Journal of Basic and Applied Engineering Research
p-ISSN: 2350-0077; e-ISSN: 2350-0255; Volume 5, Issue 4; April-June, 2018, pp. 359-362

http://www.krishisanskriti.org/Publication.html

A Study of Paper Making Process with Suggestions for Efficiency Gains

Arjun Shukla

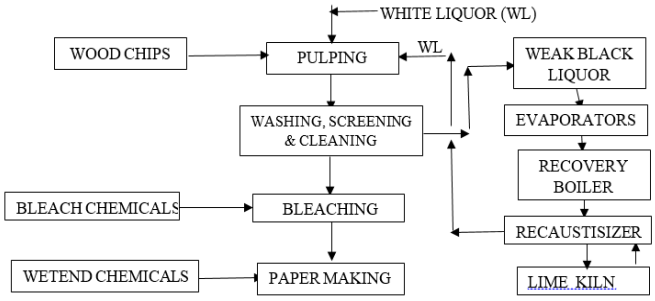
Class XII, Dhirubhai Ambani International School
Mumbai 400 018, India
E-mail: arjunshukla01@gmail.com

Abstract—*Paper has been associated with human civilization since ancient times. It has transcended its simple physical existence to become an indispensable utility. Paper is involved in most functions humans partake in such as writing down ideas, recording information, packaging, construction drawings, legal documents, etc. Even with the advent of e-paper, the industry continues to be relevant for the foreseeable future. A lot of research is being undertaken to make the process more efficient and improves its sustainability with the environment. Bearing all this in mind, it is only natural to learn that the process of making paper, from its starting state in plants/agri-residues to the finished product is complicated. It involves different Unit Operations & Processes.*

OVERVIEW OF PAPER MAKING

Paper making involves a series of different processes represented in the block diagram below.

1. Pulping
2. Washing, Screening and Cleaning
3. Bleaching
4. Paper Making



I. PULPING

Paper is made from the pulp of trees. A tree has many different parts but its main stem after de-barking is made up of organic matter known as cellulose with other colouring & binding matters. Cellulose fibres in the cell wall give it its structural integrity and durability. Paper is made from these fibres.

The process requires extraction of only the cellulosic fibres from wood. Hence, the first order of business for lumber companies is to cut trees down and then pass them through machines known as de-barker &wood chipper. The chipper cuts the entire debarked portion of the tree log into uniform and similarly sized wood chips ranging from 12-25 mm in length. This is the basic raw material required to make paper.

Wood chips are received at the paper mills, which are supplied by the lumber companies. Alternatively, debarking & chipping of wood logs could be undertaken inside the Mill. But these wood chips still contain certain non-cellulosic elements, such as lignin. Lignin is a bio-polymer which binds the three components of the cell wall, the cellulose, the hemicellulose and the pectin, together to form lingo-cellulose. If lignin, hemicellulose, or pectin remain in the pulp, the structural integrity of the eventual paper is compromised. It is thus extremely important that wood chips are treated through the process of pulping. In this process, non-cellulosic matters are separated from the wood chips to give cellulosic fibre or pulp, the basic raw material used in paper making.

*Mechanical Pulping:*There are two major types of pulping: chemical pulping and mechanical pulping. Mechanical pulping is the oldest form of pulping and, as the name implies, it uses mechanical energy through grinding machines to separate cellulosic fibres from non-cellulosic matter. This process is advantageous and cost effective in producing massive quantities of pulp as it does not take much time. It takes an average of 12 trees to make 1 tonne of newsprint via the mechanical pulping process. The average number of trees used is double in the case of chemical pulping. However, the usage of large electric power in the separation process tends to weaken the cellulosic fibre, leading to fines &paper of inferior quality (mainly newsprint). Furthermore, this process is power intensive and has gradually been obsolete.

Chemical Pulping: This is more widely prevalent today. While this does take more time and has higher expenses due to the need for certain pulping agents, it leads to stronger fibres with higher quality paper, which allows companies to increase

profit margins by putting higher prices on their superior quality output.

a. Wood Chip to Weak Black Liquor: The process begins with the cooking of wood chips with a mixture of water, sodium hydroxide and sodium sulphide called white liquor(cooking liquor) in a pressurized vessel known as the digester at 165°-170°C. The desired temperature is required to provide the reaction with sufficient activation energy in order to start right away and also to speed up the rate of the reaction.

   The objective of cooking is to de-lignify the chips and remove non-cellulosic matter like Lignin. Water is present in the digester as well to control desired bath ratio and in its presence sodium sulphide is hydrolysed as follows:

$$Na_2S_{(l)} + H_2O_{(l)} \rightleftharpoons NaOH_{(aq)} + NaSH_{(aq)}$$

   The remaining sodium sulfide dissociates or ionizes in the water alongside the products of the reaction above to give three crucial ions: Na^+, S^{2-} (sulphide) and HS^- (bisulphide). The two negative nucleophilic ions play an important role in breaking ether (R-O-R' where R represents an alkyl group) in lignocellulose and depolymerize the structure to give cellulosic fibre in a mixture of lignin fragments and organic matter from the breakdown of hemicellulose. This mixture is known as weak black liquor (WBL).

b. Weak Black Liquor to Concentrated Black Liquor: The WBL is then filtered to separate the cellulosic fibre from the mixture and is sent to a battery of multiple-effect evaporators. This mixture, in its current state, is highly toxic and can cause the environment much harm. The basic economy of the chemical pulping is the regeneration of cooking liquor from the WBL and also to safeguard the environment.

Figure 2: Multiple effect evaporators

Weak black liquor (WBL)contains 17% Total Dissolved Solids and a high amount of water.The evaporators concentrate by evaporating water from it. This makes the mixture more concentrated and more viscous. At this point, it is known as semi-concentrated black liquor (SCBL). To make it concentrated black liquor (CBL), SCBL is fed to a direct contact evaporator which makes the mixture even more concentrated with 65-70% solids.WBL on its own is not fit for burning due to high amount of water in it. Concentrated black liquor on the other hand burns easily as it reaches flash point.

c. Chemical Recovery Boiler Furnace: CBL is burned inside theChemical Recovery Boiler Furnace after mixing with Salt Cake (sodium sulphate) powder, which is smelted by carbon inside the furnace to give sodium sulphide. The Chemical Recovery Boiler also generates necessary high pressure steam and adequate by product power and necessary process steam, meeting the demand for the entire recovery island.

$$Na_2SO_4 + 2C \rightarrow Na_2S + 2CO_2$$

d. Green Liquor: The mixture as a molten smelt of salts come out of the recovery furnace hearth, which include sodium carbonate and sodium sulphide. This smelt is dissolved in water which imparts a green solution called green liquor. To recover the main chemical sodium hydroxide, slaked lime is added to the green liquor. This reacts with sodium carbonate to give calcium carbonate sodium hydroxide.

$$Na_2S + Ca(OH)_2 + Na_2CO_3 \rightarrow Na_2S + 2NaOH + CaCO_3$$

e. Rotary Lime Kiln: The precipitated calcium carbonate is filtered, removed from the mixture and is heated to decompose it into calcium oxide and carbon dioxide in a Rotary Lime Kiln:

$$CaCO_3 \rightarrow CaO + CO_2$$

   This calcium oxide (Quick Lime) is then dissolved in water to re-generate slaked lime.

$$CaO + H_2O \rightarrow Ca(OH)_2$$

f. Washing & Cleaning: Following the removal of the calcium carbonate, mixture of sodium sulphide, sodium hydroxide and water is sent to a clarifier tank to settle the solids, where once again white liquor (WL) is re-generated. The pulping chemicals are mostly regenerated and are recycled in the mill to make the process economical and efficient.

The brown coloured cooked pulp with water is fed to thewashing/screening plant to separate coked pulp from the spent liquor. The cooked pulp is first washed in a vacuum

washer/dewatering press to remove any remaining portion of chemicals from the pulp.

This entire process of chemical pulping is known as the Kraft process and is widely used in paper mills across the world due to the aforementioned advantages over mechanical pulping. However, there have been advances in the area of pulping and more efficient albeit expensive methods do exist. An example of such a method is bio-pulping, which is in the research stage as of now.

Bio-pulping: This involves the usage of a certain enzyme, lignin peroxidase, on the wood chips. This enzyme selectively digests lignin only and would thus separate cellulosic fibre and non-cellulosic matter as lignin links the two together. This process will have major environmental benefits due to reduced emissions as processes like combusting CBL are eliminated. It would also be cost effective by reducing the size of the paper mill as the number of processes that take place are lessened. This would minimize costs that the paper mill must pay such as electricity, water, chemicals, spares & consumables, man power,maintenance, etc.

BLEACHING: BRIGHTENING OF THE PAPER WHITE

The unbleached pulp still contains small portion of lignin and other organic compounds and looks brown. This pulp needs to be whitened for its end use purpose by employing suitable bleaching agent.There are two major types of bleaching processes practised in the paper industry: Elemental Chlorine Free (ECF) and Total Chlorine Free (TCF) Processes.

Chlorine is a predominant bleaching agent used in this process; however, it is toxic and needs to be handled with extreme caution. It can cause damage to the health of workers in the plant and can cause even more grievous harm to the environment by generating Dioxin.Hence ECF bleaching uses Chlorine Dioxide (ClO_2), to produce bleached pulp. 90% of the total bleached pulp produced in the World uses ECF bleaching. The greatest advantage of this process is very high brightness pulp can be obtained without damaging the fibre.

a. ECF bleaching process can be represented simply by the following sequence:

$$D_O\, E_{OP}\, D_1\, D_2$$

D_O – The unbleached pulp is taken into a tower. Chlorine dioxide is added to the pulp in order to dissolve any colouring matter in the pulp at a certain percentage.

E_{OP} – A mixture of hydrogen peroxide and oxygen is added to the pulp in order to extract the separated colouring matter and remove it from the pulp.

D_1& D_2 – In these processes, more chlorine dioxide is added to the pulp in order to remove colouring matter to the desired value. D_2, however, is an optional process which is only used for pulp that requires super brightness.

It must be noted that in between each process, the pulp is washed with water in order to remove any excess bleaching agents and the colouring matter. Also, prior to entering Bleach Plant, unbleached pulp is treated in an Oxygen Delignification Plant (ODL).

b. TCF bleaching uses chlorine free bleaching agents viz., H_2O_2, O_2 or O_3depending upon their easy availability. The brightness of pulp obtained by TCF are lower compared to ECF pulps.

If pulp is the end product, pulp sheet is formed in the forming part, pressed mechanically in presses and dried in indirectly steam heated dryers to achieve 90% dryness followed by cutting into sheets, pressed in bale press and packed in bales each of around 200 kgs. In case of pulp preparation from the waste paper there are again two different processesdepending upon the end use:

i. In case of printing/writing paper viz., Newsprint, Copier, Map Litho, Cream Wove or Tissue grades, Suitable Deinking Plant with Bleaching Process is adopted.Also, depending upon the end use, the brightness of pulp varies.
ii. In case of Fluting/Teat liner/ Multi-layer Board, the raw materials used are OCC, waste paper & someBleached/unbleached pulp on the top layer depending upon end use.

PAPER MAKING PROCESSES

The first section in the Paper making process is Stock preparation in which the Mechanical & Chemical properties are imparted to the fibre received from the Pulp Mill.The steps are as follows:

- Refining
- Blending with different grades of pulp and broke pulp, chemicals (for shade, optical brightness, sizing, retention aids and fillers)
- Broke handling& recycling
- Fibre Recovery
- Approach Flow system

Depending upon the end use of paper, the paper machine configuration changes.

Newsprint	Printing/Writing/Copier Paper
✓ Forming Part: Gap Former for very high speed and with minimum two sidedness ✓ Closed-draw presses with Shoe Press to attend very high dryness	✓ Forming Part: Hybrid Former for high speed and with minimum two sidedness ✓ Closed draw presses with Shoe Press to attend very high dryness ✓ Uni-run dryers with bottom row in Pre-dryers consisting

✓ Uni-run dryers with bottom row of dryers consisting of Vacuo-rolls ✓ Soft nip calendar ✓ Reel ✓ Winder for converting to Reels as per the market demand ✓ Reel wrapping	of Vacuo-rolls ✓ Metering Press ✓ Post Dryers with chrome coated dryer in the beginning ✓ Soft nip calendar ✓ Reel ✓ Winder for converting to Reels as per the market demand ✓ Reel wrapping ✓ Sheeters with Ream Wrapping Section
Fluting/Test Liner/Multi-Layer Board	**Tissue Paper Machine**
✓ Forming Part: Fourdrinier two-three layer ✓ Presses with double felted Jumbo Press/Shoe press to attend very high dryness ✓ Pre-dryers ✓ Size Press/Coaters ✓ Post Dryers ✓ Soft nip calendar ✓ Reel ✓ Winder for converting to Reels as per the market demand ✓ Reel wrapping ✓ Sheeters with Ream Wrapping Section	✓ Pulper for slushing of market Pulps ✓ Special Refiners ✓ Blending ✓ Krofta Clarifier ✓ Approach Flow System (foe single layer to three layers) ✓ Tissue Machine Forming Part: Crescent Former ✓ Yankee Press ✓ Yankee Dryer (Single large diameter steam heater dryer with high gloss on the top surface) ✓ Reel ✓ Winder with two ply unwind stand ✓ Reel Wrapping System

Conclusion

Some of the measures that Paper Mills can adapt to make the operation more environment friendly as well as economical are:

- Effluent sludge collected from DIP based Mill can effectively be used for producing board paperand may be used for end sealing of reels during packing.
- The sludge contains organic matters and hence the solids after sludge press can be burnt along with coal for both environment as well as saving of fuel.
- Fines generated during chipping of wood logs could effectively be used along with coal to save coal consumption.
- Fly ash generated from the Power Boiler in the Mill could be sold to nearby cement factory and also could be used for making hollow blocks as replacement for bricks in the Mill.
- The Paper Mills those who do have Lime Kilns can sell the lime sludge generated from Re-Caustisizer to nearby cement factory.

ACKNOWLEDGEMENTS:

The engineering behind the processes have always fascinated me, a would-be student of mechanical engineering. I was fortunate to learn during a summer internship stint in Summer 2018 at Sharma Fabricators and Erectors (P) Ltd., Gurgaon, India (SFE India). SFE India is a ISO 9001:2015 certified company and has been setting up Plant & Equipment for Pulp and Paper Industry including re-location of plants for over 50 years. Its clients are from all across the world.

I would like to thank a number of senior officials whose support was vital in this Project. Mr. V. Sharma, Managing Director, responded to my request for visiting their offices and allowing me to learn about the entire process with genuine enthusiasm. Mr. Sharad Dubey, Joint President (Projects) and Mr. Saurabh Dubey, Joint President (Marketing) devoted time and energy to explain the processes in a paper mill. Last, but certainly not the least, I am indebted with gratitude to Mr. M. K. Bose, Sr. Vice President (Engg) for taking me under his wings and guiding on a day-to-day basis.

References

[1] Pulping Chemistry and Technology by Monica Ek
[2] Handbook of Pulping & Papermaking by Christopher J. Biermann
[3] Paper Making Science and Technology Book of TAPPI
[4] Handbook of Pulp and Paper Technology by Kenneth W. Britt
[5] Paper Technology: An Elementary Manual on the Manufacture, hysical Qualities and Chemical Constituents of Paper and of Paper-making Fibres by R. W. Sindall.