ 25%) compared to the conventional washing system  
| | • Less space requirement |
| | • Screw press installation prior to conventional drum washing helps tremendously in reducing the dilution factor as well as the carry over of the black liquor to the bleaching section  
| | • The extraction of black liquor also helps to reduce the foaming and increase the efficiency of drum washers. |

Screening operation is also considered an integral part of pulp washing where knots, shives and other impurities are removed. Thus dewatering after screening has the function of final washing stage, when its filtrate is used as wash liquor in previous stages (counter current washing). This is known as **“Closed Screening”** where specially designed equipment is provided to avoid the risk of foaming due to increased concentration of dissolved salt and organic substances in circulating liquor. The closed screening system is now a common practice employed by the mills in
developed countries to reduce pollution. Majority of mills in India use vibratory knot-
ters for the removal of uncooked material from the pulp, while almost all the mills
world-wide have started using pressure knotters for this application. The use of
vibratory knotters allows a lot of air getting mixed with the black liquor system,
causing generation of foam, which reduces the pulp washing efficiency. The main
benefit of a pressure knotter is that it can be directly connected to the other pressure
screens, in case of a hot stock screening arrangement, and the possibility of air
entrainment is totally eliminated, which is not possible with the vibratory knotters.
The pressure screens are also capable of operating at a much higher consistency i.e.,
the range of 2% - 3.5%. This reduces a lot of pumping power and results in energy
saving.

2.2.5 Biotechnological Applications

Biotechnology has potential to increase the quality and supply of feed stocks for pulp
and paper, reduce manufacturing costs, and create novel high-value products. Novel
enzyme technologies can reduce environmental problems and alter fiber properties.
Currently, the high specificity, environmental safety and cost savings are the driving
forces behind the development of biotechnical applications for the pulp & Paper
Industry. Biotechnology is applied on a commercial scale in many operations of the
paper making. Enzymatic applications in the paper making process include
biopulping, biobleaching, biodeinking, deposit control, bioremediation, biological
color removal of effluents etc.

The method of using white rot fungi (MYCoR) process and the use of lignolytic
enzymes is quite effective up to 80% in decolorizing, dechlorinating and detoxifying
bleach plant effluents. However the major limitations to the large-scale application of
the enzyme are:

- Handling large volume of the effluent
- Requirement of energy for fungal growth
- Lack of capacity to produce large volumes of highly active enzyme.
The application of above technologies has not only been successful in reduction of AOX but also color to a significant extent due to reduced lignin content in unbleached pulp. In addition there have been other developments of treatment technologies for reduction in color. Most of these treatment technologies accomplish color reduction by separating high molecular weight chromophoric compounds from the effluent. Such processes essentially classify dissolved constituents by molecular weight or size.

These technologies include:

- **Membrane filtration**

  Ultra filtration (UF) & reverse osmosis (RO) are two common examples of such processes which are based on the principle of separation of higher & lower molecular fractions when an effluent passes through a semi permeable membrane. The driving force in such process is fluid pressure. There are three types of RO & UF systems available commercially:
  - Spirally wound sheet modules
  - Capillary fiber modules
  - Hollow core tube modules

  With the development of new membrane polymers, dynamic membranes, nano filtration membranes and system with lower energy requirements the technique has undergone more acceptability abroad in recent times.

- **Adsorption**

  It involves the use of activated carbon which is characterised by extremely large surface areas to unit weight ratios (450-1800 m²/g). The large surface areas results in substantial adsorptive capacity. The rate of adsorption is a function of carbon...
particle size. Carbon pore size, particle size, color component molecular weight and effluent pH are the significant factors influencing the performance efficiency of activated carbon. The high costs of process & its regeneration requirements are the major handicap in its wide scale application.

- **Electrofloculation**

The process involves application of an electric current to sacrificed metal electrodes having coagulating properties like Al, Fe, Mg generating metal ions & gas bubbles simultaneously. The metal ion released combines with pollutant and coagulates which are captured by the gas bubbles resulting in flotation of most of the pollutant on the surface.

All of the above treatment technologies are reported to reduce colour in the range of 88–99%. Treatment costs for color depends highly on energy costs, chemical costs, raw material furnish, end product quality etc. The major bottleneck in most of these technologies is the ultimate disposal of sludge or concentrate which is more difficult and costly than the initial removal & separation.

### 2.4 RECYCLING / REUSE OF WASTE WATER

Importance of water recycling system has been recognized abroad long back and remarkable efforts have been made since then towards achieving zero effluent discharge through recycling of waste water. The major advantages of waste water recycling are:

- Less water requirement depending on degree of back water recycling in the various mill operations
- Savings in energy
- Reduced waste water discharge
• Simultaneous reduction in effluent treatment cost due to lower effluent discharges

The driving forces responsible for waste water recycling in pulp and paper industry are:

• The high cost of fresh water.
• Inclination of the industry towards environment friendly process.
• Discharge norms laid down by regulatory authorities.
• Community perception and
• High cost of secondary effluent treatment process.

The major areas which have the potential of recycling of water are:

• Paper Machine back water
• H-stage bleach effluent
• Boiler Blow down

Many small scale agro & recycled fiber based mills in India, have taken considerable measures to reduce the water consumption by efficient use of water, reuse/recycle of backwater by identifying the potential areas for its reuse and also by setting the targets for individual process section for reducing fresh water consumption. These efforts have resulted not only in reduction of water consumption but also have direct/ indirect impact on performance efficiency, effluent load and effluent treatment costs. Some mills have been providing the treated effluent to the near by local farmers for irrigation of crops as well as utilizing themselves for horticulture, plantation etc.
However, in India the recycling concept is mainly used in white water system (paper machine back water). In most of the mills, white water is collected in sedimentation unit to recover the fibers and water is reused in paper machine as well as in other unit operations. As most of the mills are using elemental chlorine for bleaching of pulp it is not possible to use recycle concept for bleach plant effluent as it often leads to increasing operating problems of change in water quality because of the accumulation of various inorganic and organic components, odor and corrosion problem due to increased levels of calcium, chlorides, sulphates and suspended matter etc. which restricts the recycling or reuse of water to the internal process. As the mills abroad are using ECF/TCF bleaching, they are able to recycle/reuse their bleach effluent to a greater degree. The technologies available for detoxification of bleach plant effluent for making them suitable for recycle and reuse are basically Membrane filtration such as Ultra filtration & Reverse Osmosis. However due to involvement of high capital investment, requirement of higher scale of operation and consequently higher volume of effluent, these technologies have not been employed by Indian mills till date.

2.5 SOLID WASTE MANAGEMENT

US-EPA has categorized the biosolids in two classes based upon the level of contaminants in the biosolids:

- Class A: Pathogen free biosolids without site control.
- Class B: Reduced pathogen content with supplemental site control.

In addition to the pathogen reduction requirement, Class A and Class B biosolids must meet the vector attraction reduction requirement by appropriate treatment method. US-EPA encourages the production of fertilizer grade biosolids for beneficial use in a variety of land application. If the particular biosolids quality specifications are met, the product is no longer regulated with respect to
management practices and site control requirements. US administration declares that this material is fertilizer, placing it in the same category of commercial products that are not federally regulated. Member countries of European Union are also encouraging more and more use of biosolids for land application.

The main strategy for solid waste management involves the following five stages approach i.e.:

- Identification of solid waste.
- Quantification of solid waste.
- Characterization.
- Reduction at source.
- Conversion to value added product.

A major fraction of solid waste generated can be minimized by practicing good housekeeping. The various in house approach to reduce the generation of solid waste are:

- Good management of raw material storage facilities.
- Proper selection of equipments (chippers, choppers etc).
- Proper maintenance and changeover of knives / blades.
- Application of cleaner technologies.
- Use of efficient save all for maximum fiber recovery.
- Adoption of proper retention aids (economic feasibility to be considered).
- Maximum recycling of streams – closure of screening and washing system, paper machine back water etc to an extent that it does not affect the efficiency of the system and product quality.
- Proper combustion of fuels.
2.5.1 Solid Waste Management / Utilisation - Strategy & Trends

The general trends in solid waste management / utilization practiced by paper industry internationally are as under:

- As landfill
- Incineration
- Land application

2.5.1.1 Land Fill Application

Land fill has been the most common method till recent past for disposal of sludge etc. However the major factors to be considered when planning for land fill site include:

- Environmental Suitability of area for land fills.
- Geology of the area.
- Environmental impact of run off water from the site.
- Impact on ground water.
- Composition & volume of the sludge.
- Transportation cost.

The main disadvantages linked with the land fill is the possible risk of contamination of land and ground water due to which most of the developed countries are banning land fill in near future.

2.5.1.2 Incineration

The solid wastes rich in organics are incinerated mainly to reduce its volume and ultimate disposal in a feasible way which is easier & cheaper to land fill. Sludge is mainly burnt in fluidized bed and grate boilers. Burning of sludge is also associated with several limitations such as need of auxiliary fuel due to high
moisture content, emissions of dioxin, NOx, heavy metals etc in addition to other problems like:
• Storage
• Handling
• Low combustion efficiency
• Opaque stack gas
• Sticky ash formation

2.5.1.3 Briquetting

This is a technique of mass densification which has been successfully developed by CPPRI for preparing binder less briquettes from raw material waste as well as using ETP sludge as binder for briquette making. The advantages of briquetting are:

• Good substitute for conventional fuels.
• No sulfur and less ash content.
• Combustion is more uniform and sustained.
• Can be stored for extended periods.

2.5.1.4 Land Application (Composting)

Two factors viz., continued decrease in availability of landfill space and increase in energy cost in incineration, have forced the pulp & paper mills internationally to look for the land application of the same as a low cost disposal method. In composting process microorganism break down the organic matter of the sludge under aerobic conditions. It is suitable both for biosludge and sludge from primary clarifier.
The following methods are practiced for composting of solid waste rich in organics:

- Windrow method (time period - 3 months)
- Aerated pile method (time period - 1.5 to 2 months)

The main advantages of composting are:

- Increase water holding capacity and permeability of soil
- Enhances aggregation
- Reduced surface crusting
- Less capital investment

The compost prepared is used mainly for soil improvement; horticulture and landscaping of land fill sites.

2.5.2 Sludge Dewaterability

The common feature of all the above methods for improved management of biosludge generated in ETP is the requirement of sludge dewatering and needs to be dewatered to achieve high solid content as much as possible so as to facilitate subsequent handling and disposal. In a sludge suspension water exists in following forms:

- Free water (can be removed by simply gravity settling)
- Capillary water (can be removed mechanically by filtration & centrifugation)
- Bound & Intercellular water (can be removed by drying)

Sludge thickening is usually obtained by sedimentation in a circular tank or clarifier. Mechanical dewatering employs equipments based on filtration,
centrifugation, pressing or combination of these. Presses usually operate at either low or high pressure. Depending upon the type of press employed the final solids content achieved is 25-45%. In recent years the combination of thickeners & belt press is the most popular dewatering methods used by pulp & paper industry. Chemical treatment by addition of polymers / flocculants is also practiced by some mills to improve the dewaterability of ETP sludge. With the combination of mechanical & chemical methods the solid contents of the ETP sludge can be increased up to 25-30%. ETP sludge is secondary sludge is partially with primary sludge for further dewatering using either by vaccum drum filter or sludge beds.

2.6 ROLE OF CPPRI

Most of the technological developments as discussed above are capital intensive and are viable with large scale of operation. As such their adoption for small agro based mills with existing scale of operation will always be a distant dream. Today the need is to develop indigenous process technologies and equipments suitable to our kind of raw material and requirements. In this perspective Central Pulp & Paper Research Institute, (CPPRI) has made / is making extensive efforts to help the small agro based pulp and paper mills to render them cost competitive and environmentally friendly through adoption of energy efficient and eco-friendly technologies. Some of notable achievements of CPPRI are as under -.

2.6.1 Handling of Pulping Spent Liquor

2.6.1.1 Desilication of Black Liquor

CPPRI has developed the world’s first successful desilication technology for removal of silica from black liquor. The technology has been successfully tested in mills using bamboo and agro residues in India as well as overseas. The technology can help in overcoming the major bottleneck in adoption of chemical recovery system by agro based mills.
2.6.1.2 High Rate Biomethanation of Black Liquor

CPPRI has successfully commissioned High rate Biomethanation plant for treatment of black liquor in an agro based mill. The process results in 45-50% reduction in COD and 75-80% reduction in BOD along with cogeneration of methane rich biogas which is used as fuel along with conventional fuel in the boiler. The process has already proved its techno-economic viability and since then has been replicated by other mills also.

2.6.1.3 Lignin Removal & Development/ Utilization of Lignin By products

Lignin is a major non biodegradable constituent of black liquor, removal of which is necessary to improve the efficiency of effluent treatment plant like biomethanation and activated sludge process with respect to reduction in pollution loads. CPPRI has successfully conducted the pilot studies on lignin separation which indicates that a COD reduction of around 70% and color removal of around 80% can be achieved by selective removal of lignin. Moreover CPPRI has successfully carried out the work on utilization of precipitated lignin as a binder for particle boards and for resin manufacture for plywood industry. Small scale agro based mills pulping capacity below 50tpd are now in process of adoption of lignin separation technology for treatment of black liquor.

2.6.1.4 Thermal Treatment of Black Liquor

CPPRI has developed a process to reduce viscosity and improve combustion properties of black liquor enabling it to fire the back liquor at high solids concentration.

2.6.2 Elimination/ Reduction of Phenolic and Chlorophenolic Toxic Materials

CPPRI has successfully conducted studies on assessment of AOX level and status of technology in small scale pulp and paper mills including process optimisation. The effect of process variables like chlorine factor, kappa number, temperature, pulp washing, enzyme pretreatment etc. were also studied with the objective to control the discharge of adsorbable organic halides (AOX). Various physico-
chemical treatment methods like coagulation, precipitation, membrane filtration have been evaluated to treat the bleach plant effluent for reduction in pollution load (including colour and AOX) as well as increase their recycling and reuse so as to reduce water consumption.

2.6.3 Colour Removal

The high level of colour in effluent is major environmental issues faced by all section of pulp and paper industry. CPPRI is working to evaluate the techno economic viability of various end of pipe treatment methods including chemical & physical methods to reduce the colour to make the effluent suitable for discharge on land / in land.

2.6.4 Solid Waste Reduction and Utilization

CPPRI has successfully conducted trials on briquetting of solid waste like ETP sludge and other organic wastes which has good potential for combustion in boilers and thus help in supplementing the fuel requirement. CPPRI has also conducted studies on upgradation of raw materials by disc mill treatment for reduction in solid waste. Moreover utilization of flyash and cinder for value added products like cement, bricks, blocks and other building materials is also being explored on pilot scale.

In all, the need of the hour is that the mills, R&D organisations like CPPRI & technology suppliers should work collectively for developing, demonstrating & replicating cost effective indigenous technologies and equipments to improve the environmental status of the small scale agro based mills and ensure its sustainability.
Fig 2.1 Development Trends in Pulping & Bleaching

1. Cooking Bleaching
   To recovery incineration

2. Cooking Oxygen delignification Bleaching

3. Modified Cooking Oxygen delignification Bleaching

4. Modified Cooking Oxygen delignification Bleaching
   Anticipated development in cooking and/or prebleaching technology
   Organic material in effluent

Kappa number 30 20 10 0

Anticipated development in cooking and/or prebleaching technology