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Newspaper Recycling And Deinking

Reem Adel Fahmy Baher

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AND DEINKING

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1997

THE AMERICAN UNIVERSITY IN CAIRO
SCHOOL OF SCIENCES AND ENGINEERING
ENGINEERING DEPARTMENT

NEWSPAPER RECYCLING AND DEINKING

BY
REEM ADEL FAHMY BAHER

A thesis submitted in partial fulfillment of the requirements for the degree of

Master of Science in Engineering

under the supervision of:
Dr. Salah M. El-Haggar, Associate professor

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Student's Name: **Reem Adel Fahmy Baher**

Thesis Title: **Newspaper Recycling and Deinking**

The student answered the questions adequately, and the thesis is of the level of Master of Science in Engineering.

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Date: January 5, 1997

Acknowledgments

First of all I need to thank and dedicate this work to my Lord. Without His blessings and support, I would not have been able to finish it. He has always been honest with me and is continuing to be, because He can not deny Himself. I felt His love and support through out my life and during the implementation of this thesis. Thankyou Lord.

I need to thank my advisor, Dr. El-Haggar. He has been very patient with me through it all. His technical and scientific advice were always very valuable. I will never forget the great effort he gave and time he spent, till this work has finished. His nice personality has impacted my character by being my advisor.

Lots of thanks and appreciation to Dr. Tobia, who has always been available for any chemical advice. I have gained a lot from his tremendous chemical knowledge. I also appreciate his fatherly attitude that I have always felt when dealing with him.

I acknowledge all those who gave a hand and helped in this work to come true, starting by those who work in the AUC workshop. Without the effort and time you gave in manufacturing the machines needed, this thesis wouldn't have come to life. As for Mr. Zakaria, words can not express my appreciation and thankfulness for all what you kindly did to help me, and to solve all problems that we faced during the experimenting stage. Many thanks to Hamdy and Ahmed, whom I am sure have gained a good paper making experience due to the amount of paper they shared in preparing. There is also Mr Ismail, Mr. Essam, Mr. Fawzi, and Mrs. Soheir, who have helped at different stages of the thesis work and without their effort it would have been difficult finish it.

One can not forget the knowledge gained out of the experience of Racta, Seimo -Paper manufacturing firms- and ElAhram testing lab. Also all those who have been so helpful and so generous with their paper experience, knowledge and effort; namely Dr. Mohamed in Racta, Eng. Laila Ghanem & Dr. Mohamed in Seimo, Eng. Taymour & Eng. Salah in El Ahram.

I dedicate this work to my father. The most important man I really wanted to be there physically to testify it. He is the one who started by encouraging and believing in me. For him I owe all my success and all my life. It is because of him I am what I am now. I am sure he would be happy where ever he is.

I am so grateful to my mother for her support and effort. She has tried her best to help me finish that work, no matter how tired she is. She has tried to tailor all the surrounding circumstances for my best. Words would not be enough to thank her. Also my brother has been of a great help and enthusiastic about my work. I enjoyed you around.

To my beloved husband who have bore a lot with me. He has always been very understanding and helpful. He believed in all what I did and pushed hard for my success. It is because of your love and support, I accomplished this work. To my adored, sweet little daughter, in spite of the time you delayed me, yet your smiles and brightness have support me a lot. You have also bore a lot, by spending so many hours away from me in the nursery. Forgive me, much love.

To my father, mother in law, and my sister in law (Manal) who have always been there, helpful and understanding to the effort done.

Last but not least, I need to acknowledge my dear friends, Renee N., Hany H., Ayat S., Sherry Y., Dalia N. who were very encouraging throughout the whole work. Very special thanks and gratitude to sweet Shada P. who shared and helped me in checking the text.

Abstract

There is a major environmental problem that is facing the world, which is the decrease of virgin pulp resources all over the world due to the cutting down of forests for paper making industries. So forest savings are reflected on the air cleanliness, soil conservation and water. That is why in the States there is a law that controls the paper manufacturing firms to have a minimum of 50% of their furnish as recycled paper. It is expected that in a very near future paper will not be accepted in market except if it has a certain percentage of recycled paper and the other percentage virgin pulp is from a sustainable forest. On the other hand, Egypt faced a major crisis due to the last year's 40 % increase in the price of imported newspaper. This price increase not only affected the press and publication, but also placed a burden on the educational system. Where most of the government text books depends on this type of imported paper. This crisis can be solved entirely by recycling waste paper and depending on recycled paper instead of imported paper. This would lower the cost of text books as well as newspaper and magazines.

The experimenting test facility of paper recycling system was designed, manufactured and tested at the American University in Cairo. The system consists of shredder to increase the specific area of the paper, beater to produce pulp, flotation cell to remove the ink mechanically and /or chemically, hand sheet machine to produce test paper and press/dryer to dry the produced paper. The effect of beating time was tested and it proved that the best defibering reached when the drum was raised to a relatively high position for 15 minutes then lowered to the minimum for 10 more minutes. Then the flotation cell was tested for the different time, temperature, and combination of both. The

produced sheets of paper were tested based on physical (tear & tension) and optical (brightness & opacity) properties according to standard. The results proved that the optimum tension and tear values were 1.25 N/m and 40 Nm respectively at 40 oC temperature and 10 minutes time. Optical results were confirming the same results, where the brightness highest results were 43.5 % at the same flotation cell conditions. Opacity results were not of importance, since they depend on the single sheet thickness that were difficult to control.

Then the system was tested for the effect of chemicals on the deinking process. The three chemicals used were alkaline to saponify the oil base of the ink used in printing. They were of different degree of alkalinity strength: Sodium hydroxide (strongest), sodium silicate (medium) and sodium carbonate(weakest). Added to the alkalinity of the sodium silicate, has an abrasive nature added to its alkaline nature. Same properties were tested at different chemical concentration (pH). Results showed that tension maximums were at the same pH value (10) for the three chemicals used. Tension values were 1.53 N/m for sodium hydroxide, 1.35 N/m for sodium silicate, and 1.17 N/m for sodium carbonate. On the other hand, tear had the same maximum values which were 24 Nm, but at different concentrations for each chemical. For sodium hydroxide, it was at 12.5 pH, sodium silicate at 11.5 pH and sodium carbonate at 9.8 pH. Brightness tests showed that sodium hydroxide and sodium carbonate had the same trend and maximums were at the same pH level (8.5, tap water pH). While the sodium silicate brightness trend started by decreasing then a sharp increase, with the highest brightness value which was 46.2 % at pH value 11.5. In short, the waste paper recycling system proved to be efficient.

Table of Contents

Page

List of Figures

List of Tables

Chapter 1
Introduction

Ever since man has shown on earth, he has tried to find a way to record his thoughts and to express himself either by drawing pictures or symbols on stones, or by carving on walls of caves and bones. In more advanced societies sheets of brass, lead, copper or bronze were used for preserving wills, laws, treaties and agreements between nations.

The oldest surviving written records are clay tablets made by ancient Sumarians in 4th Millennium BC [14 & 20], which were also used by Middle Eastern and Mediterranean cultures. In the 3rd Millennium BC papyrus was invented by the Egyptians [3]. It was considered to be the first writing material from which the word paper derived. Papyrus is made by crisscrossing of thin sections of papyrus reed and are held together by natural glue within the reeds which are squeezed out when pressure is applied. Finally the papyrus are smoothened by rubbing with smooth stones. Papyrus continued in use in Mediterranean regions until about 10th century AD. Then, it was gradually displaced by parchment [37], which is tanned sheep skin or goats skin that is prepared as a writing material. Parchment was known in the 2nd Millennium BC and it continued in use even after the start of paper manufacturing.

The invention of paper making was driven by the need of more economical, abundant and easily used writing medium. The first recorded paper making was in the year 105 AD and credited to Ts'ai Lun of China [3,42&20]. Emperor Ho-ti ordered him to work on a papyrus substitute. Ts'ai Lun experimentation lasted for 20 years using different

materials as vegetable fibers, old hemp, cotton rags, old fishnets, mulberry bark, bamboo, and cloth that was treated with lime. However, recent discoveries show that basic and simple paper fragments were found in China in the first and second centuries BC [42]. In other words, paper making methods were developed even prior Ts'ai Lun's time. The earliest known text printed on paper is "Buddhist Surta" that has been dated as being printed no later than 750 AD [42].

True mechanization, where continuous paper production machine was not achieved until 1799, by a Frenchman called Nicholas Robert. The machine was with an endless wire mesh and a pair of squeeze rolls. The development of this machine was carried out by the British Fourdrinier brothers. In 1804, with the help of the millwright-engineer BryanDonkin, the first successful paper making machine was built in Two Waters Mill, Hertfordshire, England. From there the Fourdrinier technology was widespread. [37]

" The availability of writing material has always gone hand in hand with the development of society ." [3]. That is why paper demand is increasing world wide, accordingly the paper waste percentage is increasing in the municipal solid waste (MSW). Studying Greater Cairo as an example, the municipal solid wastes can be classified as follows; organic waste, paper and cardboard, plastics, textiles, metals, glass and others with their percentages as shown in Figure 1.1 [21]. The second highest wastes are the paper and cardboard. Knowing that Greater Cairo produces 6000 tons of waste per day, so the 21% of paper and cardboard makes 1,272 tons per day. Also the paper price has drastically increased over the last ten years worldwide. If waste paper fibers are reused, then the problem of finding new fibers for paper making will decrease with consequent reduction in

the volume of solid waste. This is not really a brand new idea because the first recorded use of waste paper for making new paper dates from 1031 AD in Japan [42]. This process did not include either bleaching or deinking. That is why the paper was grayish in color; However, they were still highly regarded.

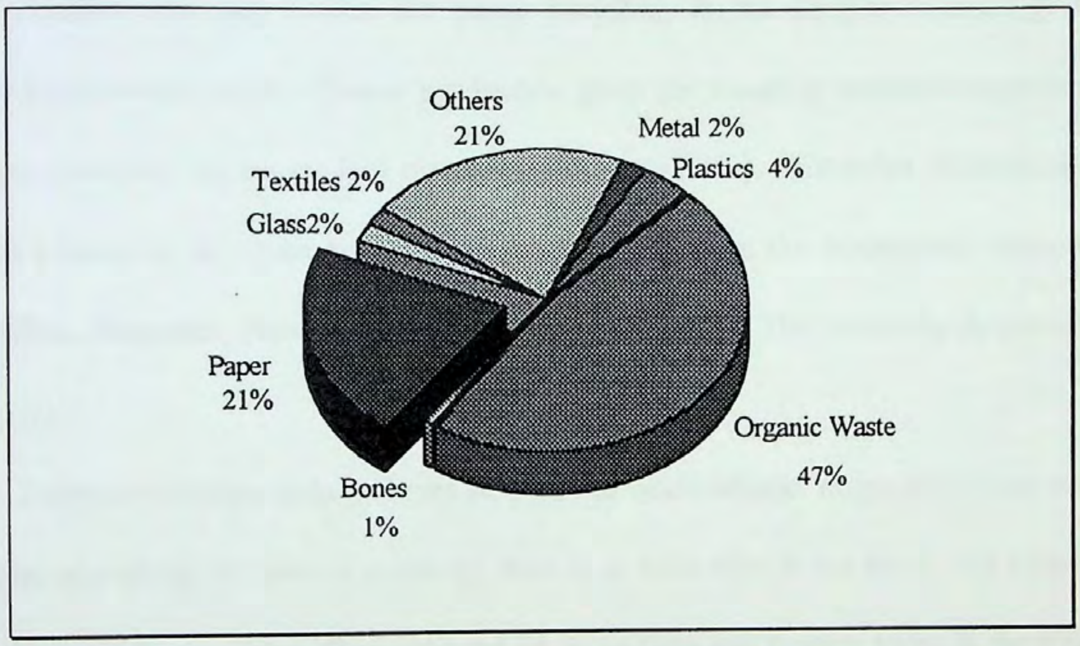

Fig 1.1 MSW Percentage In Greater Cairo

The global view of the paper and board consumption was as follows in 1992, total world paper and board consumption was 245.6 million tons. Pulp production was 164 million tons (67% of production). The other third of the raw material was provided by waste paper. The pulp and paper inputs are less than the total paper and board production, due to the losses that take place during pulping and waste paper. Waste paper has increased in use over the period of 1986-1992 [1].

Table (1.1) Global Wastepaper Use [1]

Year	Pulp & paper production (m tones)	Wastepaper consumption (m tones)	Apparent utilization rate (%)
1986	202	63	31
1990	237	85	36
1991	239	91	38
1992	246	96	39
2000	307	138	45

Another tempting reason for paper recycling is the cleaner technology trends favored by the whole world. Cleaner production gives the means to provide human benefits, uses less resources and causes less environmental damage [9]. Crittenden & Kolaczkowski [10] set a hierarchy of waste management practices based on the studies and researches of Wntz, Chiu, Patterson, Habegger, Mortino, Peters [44&45]. This hierarchy is presented in table (1.2).

Decrease of virgin pulp sources all over the world whose major source are barks of trees that take about 30 years to come up, then in an hour time is cut down. No matter how many sheets each tree forms, they are used up in no time and thrown away in the trash. So the rate of planting trees relative to paper consumption are not balanced. At one point of time, which is very soon, virgin pulp from barks of trees will not be available any more. There is also another environmental impact, which is the forest savings that is reflected on the air cleanliness, soil conservation and water protection that are directly proportional to sustainable forests. That is why in the States there is a law that controls the paper manufacturing firms to have a minimum of 50% of their furnish is recycled paper. It is expected that in a very near future paper will not be accepted in market except if it has a

certain percentage of recycled paper and the other percentage virgin pulp is from a sustainable forest.

Table (1.2) Hierarchy of Waste Management Practices

Prevention	Complete elimination of waste.	**TOP PRIORITY** ↑
Minimization	The avoidance, reduction or elimination of waste, generally within the confines of the production unit, through changes in industrial process or procedures.	
Recycling, Reuse & Recovery	The use, re-use and recycling of wastes for the original, or some other purpose such as input material, materials recovery and energy production.	
Treatment	The destruction, detoxification, neutralization, etc. of wastes into less harmful substances.	
Disposal	The discharge of wastes into air, water and land in properly controlled or safe ways such that compliance is achieved; secure land disposal may involve volume reduction, encapsulation, lechate containment and monitoring techniques	↓ **LOWER PRIORITY**

There is also the paper price problem which is facing the whole world right now. Publishers claim that the publishing industry is facing a crisis as dangerous as that of petroleum the world has faced in 1973. This pessimistic view is due to the increase in paper prices by about 30% to 40% [31]. Accordingly the elimination is impossible since paper use world wide has already increased. In Germany for example, the use of paper reached about 200 Kg per person per year, so the countries which are economically progressing will increase their paper consumption. This was clear in 1994, where the paper demand increased by 11% worldwide, so its price increased from $380 to about $450 and the pulp price increased also from $825 to about $925. This crisis is clear in the Egyptian market as well, where in mid July 1995 the price of a ton of Duplex paper has increased by L.E. 200.

According to one of the private owners of a printshop, the increase of paper price will be reflected in the coming school season where the school copybooks prices will increase [2].

To balance the paper market there is more than one way: Decreasing the waste in the manufacturing process or in the use of printing or packaging processes. This means the usage of new technologies in the manufacturing process and new equipment in the printing and packaging machines [2], according to British "Independent" newspaper, is to increase the prices of the publications and decrease their size. This is the same principal as that of avoiding the waste at the sources. What actually some of the international magazines did as "Yorkshire Own Magazine" and other small magazines was to decrease their supplements or even vanish totally from the market. Two major magazine publishers which are "Konday Nast" and "National" magazines faced the crisis by decreasing the magazines' sizes without decreasing the number of pages, such as that in the "Foge", "Tattler", and "Good House Keeping" [31]. However, the volume of production and post consumer waste is still huge and is increasing by time. So this would lead us to the third level in the hierarchy which is the recycling. In England there are two waste paper recycling factories that introduce to the paper mills recycled paper for republishing of about 370,000 tones per year [31]. According to Dr. Cohean, Egypt is a good example in this recycling idea. He added that this would have a good economical reflection, since the price of waste paper in the German market is 200 Mark per ton. He is emphasizing that the German market is willing to deal with Egyptian exporters in this field [2].That is more tempting to start a local recycling plant in Egypt with the Egyptian furnish and conditions.

Chapter 2

Background

2.1 Introduction

Before getting into the recycling process, the general paper making process should be understood. The raw material used in paper making is called pulp, which consists of any lignocellulosic materials that are broken down mechanically and/or chemically, where discrete fibers are liberated and can be dispersed in water and reformed into a web [3]. The lignocellulosic material was thought to be from either tree logs or any wood chips. Then the idea advanced to the fact that the use of any agricultural cellulosic wastes such as rice straw or bagasse...etc. can be used. In other words, paper making turned out to be a recycling process for the agriculture byproducts wastes. The pulping process steps are shown given in figure 2.1.

2.2 General paper making steps

2.2.1 Different pulping methods

Pulping is the preparation process of the fibers. The fibers could be wood, any cellulosic fibers or even used paper by separating and breaking them down to discrete fibers which are liberated and can be dispersed in water and reformed in a web by means of a mechanical and/or chemical ways [3].

2.2.1.1 Mechanical pulping (Ground Wood)

Original chemical constituent of the fibrous material are unchanged, except for removal of water soluble [7]. The pulp produced by this method are by using

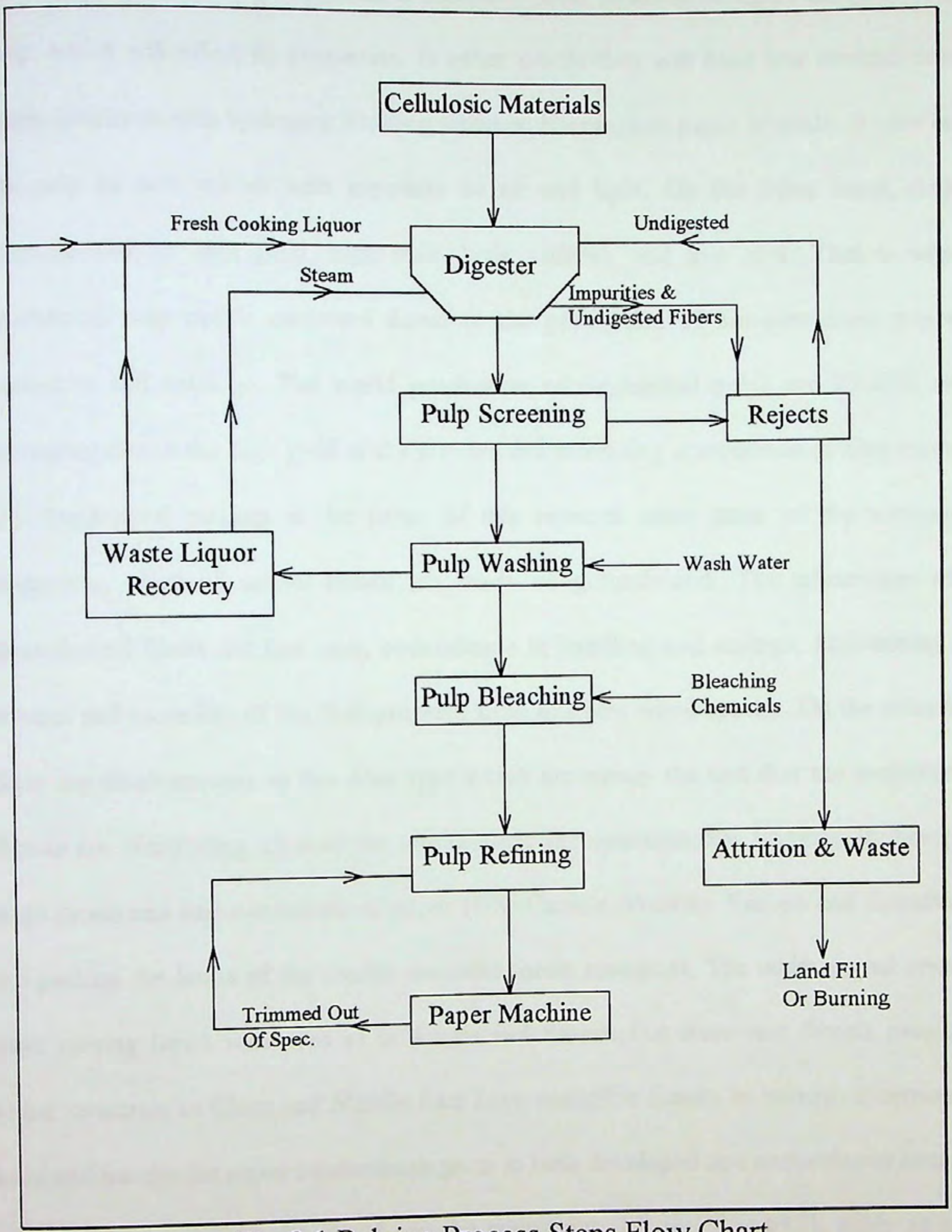

Fig 2.1 Pulping Process Steps Flow Chart

only mechanical friction to pulp lignocellulosic materials. No chemicals are used other than water or steam. It is called ground wood because grinding is the process used which is

fiber-fiber separation by peeling that is caused by shear stresses. So lignin are retained in the pulp, which will affect its properties. In other words they will have low strength because lignin interferes with hydrogen bonding between fibers when paper is made. It also causes the pulp to turn yellow with exposure to air and light. On the other hand, they are characterized by high yield, high bulk, high stiffness, and low cost. That is why the mechanical pulp use is narrowed down to the production of non-permanent papers as newsprint and catalogs. The world production of mechanical pulps are 20-25% and is increasing due to the high yield of the process and increasing competition of fiber resources [3]. Mechanical pulping is the focus of this research since most of the newspapers, magazines, most of school books are made of groundwood. The advantages of the groundwood fibers are low cost, convenience in handling and storage, high-quality pulp content and versatility of the fiber property from different wood species. On the other hand, there are disadvantages to this fiber type which are mainly the fact that the availability of forests are diminishing all over the world, since the countries that traditionally have been large producers and consumers of paper (US, Canada, Western Europe and Scandinavia) are pushing the limits of the readily available forest resources. The undeveloped countries have varying forest resources as in Russia and Siberia that have vast forests untouched. Other countries as China and Middle East have negligible forests to harvest. However, the need and hunger for paper continues to grow in both developed and undeveloped countries, such that by year 2000 the world may be consuming 4-5 times as much paper as in the 1970's [7]. To avoid this problem, other fibers from nonwood plants such as cotton, linen, grasses or reeds are used. Any woody plant whose main stem or stalk can be utilized for

pulp as straw. The advantage of this type of fibers is the availability as by-product of agriculture, so it is potentially cheaper. Also, the fiber can be harvested within 1-2 years of planting, compared to 10-20 years for trees. However, Straw is bulky, so transportation and storage are becoming a problem and the machine used for harvesting is used once or twice a year and the rest of the year they are idle.

2.2.1.2 Chemi-Mechanical Pulping

This was originally called Chemi-groundwood processes because chemical pretreatment were carried out before the mechanical pulping stage. This process was developed and used commercially in the early 1950's. The process starts by applying vacuum to remove much of the air from the logs and allow better liquor penetration, where the liquor consists of aqueous sodium sulfite Na_2SO_3 & sodium carbonate Na_2CO_3 and kept at 130-155°C for cooking; the temperature depends on the species of wood, or raw material used. Pressure was maintained at 150 psi [3]. Details on different types of liquor are explained later. Then mechanical grinding action takes place, but the grinding requirements were about half that required without pretreatment [3]. Both chemical and mechanical processes are sometimes carried out together [7].

2.2.1.3 Chemical Pulping

Selective removal of the fiber bonding lignin to a varying degree with a minimum solution of the hemicellulose and cellulose. If white paper are to be made thus purification is continued in the bleaching step[7]. The chemical structure of the lignin are broken and rendered soluble in a liquid which is mostly water. The fiber liberation point occurs when sufficient lignin is removed during pulping and wood chips become soft enough to break

apart into fiber with little or no mechanical action. It is carried out at 130-180°C, and pH value above 12. The chemical treatment is carried out in a digester which is a pressure vessel used for cooking chips into pulp. These pulps are characterized by high strength as well as high cost [3]

2.2.2 Digester and different types of liquors:

The digester is a pressure vessel used for cooking the cellulosic fibers. Its product is pulp which has the physical touch of small pieces of cotton soaked in water. The inputs of the digester are: steam for heating up the fibers, and cooking or pulping liquors which are aqueous solutions of chemicals. The fresh pulping liquor is called *white liquor,* which consists of active pulping species sodium hydroxide NaOH and sodium sulfide Na_2S, small amounts of sodium carbonate Na_2CO_3 left over from the recovery process, oxidized sulfur compounds and other chemical impurities from wood species. These chemicals are not added with constant ratios, but different combinations of them are given special names. Since these combinations can predict how well the liquor will behave. An example of the combinations is *Total Chemical or Total Alkali TA*, which is the sum of the sodium salts in the liquors as sodium oxide Na_2O, sodium hydroxide NaOH, sodium sulfide Na_2S, Sodium Carbonate Na_2CO_3. Chemicals applied are reported as concentrations of g/L or as a percent relative to oven-dry wood. One of the important combinations example is the *Active Alkali AA*, which include the active ingredients in the pulping process such as sodium hydroxide NaOH + sodium sulfide Na_2S, both as sodium oxide Na_2O. Typical value for AA is 100 gm/L. Another example of the combinations is the *Sulfidity*, which is the ratio of the Sodium Sulfide Na_2S to the active alkali AA. Typical Sulfidity is 24-28 %. If the Sulfidity is

too low, the lignin content of the pulp may be high and the carbohydrate degradation may be severe, which would lead to low pulp strength. On the other hand if the Sulfidity is too high, emission of reduced sulfur compounds increase and corrosion rate in the recovery process may be high. Other combinations exist, but no need to go through details of each, since this is beyond the scope of this research. Biermann gives the details of the combinations and their function [3]. In general the pulping chemicals are reported as concentrations in the liquor or as charge ratio to dry wood. Typically the liquor : wood ratio is between 1 : 3 to 1 : 4.

The waste liquor left after pulping is called *black liquor*, which contains most of the original cooking inorganic elements, degraded, dissolved cellulosic substances, which would include acetic acid, formic acid...etc. For each ton of pulp about seven tons of black liquor at 15 % solids (10 % organic chemicals and 5% inorganic chemicals). The black liquor is an extremely complex mixture that has to be well treated or recovered before being disposed. The black liquor must be concentrated to as high as solids contents as possible (up to 65-70%) before being burned in the recovery boiler to maximize heat recovery. The recovery boiler or heater's function are very important, since their purpose is mainly to recover the inorganic chemicals as smelt (sodium carbonate and sodium sulfide), and to burn the organic chemicals in order not to discharge them from the mills as pollutants. They also recover the heat of combustion in the form of steam. The black liquor is burnt by spraying it into the furnace through side openings. The water evaporates and the organic materials form a char and then burnt. The sulfur and sodium based inorganic materials leave as molten slag in the form of smelt that is directed to the *green liquor* dissolving tank. Further

processing of the green liquor converts it to white liquor[3]. Details on this topic are beyond the scope of this research.

2.2.3 Pulp Screening

The Pulp is screened first from any undigested fibers that are coarse relative to the required pulp specs. While hard poorly cooked lumps of wood, impurities or dirt and any other large unaccepted particles are separated from the pulp slurry using coarse screening equipment. Shorter fibers are easy to screen, so hardwood fibers are more efficiently screened than softwoods, also mechanical pulps are easier to screen than chemical pulps. The pulp is screened before washing to improve the washing efficiency.

There are different types of screens, such as *vibratory flat screens* and *rotary screens*. They have round holes and depend on the gravity flow system. There could be a high frequency vibration to help in the screening action. This type is not really used now because it is expensive to operate and maintain. However, they are useful at the laboratory level. Another type is the *centrifugal screens*. They consist of horizontal cylinder that contain round holes, and depend on the centrifugal rotation of the stock by a rotor with large paddles to facilitate the screening action. The mostly efficient type of screen used is the *pressure screen*. Its operation is more or less the same as the centrifugal screens. Its efficiency is a function of the hole size and shape, and the fiber reject rate is a function of the rotor configuration and speed. These type of screens were first introduced in the 1950's. Improvements were carried out on the holes design in the 1970's, where they were changed to tapered slots through the thickness of the screen instead of holes. This allows them to be used in any fine screening application without the blockage due to dirt trapping[3].

2.2.4 Pulp Washers

The pulp is introduced through washers which are almost always drum or counter flow washers for separating spent pulping chemicals. Typical mechanical washing setups are either a sidehill screen washing, Decker washing, screw extractor washing, or press washing.

Sidehill screen washers allow the pulp stock to slide and tumble down the wire for the removal of solids. The screen frame work are usually made of wood to avoid the problems of decay, chemical attack and corrosion. The shape and arrangement of the screen framework directly affect the water removal efficiency and overall capacity. The advantage of sidehill screen include there low cost and operation without power. Their disadvantages are high water consumption and high effluent consistency, resulting in high fiber loss. They also require large space and can be difficult to maintain for effective operation.

Gravity Decker is another type of washer which consist of perforated stainless steel cylinder covered with wire mesh, rotating in an elongated tile or stainless steel vat. As the cylinder rotates the liquid pass through the wire due to head differential between the stock level in the vat and the effluent level inside the cylinder. Fiber mat forms on the cylinder and picked up on a couch roll, and removed by a blade for discharge. Water showers are provided for continuous cleaning of the face wire. The advantage of this type is the low effluent solids. Water consumption and fiber loss are relatively less. However, the disadvantage is the high capital cost requirement [27].

The most commonly used is the *rotary vacuum washer*. It consists of wiremesh covered cylinder that rotates in a tub of pulp slurry with valves arrangements to apply vacuum. As the drum contacts the slurry, a vacuum is applied to thicken the stock. The

drum then rotates past washer showers where the pulp layer is washed with relatively clean water to displace black liquor. Vacuum is cut off beyond the wash showers and the pulp is dislodged into a pulper.[3]

2.2.5 Bleaching & Brightness:

Brightness is a measure of the reflectivity of paper to light. So higher brightness number means greater reflectivity than lower numbers[42]. Although brightness is not a measure of color, and papers with highest brightness numbers are not always seen by viewers as whiter than others with lower numbers. Yet the term brightness is used to describe the whiteness of pulp or paper on a scale from 0% (absolute black) to 100% (relative to magnesium oxide MgO standard, which has an absolute brightness of about 98%) by the reflectance of blue light (457nm) from the paper [3]. The main difference between whiteness and brightness is that brightness is measured in the blue region. Blue region is selected because the human eye and psychological system prefer blue-white to other shades. On the other hand, whiteness is equal to the presence of all the colors. In other words, if the sheet is truly white it will reflect most of the wavelengths and will not absorb one wavelength more than the other [28]. Brightness is a function of the properties of the pulp used such as groundwood or lignin content. It is also affected by the fillers and additives to the paper such as clay, calcium carbonate or titanium dioxide [42]. Bleaching is the increase of the pulp brightness through treatment of fibers with chemical agents. The bleaching strategy of chemical pulps is different than that of mechanical pulps. The chemical pulp bleaching depends on the idea of removing lignin which leads to greater fiber-fiber bonding strength, but decreases the length of cellulose molecules that results in weaker

fibers. On the other hand, the idea of bleaching mechanical pulp is achieved by chemically altering the portions of the lignin molecule that absorb light and have color. Exposure of pulps to air, light, heat, certain metallic ions and fungi causes it to gain yellow color. This is known as color reversion. This color reversion phenomena is due to modification of residual lignin forming chromophores. So, mechanical pulps are susceptible to color reversion more than chemical pulps. However, chemical pulps are to reverse color on exposure to high temperature. This explains the phenomena of newspaper getting yellowish in color with time and exposure to light.

2.2.6 Pulp Refining/Beating

To develop the optimum paper making properties, a mechanical treatment for pulp fibers are carried out. The process is interchangeably named refining or beating. Refining increases the strength of fiber to fiber bonds by increasing the surface area of the fibers and become more pliable to conform around each other and thus leads to a denser sheet. This refining action weakens the individual fibers which are made shorter due to cutting action. In short, most strength properties of paper increase by the refining process since these properties depend on the fiber to fiber bonding. However, tear strength decreases, since they depend on the strength of individual fiber. During pulp spreading in the paper machine, the trimmed or out of specifications paper are sent back to the beater to reform them into paper [3].This refining / pulping process is considered the first step in the recycling process where waste paper is used as a source of fiber.

2.2.7 Paper making machine

There are basic steps which are followed for either hand or machine made paper. The steps are as follows:

1. *Forming* the paper by applying the pulp slurry to a fine screen mesh or wire cloth
2. *Draining* step which drains water by means of a force as gravity or pressure difference developed by water column.
3. *Pressing* to dewater the pulp further by squeezing water from the sheet.
4. *Drying* step by either air drying or passing the sheet over in a hot atmosphere.

If the process is manual the production is done sheet by sheet, but if a paper machine is used then it continuously forms, dewaters, presses and dries a web of paper fibers[3].

2.2.8 Printing Methods

In order to start a deinking process i.e. removing the ink from the paper, the method of applying ink on paper has first to be understood. There are multiple methods of ink application. There is either a manual process by writing using pencils or pens, there is also an office dry application through the photocopying machines or printers which use toner, or liquid application as through presses which would produce thousands of printed pages per day. Liquid application will be the concern of this study. There are different press printing procedures, which differ according to the method of ink application and the drying procedure. Typical printing processes are as follows:

- *Gravure:* where the printed image are etched on the printing cylinder, such that the printing area is a depressed surface that will contain the ink and the extra ink are

scraped off by a doctor blade. Then the cylinder rotates facing the paper to be printed applying the ink.

- *Letterpress:* The printed image is raised above the surface on the printing cylinder, and ink touches only the raised surface. Then the cylinder rotates to face the printing paper to apply the ink on it.

- *Flexography:* the printing plates are made of rubber and it is a very delicate process which is mainly used for printing on tissue paper ...etc.

- *Screen:* the printing area is cut in a metal sheet and then this sheet is either wrapped around the printing cylinder or directly placed on the paper to be printed. Then ink is applied on the screen where the non printing area is protected from the ink by the screen.

- *Offsett Lithography:* the printing and non printing area are on the same plane. The whole process depends on the fact that grease and water do not mix. This process has some advantages as being fastest press operation, the printed images and pictures are clear, and finally it is a cleaner process compared with the previous processes.

According to some field visits to different print shops in Cairo such as El-Ahram press, AUC press and two private print shops, all of them were using the offset printing process. That is why the concentration in this study will be on the type of ink used in this process.

The process starts by some preparations where the image or the material to be printed are prepared for photographing first. The photographed films are considered to be the negative of the printing material. Then the negative is placed over a sensitive plate that is covered with chemicals that are sensitive to light. Where the areas exposed to intensive light change their chemical properties and considered to be cured, the other areas are not and can be easily washed out with chemicals and water. At this stage a plate is ready with the printing areas having a high affinity to grease and the non printing areas having a high affinity to water. These plates are then mounted on the printing cylinder in the press machine. There are dampening rollers and ink rollers which touch the plate cylinder simultaneously. Then the plate cylinder face a blanket cylinder which is made of rubber and the inked image is transferred to the rubber, next the image is transferred to the paper cylinder for printing. This process is used in newspaper and magazine printing as well [30].

2.3 Ink Function & requirements

Major function of ink is to provide contrast on the paper to make the printing areas readable and the images clear. Also it has to be applicable by the printing process. In other words, in the case of Offset printing process the ink has to have grease. It should change quickly from a liquid film to a dry film. It has to remain unchanged on the sheet for the time required of the print such as rubbing off. The more complicated the printing process, the more complicated the ink formulation; consequently, the more complicated the deinking process.

2.3.1 Ink Components

The major components of any liquid ink should be colored solids and vehicles. The colored solids are pigments and not die, because dies are easily spread through the paper fibers and could fade out if exposed to light. The typical pigment properties are not to be soluble in vehicles, since they have to be only suspended [46]. They could be mechanically dispersed for future deinking and their particle size differ according to the color of the ink.

As for the vehicles, they are liquidous material which provide transfer of the pigments and bind it to the sheet except if the printing process is electrostatic. The major consistuents of vehicles are vegetable oils, resins either natural or synthetic, plastics and volatile solvents. Other additives are used to adjust the chemical nature of ink or to give it specific properties such as waxes, plasticers and drying agent. These are added in minute quantities [27]. Solidifying method of the ink depend mainly on the vehicle consistence. The typical solidifying methods are either by absorption of the ink through the paper fibers, or by evaporation, oxidation, heat curing, ultraviolet curing...etc.[30].

2.3.2 Ink solidifying processes

- *Absorption:* oil in the vehicle is absorbed into the porous paper sheet so increases the viscosity of the ink surface (not subject to saponification by an alkaline treatment, so its removal depends on emulsification). This kind of ink is mostly used in printing newspapers since it produces a smudgable printed matter, because of the absorption is not synonymous with drying.

- *Evaporation:* the vehicle is volatile where it contains some type of ester of rosin or metal resinate binder dissolved in an appropriate solvent. It dries by its evaporation.

This method is used by letterpress and web offset printing. Rosin esters do not saponify under typical deinking methods. Metal resinate can be saponified with a strong alkali.

- *Oxidation:* ink sets by absorption into the fiber and polymerization of oil such as linseed, soyabean, tung, dehydrated castor or certain other resin vehicles. These types of ink produce a polymerized film that are not soluble in common solvents. It can be partially saponified by a strong alkali at a moderate to high temperature It is used by offset or lithographic sheetfed printing.

- *Heat Curing:* chemically formulated to harden by polymerization in the presence of heat. It is used in certain publications as Times & News week magazines.

- *Ultraviolet Curing:* chemically polymerizes to a higher molecular weight acrylic polymer film when exposed to UV radiation. Very difficult to disperse UV inks by chemical means and it becomes even worse when the furnish ages.

- *Infrared Hardening:* ink formulation is the same as that of oxidative inks, but the ink film is not as flexible, durable, or chemically resistant. Used in sheetfed offset lithographic printing.

- *Precipitation:* binders in the ink precipitate into a hard film in the presence of water, steam, or chemical addition after ink application.

- *Gelation:* certain binders are contained in petroleum vehicle. Upon printing the oil drains into the paper leaving pigment and binders as a gel. It has limited applications.

- *Cooling:* ink is applied at a temperature above its melting point and solidifies upon cooling. Limited commercial use.

2.4 Recycling

After a long era of paper making and paper production with all its different categories, either writing paper with different grades, photocopying, printing (books, laser printing, newspaper, magazines), packaging, cartoons or tissue papers, a high percentage of the municipal solid wastes turned out to be paper. This lead to two environmental problems. First is the disposal problem which used to be through either landfilling or incineration. Both solutions are expensive and are not considered to be long term solutions. The second problem is the decreasing availability of the virgin cellulosic fiber relative to the rate of paper production and consumption. So the solution to the two problems is to reuse the same paper fibers once more by recycling them. In 1989 in the U.S, almost 30% of the paper consumed was recycled, while Japan had a recovery rate of 50%. Other developed nations tend to have recovery rates between 30-50%. Definition of paper recycling could be as follows : " Obtaining fiber from recycled paper is a matter of separating impurities from the usable fiber" [3]. The recycled fibers could be either paper or paperboard arising outside the mill or off specification paper produced at the mill and reused in the mill. The later type is called *broke*. The major sources of the waste paper which are from corrugated boxes, newspapers and office papers are about 80% of the total paper waste. Most of the waste paper are used in paper boards, chipboard, and roofing materials where color is not important. Less than 20% of the waste paper is deinked to be used as newsprint, tissue, or other bright grade papers. To get a high quality of recycled fibers, they should be well segregated. In other words, the newspapers should not be mixed with magazines, or brown

paper since each of these types has its own contaminants and its own fiber specifications. The contaminants could be classified as stickies, fillers such as grit, sand, metallic objects, or ink. Deinking became the major problem which requires a good study for its technology, inorder to produce a good quality of recycled writing, typing or newsprinting paper. The general paper recycling steps are shown in figure 2.2 in a flow chart.

2.4.1 Pulping of Recycled paper

Three forms of energy are applied to perform the pulping, mechanical, chemical and thermal. This is considered to be the starting process of the deinking stage. Since, the swollen fibers rub against each other in the pulper with water and waste paper. On experimental basis a beater such as a valley beater would do this step.

2.4.2 Screening

Larger and heavier contaminants are trapped and removed. This is applicable for mass production only. Screens used could be the same as the ones used for pulp forming from cellulosic fibers. Since in the experimental stage no real contaminants are considered except the ink.

2.4.3 Flotation

The Pulp slurry (stock) is aerated and foaming agents can be added at this stage to attract ink particles to air bubbles and rise to the surface to be removed. Flotation process can be devided into 3 phases, collision of ink particles with air bubbles, attachment of ink particles to air bubbles, and flotation of inked air bubbles to the surface for separation by skimming. Chemicals could be added at this stage to increase the efficiency of ink removal from the fibers. Examples of the chemicals are Alkali base materials since they swell the

fibers and loosen the ink particle from the fiber. Sodium hydroxide is an example that acts with the oil base of the ink and form soap. It enhances the foam formation. Other chemicals could be used as sodium silicate which is even better since it has the alkaline group and at the same time has abrasive particles which help in friction of fibers to loosen off the ink particles and disperse them in the fibers slurry.

2.4.4 Centrifugal Screening:

Light weight contaminants are to be removed at this stage, such as plastics, synthetics, and stickies.

2.4.5 Washing

Smaller ink particles that are not removed by flotation are removed at the washing stage. Also clay and other paper fillers are washed out with the water. The type of washer used could be the same as that used for pulp forming from cellulosic fibers.

2.4.6 Dispersion

Pulp slurry is thickened and any remaining ink is dispersed into very small particles to become invisible. It means that the finer the dispersion of ink, the higher the ink removal by a washing device. In other words, the washing techniques and other ink removal techniques are not practical if the deinked pulp is not well dispersed. So the washing stage could be repeated after the dispersing stage.

There are two dispersion methods. First, mechanical dispersion where shear forces are encountered during pulping and/or deflaking would be applied on ink.

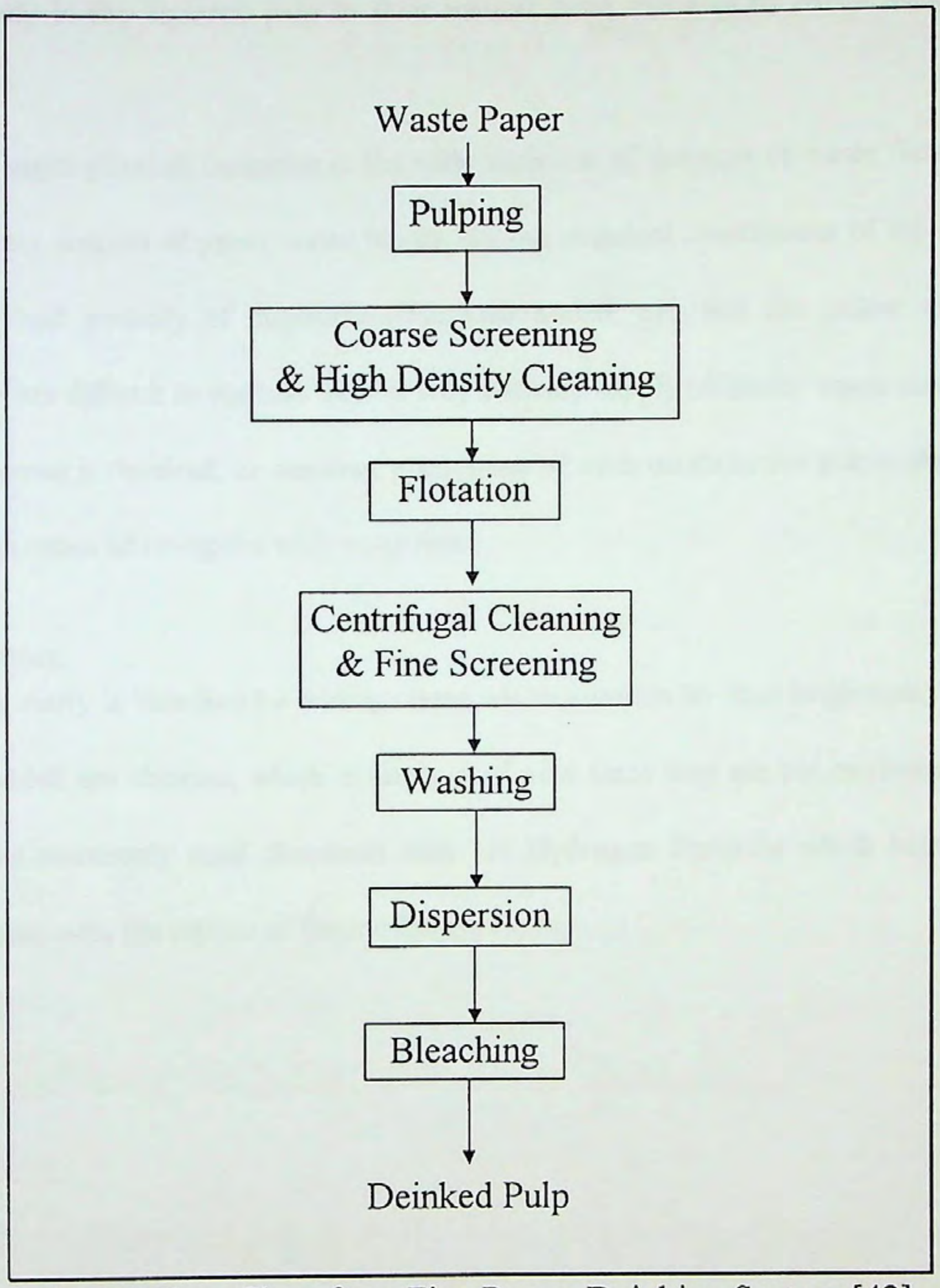

Fig 2.2 Flow Chart for a Fine Paper Deinking System [42]

Fine dispersion for washing is still not reached, chemical dispersion is still primarily depended upon. The second method is the chemical dispersion, whose objective is to release the ink pigment particles from its vehicle with the least fiber damage and to suspend the

particles freely in the aqueous pulp in their natural form and size to enable mechanical removal.

The major physical limitation is the wide variation of the type of waste furnish due to the different sources of paper waste inputs. So the chemical constituents of the furnish, as the type and quantity of dispersion chemicals added, pH, and the pulper chemical environment are difficult to control. That is why a steady supply of similar waste material in deinking process is required, or constant proportion of each waste in the pulper should be maintain a as ratios of newsprint with magazines.

2.4.7 Bleaching

Pulp slurry is bleached by adding chemicals to increase its final brightness. Typical chemicals added are chlorine, which is rarely used now since they are not environmentally friendly. The commonly used chemicals now are Hydrogen Peroxide which believed to bleach the pulp with the release of the available oxygen.

Chapter 3
Literature Review

3.1 Introduction

In this chapter an overview on the importance of paper from the economical and availability point of views are carried out. Also an overlook on the world's consumption of paper and needs are discussed, which would reflect automatically on the importance of finding new sources of fibers to make paper. Even if it is the reuse of the same fibers, by recycling the paper. Different researches were carried out in the paper recycling field. Either to replace the fiber type or to check the effect of multi recycling stages of the same fibers on its physical properties.

3.2 Importance of paper

El-Ahram daily newspaper published 2 articles within 5 weeks in 1996 on the paper crisis. The first one was anonymous and made some kind of a survey on the problem and its effect on the different world wide, well known magazines, school books, as well as writers and publishers. The second article was an interview with Dr. Menfrid Cohean, the union president of paper producers in Germany. He discussed the problem and suggested solutions. Then a forecast report on pulp and paper prices from Pira International was published as an article in the Financial Times newspaper in July 1995, by Harding.

The first El-Ahram article reflected the publishers claim that the publishing industry is facing a crisis [31], as dangerous as that of petroleum the world had faced in 1973. This pessimistic view is due to the increase in paper prices by about 30 to 40%. Prices will

drastically increase this year for all the publishing industries, either newspapers, magazines or books. Facing this crisis the British "Independent" newspaper said that there are two methods, first by increasing the prices of the publications and decreasing their size. The second method is by paper recycling. "Yorkshire Own Magazine" and other small magazines has to decrease their supplements or even vanish totally from the market. Two major magazine publishers which are "Konday Nast" and "National" magazines faced the crisis by decreasing the magazines' sizes without decreasing the number of pages, such as that in the "Foge", "Tattler", and "Good House Keeping". By the increase of cost prices, which reached 5 pence per monthly magazine, all plans for an increase in the number of supplements or production of new magazines to the market and change the glazed cover are nearly canceled to decrease the cost. However, publishers are worried that these steps would decrease the distribution. Especially that newspapers faced a decrease in purchasing rate by 2 % , so they developed and updated their publications. But now with these economical circumstances it is impossible to continue developing or updating them. This crisis affects the publication of books as well, although the paper cost is no more than 5 % of its budget. However, its profit will decrease by 5 %. Publishers expect that school books will be affected from the cost point of view more than the other books. On the other hand, "Hoder Headline" publisher decided to lead the opposite direction. Which is to decrease the book prices, where the increase of sold quantity will balance the increase in prices. As for the waste paper recycling is considered to be one of the most effective methods to face such a crisis. The old magazines and newspapers started to have a price which reached about 40 Sterling pounds per ton. Republishing of 280,000 tons of waste paper will take place per

year from a new factory, plus 90,000 tons from another smaller factory in England. Most analysts believe that these new prices will continue in 1996 until the increase of the production and cost will automatically decrease (optimistic view)

According to Aref in the second El-Ahram article, experts emphasize the fact that paper prices will continue increasing by 20% within the next five years [2]. He interviewed Dr. Menfrid Cohean who said that by the increase in the paper prices will cause a lot of changes and will affect the printing and packaging production worldwide. By the end of the twentieth century paper prices would increase. Dr. Cohean explains this by the fact that by the end of an era, the important characters in the world, whether businessmen, politicians or writers are encouraged to register their impressions and memories about a finished era and their view for a coming one. Which would increase the amount of paper used in printing. Other reasons for increasing the paper demand are the increase in social and economical levels. Which would increase the individual use of paper either in printing or packaging. In Germany for example, the use of paper reached about 200 Kg per person per year, so the countries which are economically progressing will increase their paper consumption. This was clear in 1994, where the paper demand increased by 11% worldwide, so its price increased from $380 to about $450 and the pulp price increased also from $825 to about $925. Aref added that the world is searching for other sources for paper manufacturing. Especially that special cellulosic tree fibers are used and are mainly concentrated in Finland and Sweden. But, environmental awareness associations and the green group are pushing so hard to protect the forests and the trees. Over and above the cost of chemicals used in paper making are increasing. Dr. Cohean said that there are new researches and trials for making

paper by a chemical and mechanical methods using new materials. He also added that Spain and Portugal have entered the paper manufacturing world. In Germany, they carried out some successful tests on a new plant called "Kanabes", and they produced a high quality of paper. However, there was a major problem in using this plant. Beside its high cost, there is an anesthetic (drug) material produced as a by product which would have the same effect as Morphine. The amounts of this material produced by this Kanabes would be more than the medical usage. As for the other materials used they are either too expensive to use or heavily pollutant and the paper quality produced are of very low quality such as bagas and rice straw, so it is used only in packaging. To balance the paper market there is more than one way. First, to decrease the waste in the manufacturing process or in the use i.e. printing or packaging processes. This means the usage of new technologies in the manufacturing process and new equipment in the printing and packaging machines. Second way is to recycle waste paper. Where according to Dr. Cohean, Egypt is a good example in this recycling idea. He added that this would have a good economical reflection, since the price of waste paper in the German market is 200 Mark per ton. He emphasized that the German market is willing to deal with Egyptian exporters in this field. As for the case in the Egyptian market, according to Aref, is showing the start of a crisis. Where the mid of July 1996 the price of a ton or Duplex paper has increased by L.E. 200. According to one of the private owners of a printshop, the increase of paper price will be reflected in the coming school season as the school copybooks prices will increase.

According to the forecast from Pira International, the established paper and packaging research center, "the world pulp and paper industry are about to reach the peak of its

current cycle, but the coming decline will be less severe than last time"[23]. They published a report " Pulp and Paper beyond 2000". They suggested in the report that after sharp price rises for paper and board over the last 18 months, prices will reach an unsustainable high in 1995-96. Waste paper prices have tended to lead price declines in the industry and are expected to start falling from next year. Pulp consumption should maintain more consistent growth as it becomes used in a wider variety of products. According to the Pira study, world pulp consumption until 2000 will grow at a steady 1 per cent a year and the five years after that at 1.5 per cent a year. As for the waste paper recovery, in the US, it is expected to continue a grow reaching about 46 per cent by 2000 and 49 per cent by 2005. In the rest of the developed world, waste paper supply is already higher and expected to reach market saturation at 50 per cent by 2005. According to Pira, the share of world paper and board output tonnage held by the largest companies could be well over 80 per cent by 2005 from the 65 per cent today.

An overview on the problem in North America is reported by Garbutt [17]. The landfill capacities are decreasing. One way to overcome this problem is to reduce the amount of the municipal solid wastes being passed over to these landfills. This could be achieved by increasing the recycling attitudes. It is estimated that paper and paperboard are approximately 36% of the municipal solid waste stream in North America. Local and regional governments have passed laws or made a voluntary agreements with industry to expand the recycling of paper and paperboard. In 1991 and 1992, 17 de-inking plants were to come on-line with total estimated annual pulp capacity of 1.6 million metric tons every

year to produce de-inked fiber for use in the manufacture of newsprint. Old magazines were to be used by most of these plants in a substitutional amounts.

3.3 Paper Recycling

To find sources of fibers and to solve the municipal solid waste problem, Placzek [34] at Tempico cooperation invented a process that's called by the company's name. In the process, fibers are extracted from unsorted, raw municipal waste as presented to be used as a fiber resource. A horizontal rotary processor operated at high temperature and pressure that separates the processed pulp from the rest of the waste stream in shaker screens. This pulp is then deinked using special chemicals and standard deinking plants using pilot plants. Then the deinked pulp is bleached to produce newsprint grade paper fiber. The cost of fibers with this tempico process should be similar to those from other fiber sources.

Another idea is to recycle the same fibers more than once. It is expected that the fibers properties will deteriorate. A couple of researches on this point were carried out. First one was done by Ellis & Sedlachek [13]. They analyzed the relationship between recycled fiber content and strength of the final product based on a network theory of paper. The theory states that strength could be a function of fiber tensile strength, of the coarseness, perimeter and length distribution of the fiber, the fiber-fiber bond strength, and the relative bonded area. The results of this analysis, which was carried out on various fibers, showed that over repeated recycling the fiber strength is reduced by 7% , and fiber coarseness was slightly reduced. However, the fiber-fiber bond strength is not affected.

The second research was carried out by Chatterjee et.al.[8]. They studied the effect of recycling on the fracture of paper. Types of paper used for the testing are unbleached

Kraft, high yield sulfite and thermomechanical pulp under controlled recycling treatment. Out of plane tearing strength and in plane fracture resistance were the characterization of the fracture behavior. The results showed that both tearing strength and fracture resistance depended on the extent of recycling, these two results do not correlate together.

3.4 Deinking

Type of paper used, time left since printing till deinking takes place (aging), and printing methods are all factors that affect the deinking efficiency. Researches are carried out to develop an experience and knowledge of the effect of these factors on the different deinking procedures. One of the researches was carried out by Cathie et. al. [6]. They studied the effect of aging on electrophotographic paper grades and was assessed using two base papers. Earlier studies had suggested that deinkablilty of such grades was related to base paper whether virgin or recycled. They came up with the following conclusions: pulper brightness and post flotation brightness of printed recycled base paper were unaffected by aging. On the other hand pulper brightness and post flotation brightness of the printed virgin base paper generally decreased with time. The reasons for the differences between the two base paper types were unclear.

Another research was carried out on the coated and uncoated papers by Frank [15]. He tested the effect of the heatset prints on coated and uncoated papers on its deinkability relative to the contents of the oxidative drying ink components. The results were that the heatset prints on the coated paper were readily deniable, irrespective of the contents of the oxidative drying ink components. However, prints on uncoated paper deinkability was graduated depending on the level of oxidative drying components.

Gottsching et. al. [19], studied the effect of different printing method on deinking. Laboratory trials were carried out with 100% newspapers, that are printed by various processes. The de-inking conditions, slushing and reaction with both de-inking processes flotation and washing, were constant all over the testing. The de-inking agents used were commercial products used in commercial de-inking plants. Brightness of the slushed stock before flotation varies according to the printing process applied. The flexo printing process produces less brightness (13 points less) compared to the common printing processes such as offset and letterpress. Where the major difference between the flexographic newspaper printing and the other printing processes is the printing ink, which water based instead of oil based.

There are different furnishes of deinking plants, depending on the type of waste paper introduced to this plant. However, researches were carried out on the different deinking furnishes. The most prominent deinking process is the flotation system. According to Harrison [24], flotation removes most of the ink particles when combined with other deinking process and specific deinking chemicals. Different ink particle size require various types of equipment for effective removal. There are different processes that are either used simultaneously or one of them used alone or combined, depending on the type of furnish and the finished pulp required. In washing process water is separated from the fiber. So the ink particles, in the size range 1-10 microns, that are hydrophilic (attracted to water) are washed out with the water in the dewatering stage. In flotation process, where air and chemicals are added to the solution. Particles with size ranges of 10-150 microns and are hydrophobic (repel water). Attach themselves to the bubbles formed by the air / chemical

additives and float to the surface and then skimmed off. As for the cleaning systems, it is controlled by the specific gravity of the particles that are usually large in size (100-1000 microns). Screening process removes only the large and stiff particles with size range 1000 microns and more. However, ink particles are sometimes large but not shaped like plates and not stiff, so they tend to pass through the screen slots. Flotation generally is the most efficient process, but cleaners and screens are required for removing contaminants such as stickies and plastics. They also remove the inks that flotation systems have difficulty in handling.

Different designs of flotation cells are developed and tested. One of them is that developed jointly by Britz and Linck from Sulzer-EscherWyss GmbH and Knelisson from Buhrmann-Tetterode Nederland BV [5]. Its a special type that is known as the CFS Compact flotation cell for removing dirt specks efficiently. Since the basic concept of de-inking by flotation is to adhere the ink particles to the air bubbles. For a given air volume, the specific surface area increases with reducing the bubble diameter. In order to apply the greatest flotation of ink particles, it requires the largest possible air bubble surface area. In other words, smallest bubbles would give the de-inking effect. According to Isler's claim [26], air bubbles' diameter smaller than 0.1 mm tend to adhere fibers, but bubbles' diameter larger than 0.5 mm would have enough buoyancy to rise through the elastic network formed in the fiber suspension. However, the ratio of air bubbles' diameter to ink particle size has to be taken into consideration. As shown in figure (3.1), a bubble diameter of 1 mm with various sized ink particles, the contact area of the ink particle decrease with increasing particle size according to the radius of curvature of the bubble. To avoid the ink particles

away by the surrounding flow stream, larger bubbles with a larger radius of curvature is required. The CFS was developed for removing large dirt speck via large bubbles. The small ink particles were already taken care of through the CF [29] flotation cell. Tests on the CFS were carried out using mixed newspapers and magazine stocks. It showed that the CFS are not only efficient for the large dirt specs, but it has a very good potential for flotation of the microscopically small ink particles. Brightness enhancement is about 70% of that of the conventional CF cell. The CFS cell was specially developed for the efficient flotation of entire visible particle size range of 60 - 450 m.

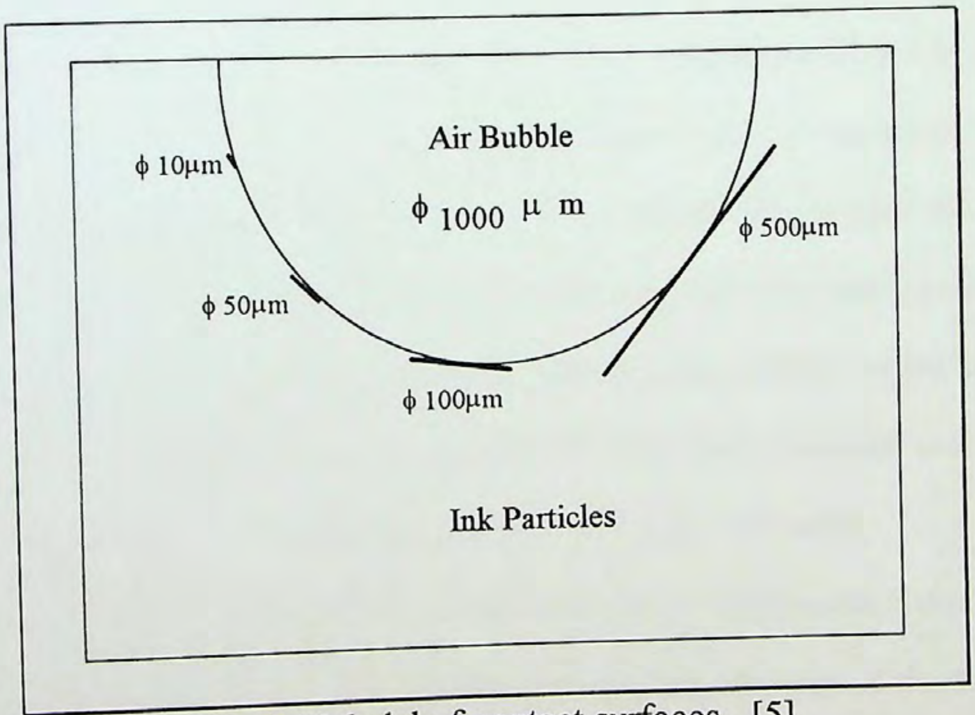

Fig 3.1 Model of contact surfaces. [5]

Chemicals are added to some of the deinking furnishes to increase its efficiency. Type of chemicals use and amounts are researched. There are general known chemicals that are used in most of the deinking plants. The most important ones were discussed by Harrison [24]. Such as sodium hydroxide which creates alkalinity and release ink to the

suspension, sodium silicate acts as a dispersant or releases ink and stabilizes alkalinity, hydrogen peroxide that gives higher brightness to the pulp by suppressing the yellowing action caused by the alkaline mechanical pulp, soap is used as a collector chemical in combination with calcium, finally, the calcium salts that interacts with soap to make insoluble sticky particles on the ink surface. So these water repellent particles have a strong tendency to attached themselves to air bubbles.

Togashi and Okada [41] made their research on the combination of chemicals that they call DeInking Agent (DIA). They found that the higher the penetrability of the DIA, the lower the amount of non-detached ink. On the other hand, conventional DIAs with strong penetrability, generate unacceptable high level of foam that would interfere with subsequent process steps after leaving the froth flotation cell in the pumps or chests. So they developed a new DIA, they named (MHAD). Where they changed the molecular configuration of the DIA. It resulted in a higher ink-releasing ability and appropriate foam generation in the flotation cell that disappears after flotation. MHAD proved to be better than the Kao's standard deinking agent (FOAD) from the adsorption and wetability, penetrability, foamability, and deinking results in both lab and mill scales.

Also Stratton [39] carried out a study of the effect of physiochemical properties of chemicals used in the flotation process. It showed that the efficiency of the flotation cell affects the attachment between the contaminant and the air bubble. The study was carried out on hot melts and laser-printed inks. The variables which affected the ink attachment are bubble size, deinking liquid surface tension, and contaminants surface energy.

Borchrdt et. al. [4] invented two lab methods for studying the process of ink separation from cellulose fibers. One of them is a modified spinning-drop tensiometer that can measure the interfacial tension between deinking surfactants and model inks within time frame of the pulping stage. The other is one dimensional HNMR imaging can measure the rate at which model inks separates from cellulose fibers. Both methods show promise as rapid screening tools for predicting the deinking defective's of surfactants.

Chapter 4
Experimental Test Rig

4.1 Introduction

This chapter consists of the experimental setup, procedure and standard reference of the optical and physical properties of newspaper according to Egyptian Standards. The experimental facility was designed and manufactured at the American University in Cairo as a production line to run our tests. It can be used later on as a model to provide technical assistance to those who are interested in such business. It consists of a standard office shredder to increase the specific area of paper, beater to produce pulp, flotation cell to deink the waste paper, where at this stage chemicals could be added. Hand sheet machine and press/heater are used to prepare the sheets. Finally, the prepared sheets are tested for the physical and optical properties according to the Egyptian standards.

4.2 Experimental Facility

The experimental set up to recycle the waste newspaper is composed of an office shredder, beater, flotation cell, hand sheet machine and a press/heater as shown in the flow chart shown in figure (4.1). In the following paragraphs an idea of the different recycling stages are presented.

4.2.1 Standard Shredder

It is a machine used to decrease the size of paper and increase its specific area. This would facilitate the beating process and lower the time required to refine the fiber and form the pulp. The machine is a normal standard office shredder, which consists of two rotating

blades that shred the sheet of paper into thin ribbons by passing it between the blades. This machine is not used in paper manufacturing industry, but it is convenient enough for research.

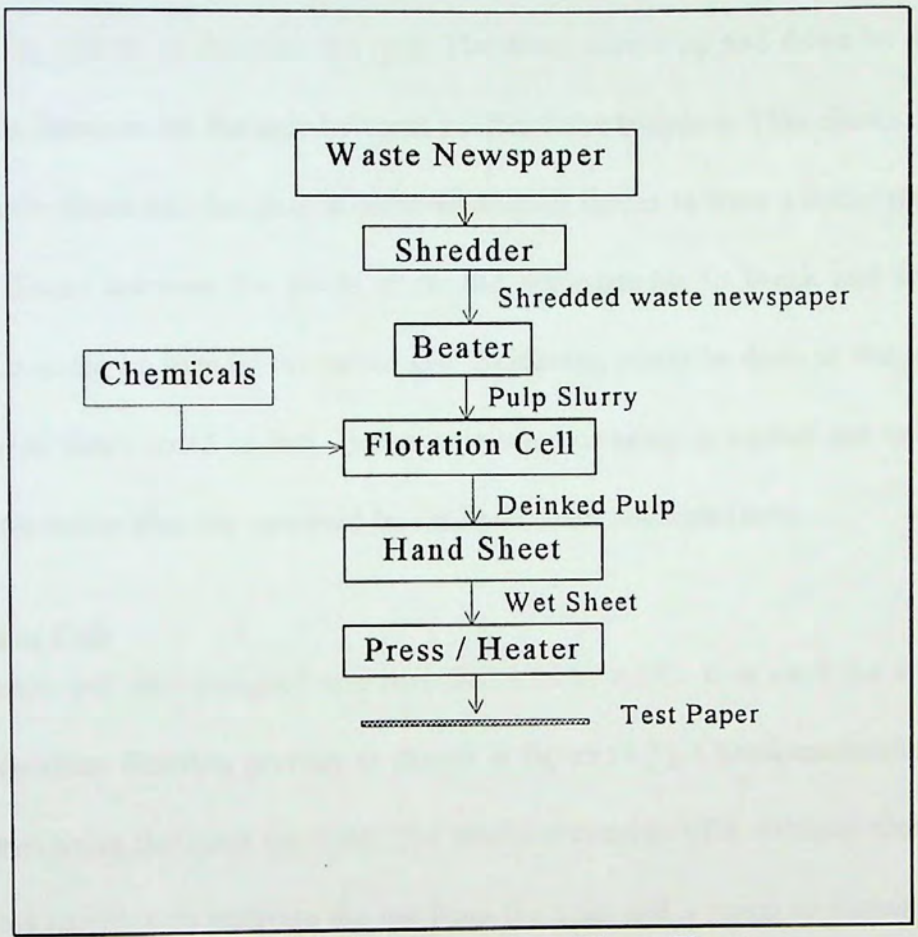

Fig 4.1 Testing Procedure Flow Chart

4.2.2 Beater

This device was invented in 1700's and was called Hollander Beater [3]. The one manufactured in the AUC workshop and used in this research is called a valley beater, which is considered to be a laboratory version of the beater see figure (4.2).

It is used for refining the fibers and producing the pulp slurry. It is a batch process, where the pulp slurry circulates in a stainless steel oval tank. It passes between a drum in the midsection of the tank, that has a cylindrical roll shape with bars and a bedplate with angled slots. The drum rotates with a constant rpm using a motor that transmits the rotation through a pulley system to decrease the rpm. The drum moves up and down by means of a gear system to decrease the distance between itself and the bedplate. This allows the pulp to pass between the drum and the plate at different friction forces to have a better pulp quality. The friction forces between the fibers allow the ink particles to break and float to the surface, which could be seen by the naked eye. Skimming could be done at this stage but a large amount of fibers could be lost. However manual cleaning is carried out using a sieve that has a mesh wider than the one used by the hand sheet machine (m/c).

4.2.3 Flotation Cell

Flotation cell was designed and manufactured at AUC. It is used for applying the mechanical deinking flotation process as shown in figure (4.3). Chemi-mechanical deinking could be tested using the same machine. The machine consists of a stainless steel container with an angled partition to separate the ink from the pulp and a pump to circulate the pulp slurry through a jet pump. The jet pump is used to entrain air and cause a turbulent flow to facilitate removing the ink. The pumped slurry through the jet pump faces a disc, which is 3 cm below the jet pump, to form a turbulent flow. The entrained air, and the turbulent flow of the slurry will help the ink to be separated from the pulp mechanically by friction and float to the surface; mechanical deinking. There is also a heater to test the effect of

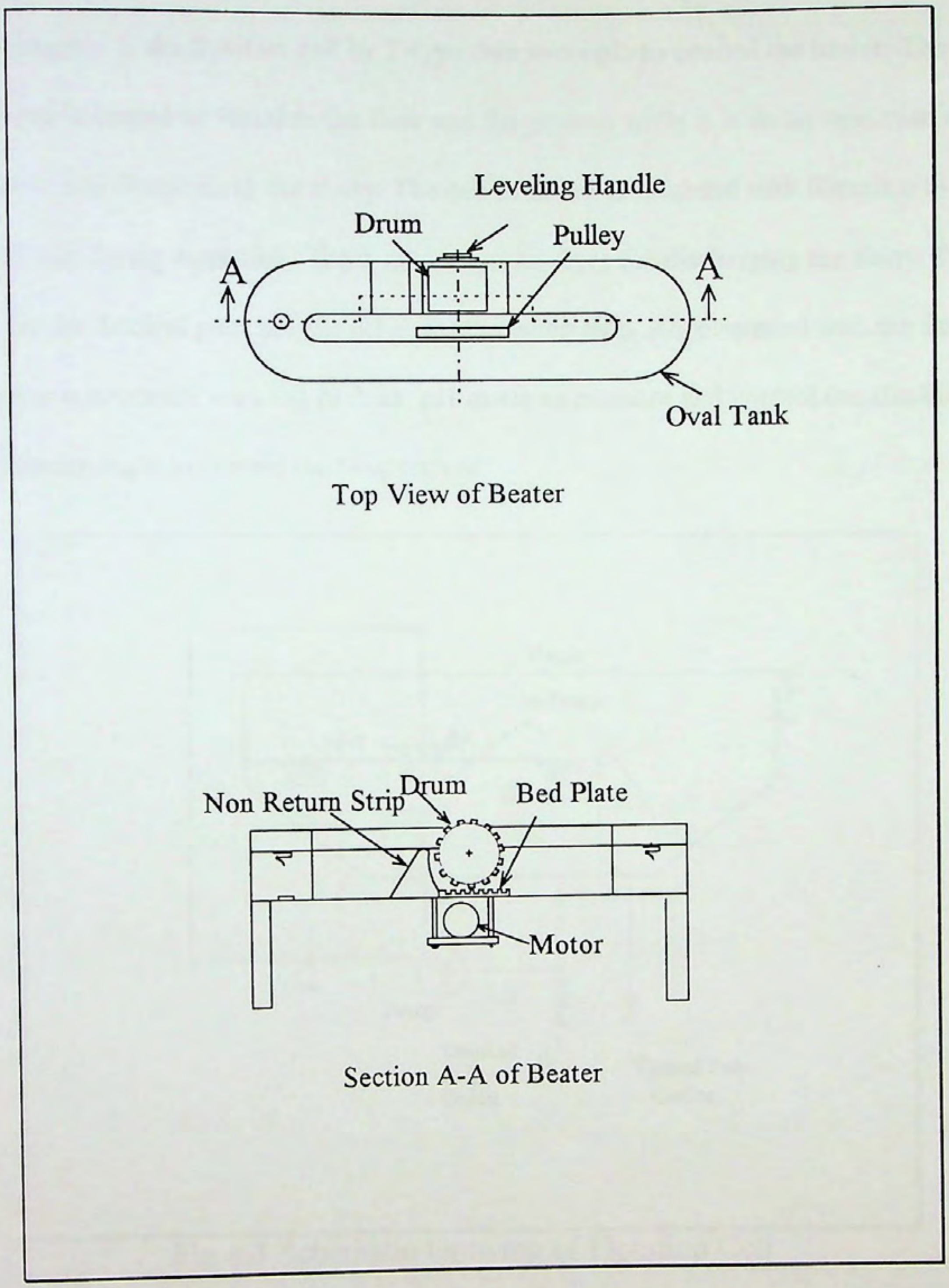

Fig 4.2 Schematic Drawing of Beater

temperature on the deinking flotation process controlled by a thermostat. The temperature was measured in the flotation cell by T-type thermocouple to control the heater. The cover of the cell is hinged to visualize the flow and the process while it is under operation and to be able to add chemicals to the slurry. The cell container is insulated with fiberglass to avoid loss of heat during operation. There are two exit valves for discharging the slurry. One of them for the deinked pulp and the other for the inked pulp. Accompanied with the flotation cell other instruments are used such as: pH meter to measure and control the alkalinity, T-type thermocouple to control the temperature.

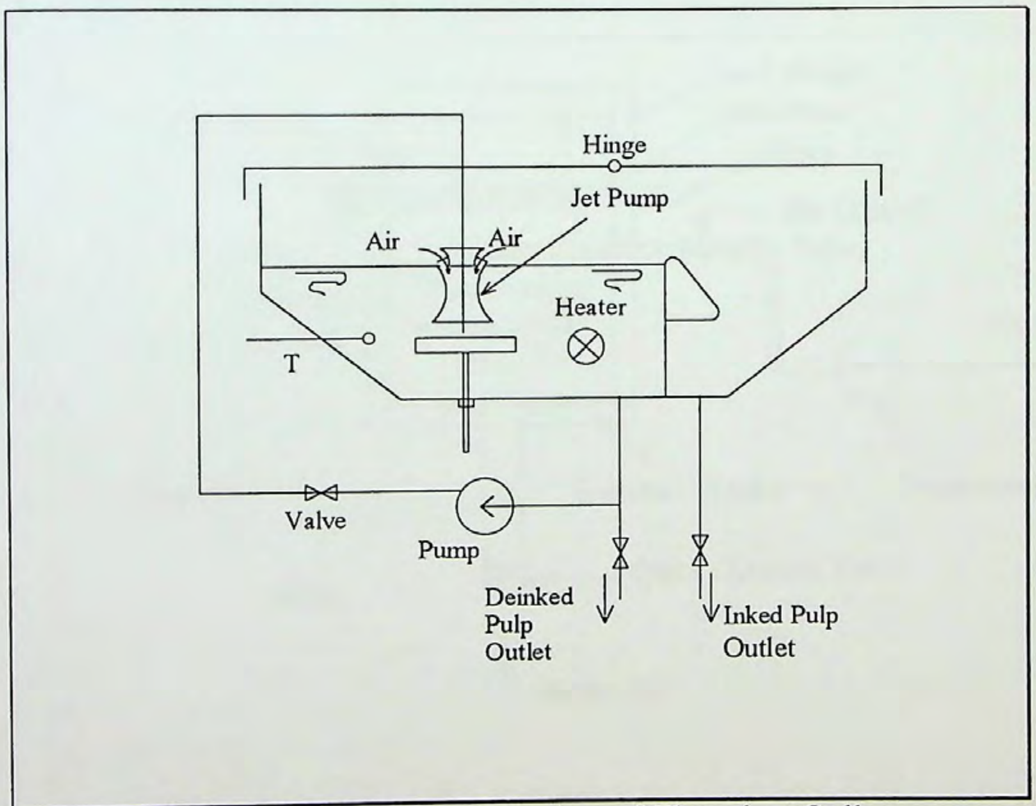

Fig 4.3 Schematic Drawing of Flotation Cell

4.2.4 Hand Sheet machine

The hand sheet machine as shown in figure (4.4) was designed and manufactured at AUC. It is a device to produce circular hand-sheets in a standard way to be able to perform

physical and optical tests. Its design ensures a high degree of uniformity and sheet quality due to the presence of an air injection system. It consists of a hinged top cylinder which acts as a stock suspension container. The bottom cylinder supports the grid plate, which is a forming wire of mesh 200 (ASTM No. 200). The bottom section contains also all the associated piping. A source of water is introduced to the bottom cylinder to fill it up and continue to the upper cylinder. A known amount of fibers are added to the water in the upper cylinder. Air is introduced to the slurry through the air injection system by gradually opening the air control valve. The air bubbles mix the fibers well. The air control valve is

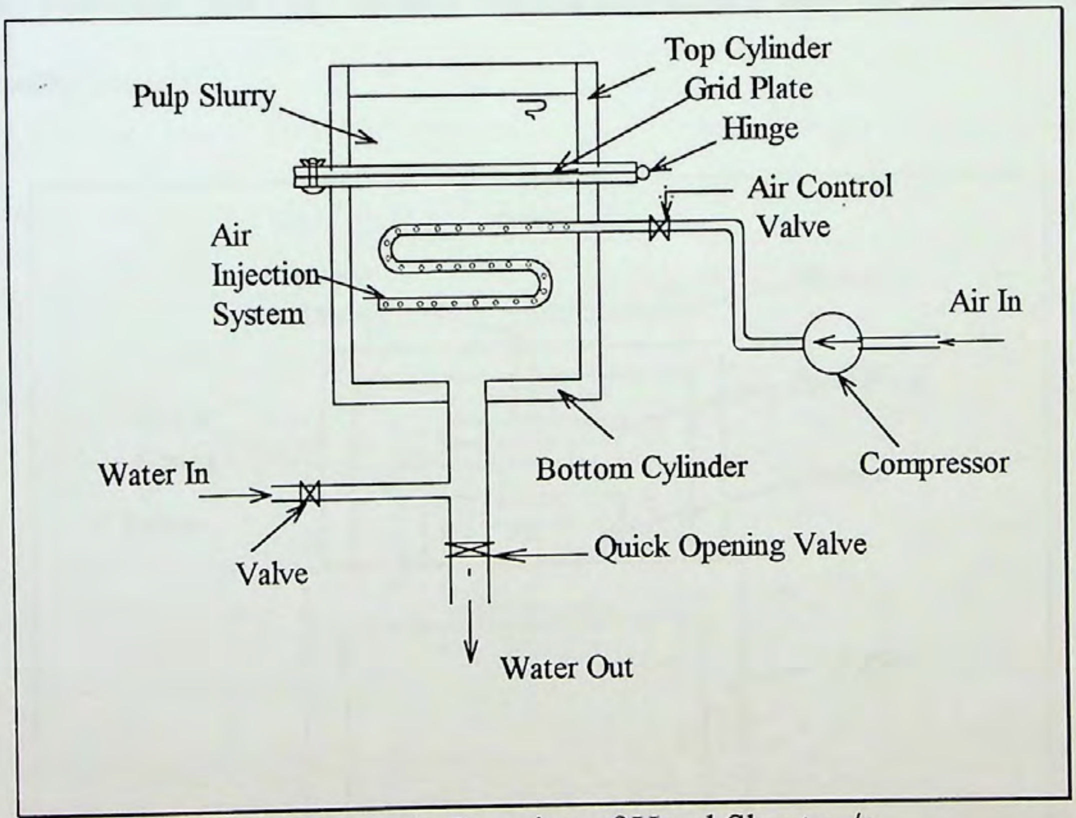

Fig. 4.4 Schematic Drawing of Hand Sheet m/c

closed and the system is left for a second to settle down. Then water is sucked out by opening the quick opening valve. The fibers rest on the mesh and picked up on a piece of

cardboard and covered with a light square piece of paper and then introduced to press/heater machine for drying.

4.2.5 Sheet Press / Dryer:

The sheet press/dryer was designed and manufactured at AUC. It is a press that presses the sheet to get a uniform, flat, non-corrugated sheet. It consists of steel table, frame, press plate, screw drive, handle, heater and heater casing as shown in figure. (4.5). A heater is placed underneath to evaporate the water from the sheet in a short time and at the same rate across the sheet to avoid its corrugation. Paper will be placed between the heater casing and press plate from 5 to 7 minutes. The produced paper is ready for testing on any other handling process.

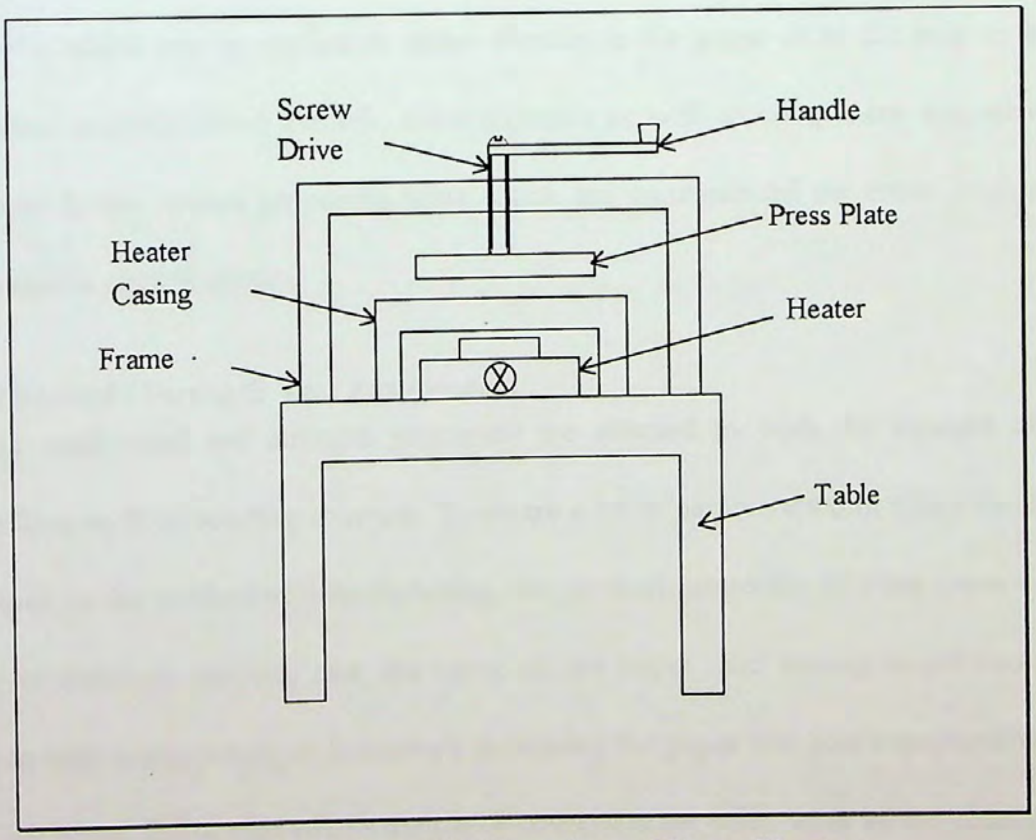

Fig 4.5 Schematic Drawing of Press/Heater

4.3 Properties of Recycled Paper

Standardized test methods for the properties of paper products constitute a common language for communication between sellers and buyers of paper. They are also used for the exchange of knowledge between scientists and in the development of new products and researches. Paper is a very complex advanced material, so working in research and development within the paper industry requires this standardization. Also, the trade with paper products is largely international and mandates definition of the raw material. The most important properties to be measured are physical ones, such as basis weight, formation, trim, curl ...etc. and these properties are controlled by the manufacturing process efficiency. Other important properties to be measured are the mechanical properties such as tension, tear, friction, abrasion, fold endurance and others. There is also the chemical analysis tests, which can be applied to either directly to the paper or to the pulp or both. This chemical analysis detect the ash, silica contents as well as component any selected. Finally, there is the optical properties tests which are concentrated on either brightness, whiteness and/or optical degree.

4.3.1 Mechanical / Strength Test Equipment:

The mechanical and strength properties are affected by both the strength of the fibers and fiber to fiber bonding strength. There are a lot of parameters that affect the paper strength such as the method of manufacturing, the physical properties of other paper as the thickness or moisture content, also the aging of the paper, and storing conditions (e.g. exposing to high temperature, or humidity). Assuming the paper was just manufactured so, the most important factor that affects the paper strength is the orientation of the fibers in the

paper. In other words, tension value of the paper along the machine direction are stronger that across the machine direction.

4.3.1.1 Tensile Tester

It tells how well the paper will resist breaking during a process such as printing. It measures the force required to break a test piece of a given dimension. Tensile strength failure will occur as a result of either inadequate bonding between the fibers, or fiber failure. Tensile strength units [N/m] which is the maximum tensile force per unit width (F/b) that a test piece will withstand before breaking in a tensile test (ISO 924/2).

The measured strips are 20 cm long by 1.5 cm wide. They are clamped between two clamps that have high friction to avoid their sliding during the measuring process. The upper clamp is fixed and the lower one moves down slowly at a constant rate. The ultimate force is recorded through a dial gauge.

The strength of the paper differs according to the fiber orientation. There are two directions. First machine direction which is parallel to the direction of travel of the paper mill cloth, that is called parallel to machine direction. The other direction is cross direction, which is perpendicular to the machine direction. Paper tends to be stiffer and stronger in the machine direction than the cross machine direction [3]. However, in this research case there is no fiber direction. Since the test sheets were prepared by the hand sheet machine which randomly orients the fibers. The test was carried out just to give a general average idea about the tensile strength of the recycled paper. The device type used is: 'KARL SCHRODER KG Materialprufmaschinem, 6940 Weinheim'

4.3.1.2 Tear Tester

The internal tear resistance measures the energy required to propagate an initial tear through several sheets of paper for a fixed distance. The difference in potential energy of a pendulum before and after the test is measured by an angle along the pendulum. [3]. The units for tear resistance used are [Nm], gram force. Tear resistance indicates the behavior of paper in various end use situation, such as evaluating web runnability, controlling the quality of newsprint and characterizing the toughness of packaging papers where the ability to absorb falling or hitting shocks.

The machine used is user friendly. Calculations, calibrations, internal tests, zero settings, pendulum release, pendulum fixing, and read outs are automatically provided by a built in microcomputer. The clamping and release of the pendulum are pneumatic, which helps in an accurate and stable results. The number of sheets used per test are 4 of dimensions 7.6 x 6.3 cm. The steps of the test are by first clamping the 4 sheets between split jaws, then an initial cut is made in the samples between the jaws with a built in knife. Read out of the average amount of work consumed to tear the sheets divided by the total tearing length is the internal tearing resistance, which is a mean value. The machine direction does not affect the tear resistance value. The device type used: ' MESSMER Instruments Limited, Digi-Tear'

4.3.1.3 Friction

It is a measure of smoothness of the paper. In other words, it is the measure of the surface contour of paper. It is measured by measuring the time to draw 10 ml of air radial over the surface of paper clamped in an anvil. The anvil consists of two circumscribed rings. The inner one has 4 small holes through which air is introduced. Air that would escape from

this inner ring is trapped within the second ring and diverted to one of the flow meters. The rougher the paper surface, the faster the air will escape through the inner ring [3].

This friction measure is directly affected by the manufacturing process. The smoothness of the wire that paper is spread on, also the smoothness of the press rollers in the mill. The method by which the paper is prepared is not really a reference. It is expected that preparing this same pulp on an industrial paper mill will give different result. That is why the recording of this friction parameter is not done regularly.

4.3.1.4 Oil Absorption

It is a device that determines the weight increase of a sample, exposed to oil for a specified time. The difference in sizing and absorption are important for writing and printing results, also for the appearance of material after handling and practical use in real life.

The test piece of paper which is about 100 cm^2 tested area is weighed before the test. Then it is placed over the cylinder containing oil, covered with the cover disc and rotated upside down (180°). Kept so for a certain period of time (few seconds) using a stop watch, then turned back to its normal position. The tested paper is pulled out to skim off the excess oil, then the paper is re-weighed. The results before and after absorption are documented in terms of grams per m^2 (gm/m^2) according to the standards.

4.3.2 Optical Test Equipment

Color is the measure of the hue or chroma (grades & degree of color). That is why it is very difficult to be expressed in numbers and is sometimes expressed descriptively as "red" or "blue". The spectral reflectance, transmit and color of paper are measured in terms

of wavelength (poly-Chromatic) in T442. Related tests are T524 and T527. The perception of color is dependent upon the light source used to view the object.

4.3.2.1 Brightness

It is the measure of whiteness of paper. "It is the percentage of diffuse reflected light from a thick pad of paper to visible light at a wavelength of 457 nm. This is designated as R_∞ which is in the blue range of light, that yellowish paper would absorb this light instead of reflecting it. If a black body is placed behind a single sheet of paper and the diffuse reflectance is measured, a lower value is obtained (unless the paper is opaque) and is designated as R_0.

There are two main types of instruments used. The G.E. brightness (TAPPI Standard T 452) where the light is illuminated on paper at 45° angle and the reflected light at 0° is measured. A simple orifice directs some of the light from the source to a reference cell that is used to compensate for slight changes in the light output of the source. The other test is the Elrepho test (TAPPI Standard T525). The light source is diffuse and the reflected light is measured at 90° from the surface of the paper. The diffuse light source is a sphere coated with titanium dioxide from which light from two light bulbs reflects. A reference photocell measures the light on the diffuse white surface near the sample. Since the reference photocell detects changes in the light level, large changes in the light source have almost no effect on the reading of paper brightness. A variety of filters can be used with this instrument, but the most commonly used is the 457 nm [3&7].

The type used in this research is Elrepho-Data Color 2000

UV = 100
Spot = 27

The device is first calibrated before each test by using a white reference which is MgO that is considered to reflect light 100%, and black block which would reflect no light 0%. The calibration is done once in the presence of filter and another time with no filter. Then, 5 sheets were used as a batch for test. The sheet was first tested over the batch and then a single sheet over the black body. This test is carried out minimum of 3 times for each batch and averaged.

4.3.2.2 Opacity

It is the ability of paper to hide or mask a color or object in back of the sheet. High opacity in printed paper allows one to read the front side of the page without being distracted by print images on the back side. Printing opacity is defined as:

$$\text{Printing opacity} = \frac{R_0}{R_\infty} \times 100\%$$

Opacity is the result of light scattering in many directions when the path of light is bent. This occurs when light goes from material of one index refraction to another one with different refraction. To understand opacity a comparison between cellophane and paper is made. Cellophane has almost the same chemical structure as paper, since it is fairly pure cellulose. However, cellophane is transparent because it is solid, dense and has two uniform parallel surfaces. On the other hand, paper has air spaces that provide interfaces for light to scatter. This is known as bulky sheets, which have much higher opacity than dense sheet. However, bulky sheets are less strong than dense sheets since fiber to fiber bonding is poorer in bulky sheets.

4.4 Experimenting Test Procedure

Old newspaper are gathered and weighed (250 gm) for each patch per test trial. The paper is shredded using a standard office shredding machine to decrease the size of paper and increase the specific area. This would facilitate the beating process and decrease the time required to defiber the fiber and form the pulp. Then, the shredded paper are introduced to the beater machine and a volume of 30 liters of tap water are added. The beater consistency is approximately 0.83%. Where consistency is defined as the measure of the solids content. In other words, it is the dry weight of fibers and other solids devided by the total weight of stock weight and expressed as a percentage [3].

$$\text{Consistency} = \frac{\text{weight of dry material}}{\text{weight of suspension}} \times 100\%$$

The drum is first positioned at a higher level away from the cutting plate to avoid jamming of the fibers. After about 15 minutes the fibers get finer but not enough for paper forming. So the drum is lowered to the closest position between the drum and the cutting plate to increase the defibering action. This is left for 5-10 more minutes.

The pulp is then washed in the sieve, and manually squeezed from water. The pulp is placed in the flotation cell. However, this step is only done in the last 13 tests. In the flotation cell about 17 liters of tap water are added to the pulp. Its consistency is approximately (+/-) 1.3%, taking into consideration that some of the 250 gm of fibers are lost on the way. It is calculated on 225 gm of dry fibers. The Slurry has to be at the maximum level relative to the foam spilling section to give a chance to the foam to float and spill in its place. Different test runs are carried out with the flotation cell with different

batches. First trials were for mechanical deinking tests then chemicals are added at this section for chemi-mechanical tests.

The pulp slurry are then washed in the same previous sieve manually. The slurry are taken in a container and water is added to be prepared for hand sheet formation. By trial and error of slurry volume relative to final sheet weight, the close volume required are known. It is usually in the range of 150 - 200 ml. The sheet is formed in hand sheet machine and then pressed and heated up to evaporate the water in the pulp in the press/heater device. Then, the sheet is weighed to check if the sheet forming volume needs to be readjusted. About 10 sample sheets are prepared for each batch test run for further physical and optical testing.

4.4.1 Tested Properties

The newsprint paper standards required by the Egyptian Organization for Standardization for news prints paper are obtained from Japan's Standards No. 3001-1964. Seven different organizations have shared in formulating these standards, which are El-Ahram, Dar El Tahrir for print & press, Dar El Maaref, El Waraq El Ahleiah Co., Racta Co., Institute of Chemistry, Egyptian Organization for Standardization. These standards were also decided upon after multiple testing of different newspaper samples [12].

The standards are as follows:

1. Weight (Kg/m2)	48 + % 2.5
2. Thickness (mm)	0.07 + %10
3. Tension (N/m)	1.8 > in the m/c direction
4. Elongation (%)	0.7 >

5. Tear (gmF) 28 >
6. Friction according to agreement
7. Oil Absorption according to agreement
8. Moisture (%) 6 - 8
9. Brightness (%) 55 >
10. Opacity (%) 89 >

Most of these standard tests were carried out along through in the research. But not all the tests were carried out for each batch. The actual related test required for this research is the brightness, which reflects the degree of whiteness. In other words, it would tell the amount of deinking that took place. However, the opacity was also measured since it is on the same device of brightness and it would reflect if it is a good printable paper or not. Also, the tension and tear tests were almost carried for all the samples to check effect of the different parameters on the physical properties of the paper. Elongation, friction and oil absorption were not carried out very frequently since these physical properties are directly proportional to the manufacturing process and the efficiency of the paper mill itself. The simple manual hand sheet formation is acceptable on a research scale.

Chapter 5
Results and Discussion

5.1 Introduction

Different samples of paper were prepared at different conditions and by controlling the different variables such as, time of beating, time and / or temperature in flotation cell, and the addition chemicals. Then, these samples were taken for physical and optical testing. In short, the samples were prepared as mentioned previously in chapter 4 by first weighing the paper to be recycled, then they are shredded in a standard office shredder to facilitate the beating process through increasing the specific area and decreasing the size. The shredded paper are then placed in the beater with the drum placed at a high level to avoid jamming of the fibers. The beater is left for 15 minutes, then the drum is lowered down and left for 10 more minutes. The pulp is washed in a sieve, then introduced to the flotation cell. Time and temperature are changed according to the conditions required to be tested, also chemicals are added to check their effect on the deinking process. Finally, the pulp slurry are washed again in the sieve and become ready for preparing the hand sheets of paper using the hand sheet machine and the press dryer to get rid of water and most of the moisture contents in the paper. These sheets were tested for physical properties, which are mainly tension and tear. Also the optical properties are tested as the brightness and opacity.

5.2 Effect of Beating Time

Paper was left in the beater for 5, 10, 15, 20, and 30 minutes to check if there is any effect of time on the produced pulp. Visual inspection of the pulp quality was carried out. Samples of the paper were prepared manually. In other words, the pulp were taken on a sieve, pressed on a piece of cloth and left in air to dry. Then a close look at the produced dry pulp was done. If the pulp, whether slurry or dry, still contains some of the shredded paper without being defibered, then the beating time was not enough. The process proved to be efficient after many trials and errors with the beater drum at different levels. The objective behind these trials was to reach the optimum time of beating with best defibered pulp. Where the optimum time is the least beating time with highest energy and time conservation. The best results obtained was a beating time of 15 minutes, with drum at a high level followed by lowering the drum to the minimum level and leaving it for 10 more minutes.

5.3 Effect of Flotation Cell Time

5.3.1 Effect of Flotation Cell Time at Room Temperature

Pulp was prepared at the beater, by leaving it for 15 minutes with the drum at a high position, then lowered to the minimum level and left for further 10 minutes. It is then taken to the flotation cell at room temperature and left there for different time intervals (5, 10, 15, 20 and 30 minutes). Hand sheets were prepared for physical and optical test (tension, tear, brightness and opacity).

As shown in figure (5.1) and figure (5.2), when time in flotation cell increases, tension and tear of the prepared paper are almost constant up to 15 minutes. They then drop sharply till 20 minutes, where a turning point exists. In other words, sharp increase in the

trend takes place starting at the 20 minutes up to the 30 minutes. Maximum points are at the 30 minutes time for both tension and tear. Which reached 1.3N/m and 32 Nm for tension and tear respectively.

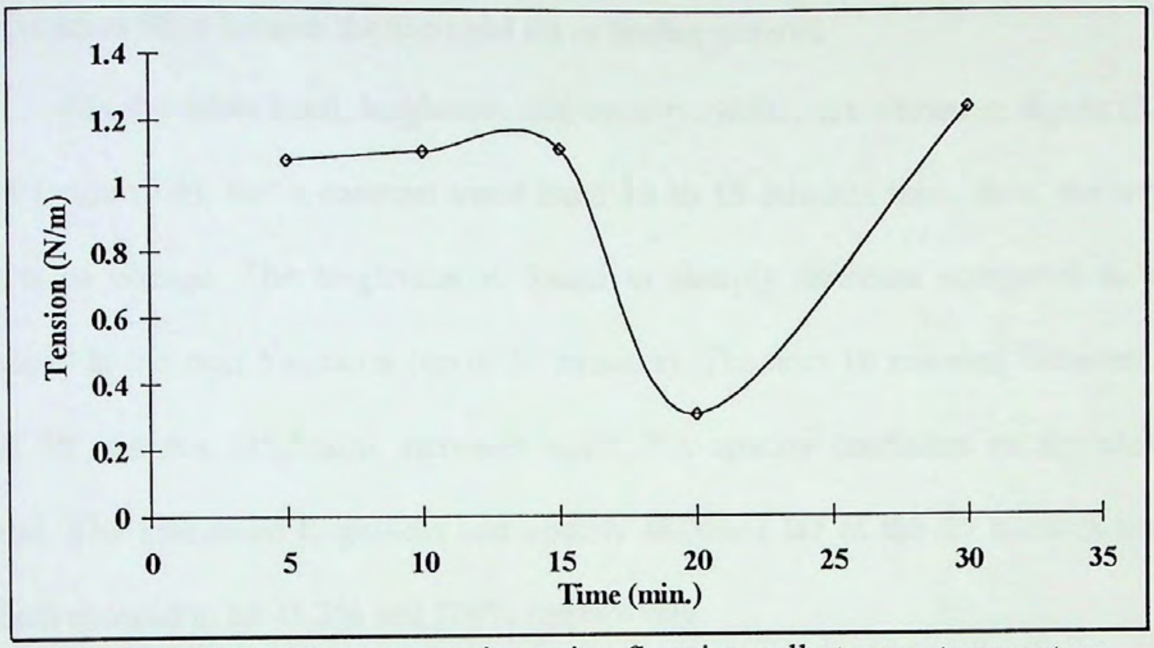

Fig 5.1 Effect of time on tension using flotation cell at room temperature

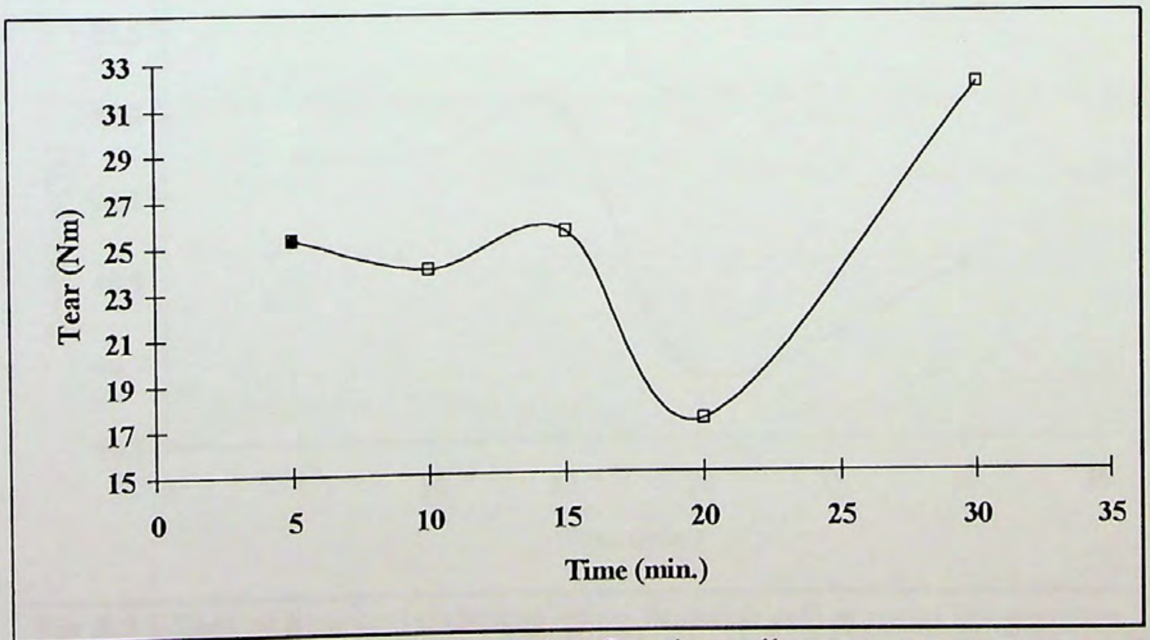

Fig 5.2 Effect of time on tear using flotation cell at room temperature

Trend of variation of both tension and tear are almost the same. Flotation cell causes friction between the fibers, thus refining the fibers and decreasing the fiber-fiber bond strength. By giving enough time i.e. up to 30 minutes, extra fine fibers are formed, which might act as fillers between the fibers and act as binding material.

On the other hand, brightness and opacity, which are shown in figure (5.3) and figure (5.4), had a constant trend from 10 to 15 minutes time, then, the trend starts to change. The brightness is found to sharply decrease compared to the opacity at the next 5 minutes (up to 20 minutes). The next 10 minutes, between 20 and 30 minutes, brightness increases again, but opacity continues its decreasing trend. The maximum brightness and opacity obtained are at the 15 minutes time, which showed to be 41.3% and 100% respectively.

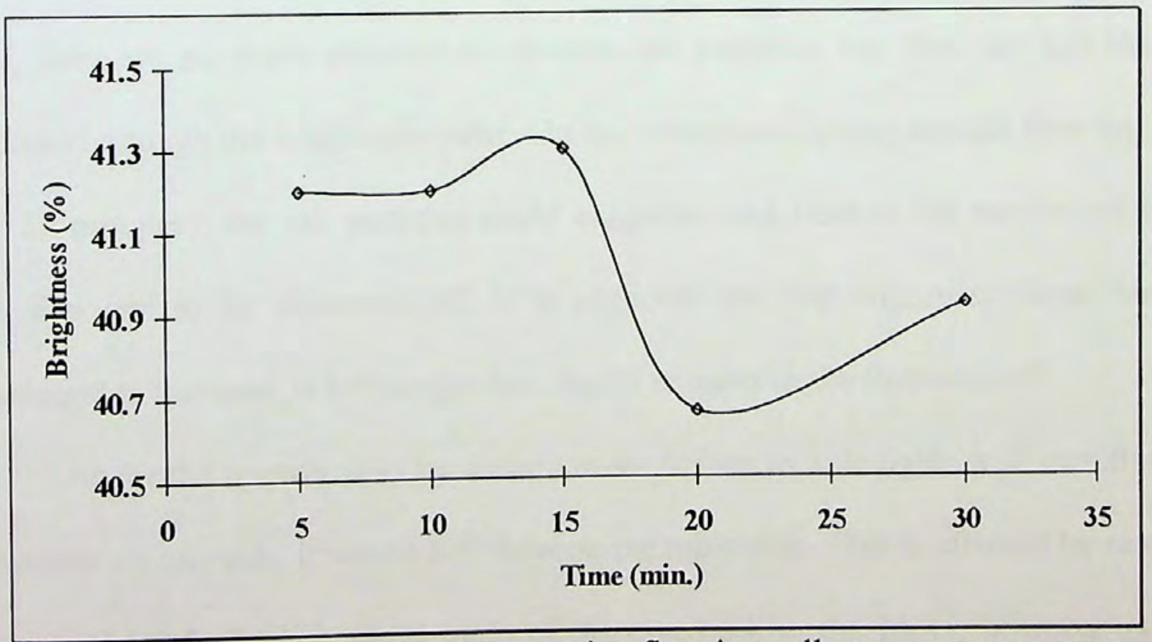

Fig 5.3 Effect of time on brightness using flotation cell at room temperature

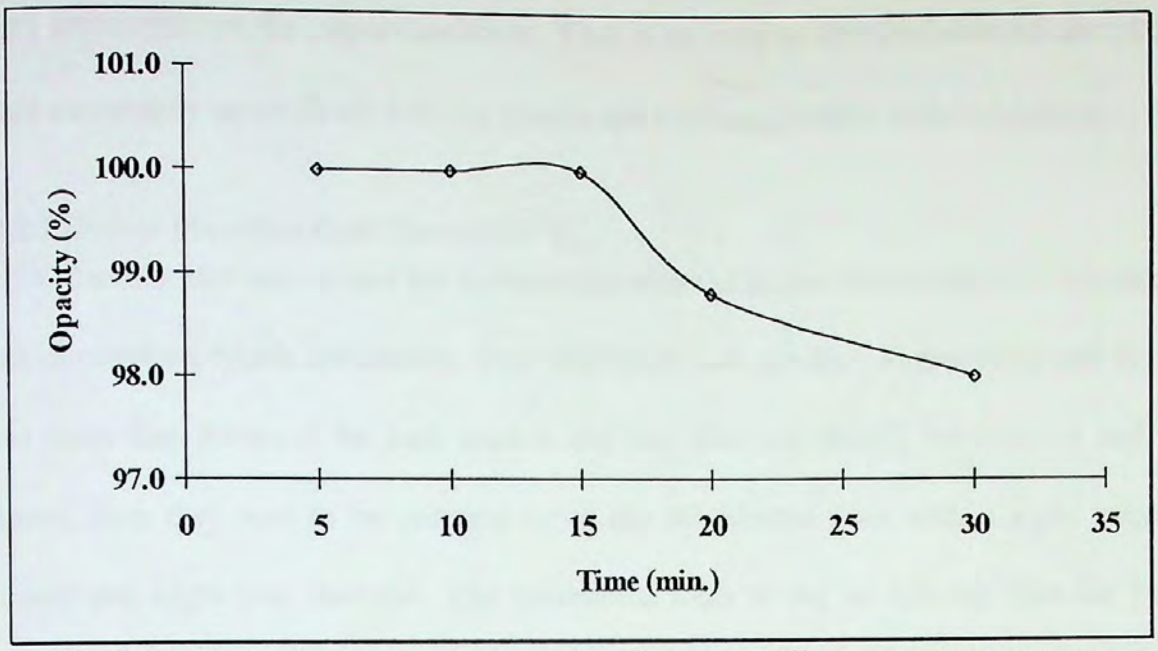

Fig 5.4 Effect of time on opacity using flotation cell at room temperature

The difference in brightness between 10 and 15 minutes are negligible. However, the trend sharply decreases after the 15 minutes. This could be justified that ink particles are broken to fine particles that are dispersed along the fibers, such that, they are no more detected as discrete ink particles, but they are still there reflected through the brightness value. On the other hand, giving enough time (up to the 30 minutes), the ink particles could coagulate and float to the surface of the flotation cell to be skimmed off. It is expected that the brightness might have continued to increase, if left longer than the 30 minutes in the flotation cell.

As for the opacity, it is by definition the ability to hide light, or if something is written on one side, it would not show on the other side. This is affected by many factors: One of which is the amount of dispersed ink in the paper, however, it is

more dependent on the paper thickness. That is as long as the thickness of the paper is not accurately controlled, then its results are not comparable with brightness.

5.3.2 Effect of Flotation Cell Time at 50 °C

Another test was carried out to check the effect of higher temperature (50°C) on the same parameters, which are tension, tear, brightness and opacity. Figure (5.5) and figure (5.6) show that the trend for both tension and tear decrease sharply between 10 and 15 minutes, then they tend to be constant up to the 30 minutes time, with a slight tension increase and slight tear decrease. The maximums were at the 10 minutes time for both tension and tear, reaching values of 1.2 N/m and 30 Nm for tension and tear respectively.

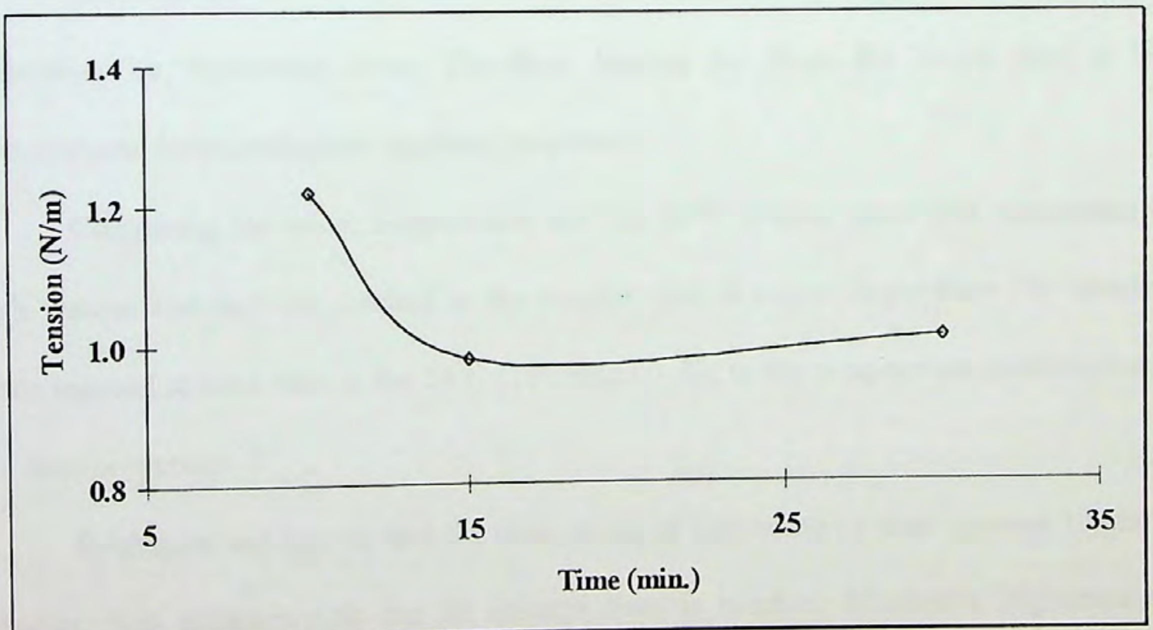

Fig 5.5 Effect of time on tension using flotation cell at temperature of 50 °C

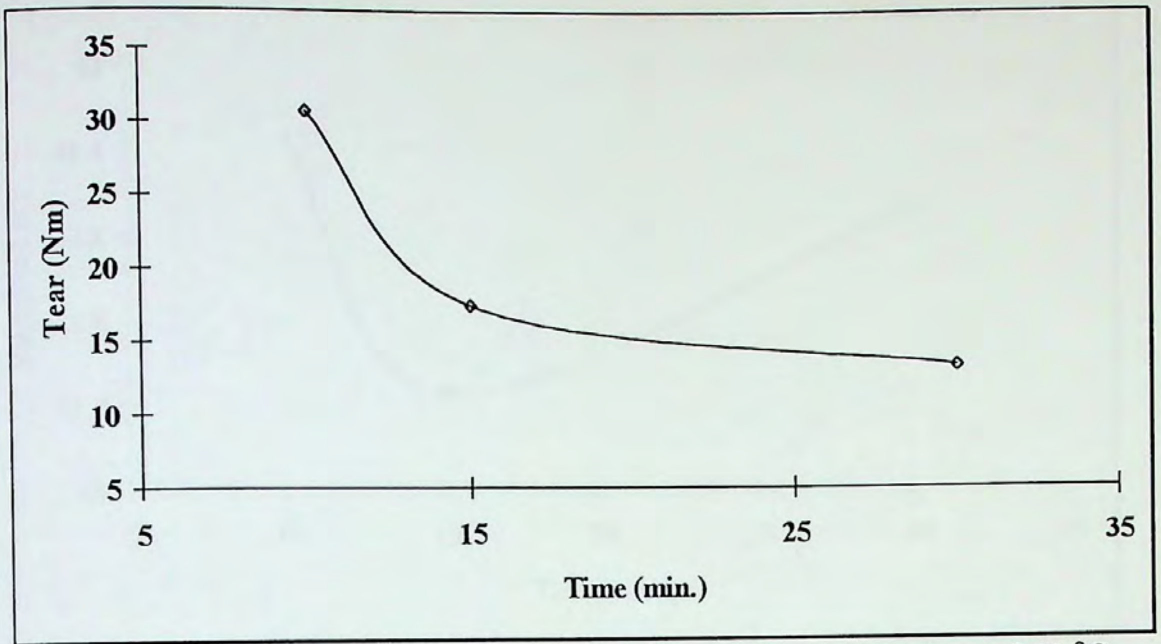

Fig 5.6 Effect of time on tear using flotation cell at temperature of 50 °C

Temperature decreases the binding forces and might be degrading the fibers themselves i.e. weakening them. Therefore, leaving the fibers for longer time at high temperatures deteriorates their physical properties.

Comparing the room temperature and the 50°C results, show that maximums for both tension and tear are reached at the longest time at room temperature (30 minutes), while reached at least time at the 50°C (10 minutes) due to the temperature deterioration of the fiber properties.

Brightness and opacity had the same trend, of decreasing by time between 10 and 15 minutes, then increasing till the 30 minutes time is reached. Maximum brightness and opacity are at the 10 minutes time, with the values reaching 42.6% for brightness and 98% for opacity, as shown in figure (5.7) and figure (5.8).

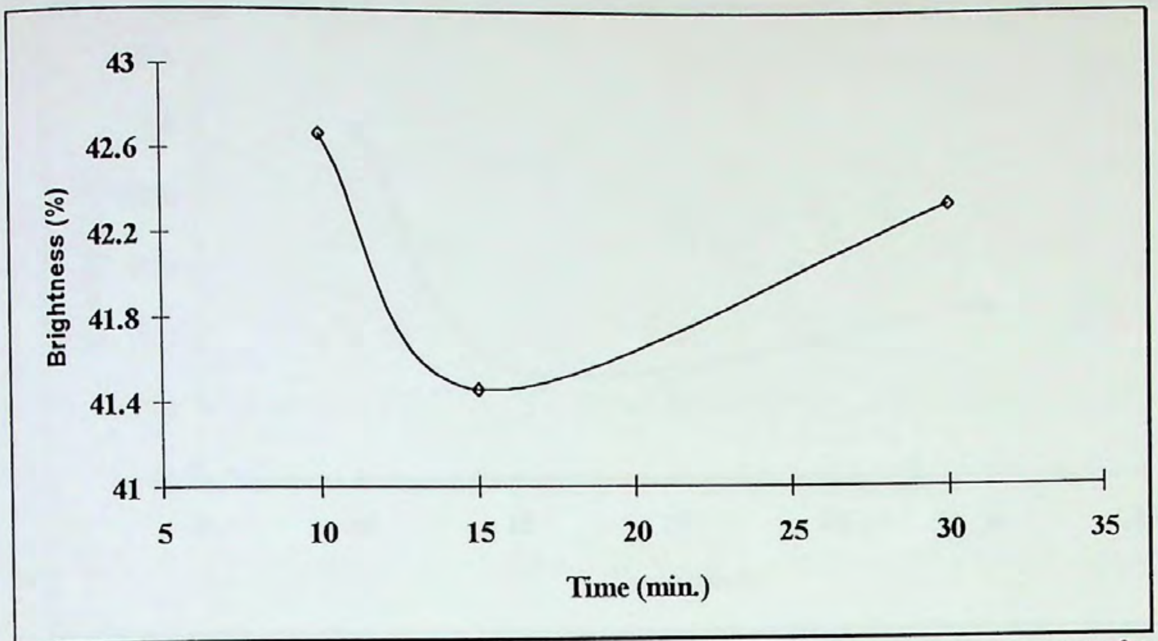

Fig 5.7 Effect of time on brightness using flotation cell at temperature of 50 °C

The reason for the decrease in the brightness is as mentioned before: the breakage of the ink particles into fine particles that are trapped in the pulp slurry. Which if given more time, would lead to an increase in brightness.

Comparing the maximums of brightness in both cases, room temperature and high temperature (50°C) showed that its value is higher at the 50°C at less time (10 minutes) than that at room temperature for longer time (15 minutes). The values as mentioned before are 42.6% and 41.3% respectively. This proves that higher temperature would cause swelling of the fibers, and change the viscosity of the oil vehicle base of the ink, so a pealing off and an easy separation of the ink particles from the fibers would take place and would be suspended in the slurry without redepositing.

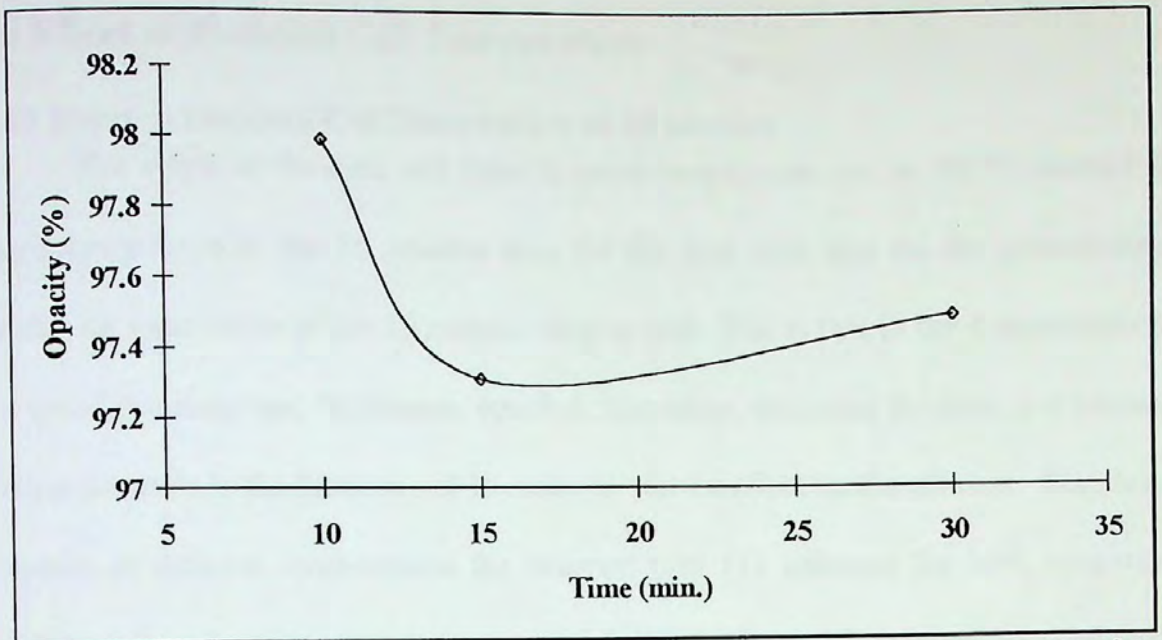

Fig 5.8 Effect of time on opacity using flotation cell at temperature of 50 °C

In spite of the fact that the results produced show that brightness and opacity have the same trend, even the maximum points are at the same time tested. Yet, the opacity results are directly proportional to the individual thickness of each paper on its own.

Comparing room temperature and 50 °C tests, trends in both cases are quite clear, although data points were missing in the 50°C temperature test, such as that of the 5 minutes and the 20 minutes. If the 20 minutes data point was tested, it might have showed the trend at the 50°C temperature test more detailed. The results still make sense, for example, the turning up point is shifted from the 20 minutes time in the room temperature test to the 15 minutes time at the 50 °C temperature test. This is a logical shift, since the temperature is expected to fasten the deinking process, which is reflected in the brightness test.

5.4 Effect of Flotation Cell Temperature

5.4.1 Effect of Flotation Cell Temperature at 15 minutes

The effect of flotation cell time at room temperature and at 50 °C showed that maximum point is at the 15 minutes time for the first case, and for the second case, a turning up point exists at the 15 minutes time as well. This is true in the 4 parameters that are tested (tension, tear, brightness, opacity). Therefore, this point is taken as a reference, and temperature in the flotation cell is varied to test its effect on the process. Samples are prepared at different temperatures for constant time (15 minutes) for each temperature condition, then the same parameters previously checked, namely tension, tear, brightness and opacity are retested.

Figure (5.9) shows that tension is almost constant between the 27 °C and 40 °C, then it sharply decreases at 45 °C, where a turning point takes place. This is followed by sharp increase up to 60 °C. On the other hand, as shown in figure (5.10), tear starts by a sharp decrease trend from the 27 °C to 45 °C might be because of the attack of the high temperature to the fibers which are reflected in tear test. From the 45 °C to the 60 °C an increase in the tear value takes place, but with a lower slope, when compared with tension. The maximum point for tension is at the highest temperature (60 °C) which is 1.3 N/m. As for the tear, its maximum point is at lowest temperature tested which is room temperature (27 °C), where its value is 20 Nm.

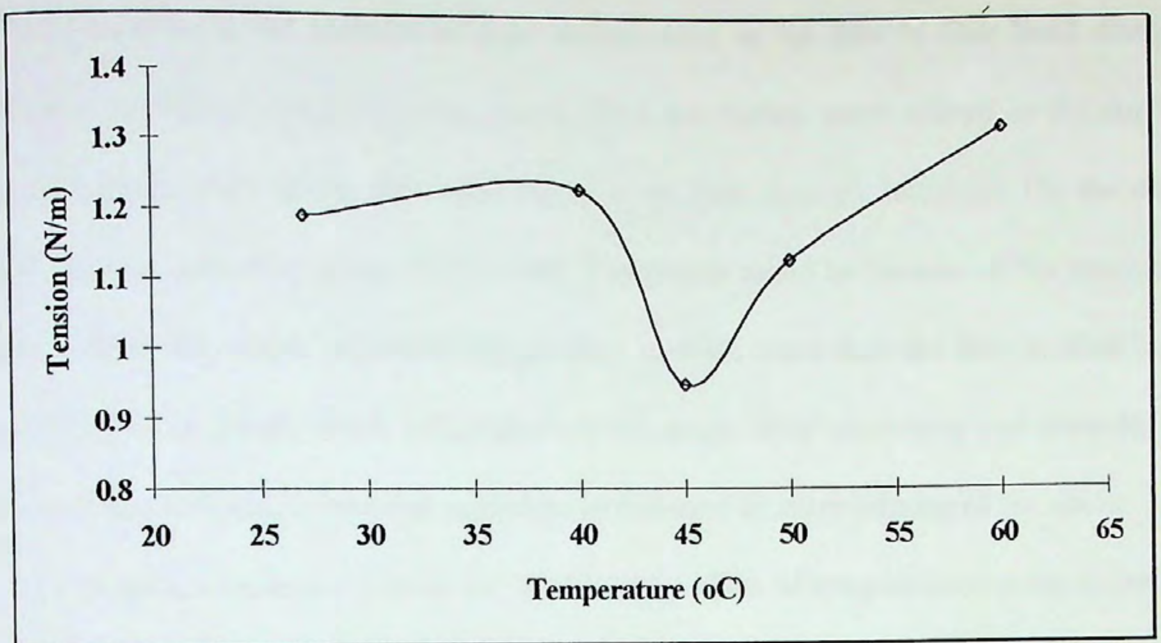

Fig 5.9 Effect of temperature on tension using flotation cell for 15 minutes time

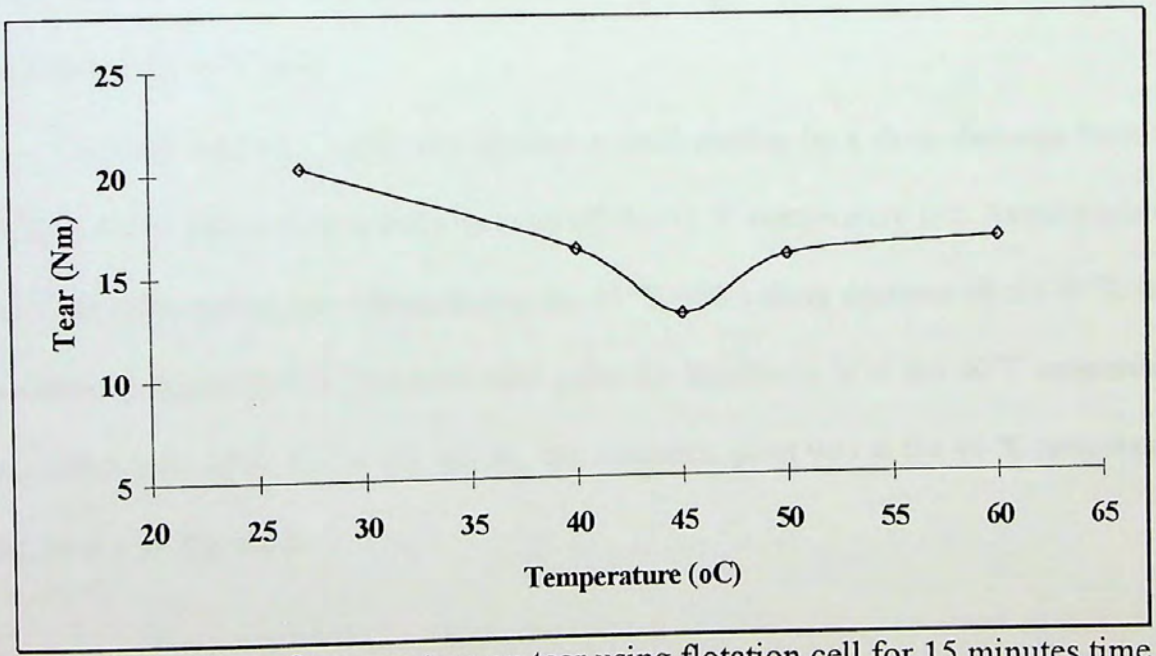

Fig 5.10 Effect of temperature on tear using flotation cell for 15 minutes time

The tension trend is the same as that of time-tension test, which started by a constant trend till the 40 °C followed by a decrease then a re-increase. The reason is that temperature had the function of time on the fibers. It might have attacked the coarse fibers

and refined them in the presence of other coarse ones, so the fiber to fiber bond strength decrease. At higher temperature the coarse fibers are further more refined so the surface area to volume ratio of the fibers will increase, so their strength increases. On the other hand, the tear started by a decreasing trend. The reason could be because of the sensitivity nature of the test, which reflects the single fiber strength more than the fiber to fiber bond strength. So the attack of the temperature to the single fiber coarseness and strength are shown in the decreasing trend that tended to be constant by extra refining of the fibers.

Brightness tests are carried out to check the effect of temperature on the degree of deinking. It is noticed from figure (5.11) that the brightness sharply increased from the 27 °C and 40 °C, then it started to decrease, but with a lower rate, and tended to be constant till the 60 °C test.

Opacity was also tested, and showed a trend starting by a sharp decrease from the 27 °C to 40 °C, followed by a sharp increase till the 45 °C temperature test. Another turning point, but a decreasing one, takes place at the 45 °C with a sharp decrease till the 60 °C test, as shown in figure (5.12). The maximum point for brightness is at the 40°C temperature test, which is 43.25%. As for the opacity, the maximum point was at the 45 °C temperature test, with a 97.8% value.

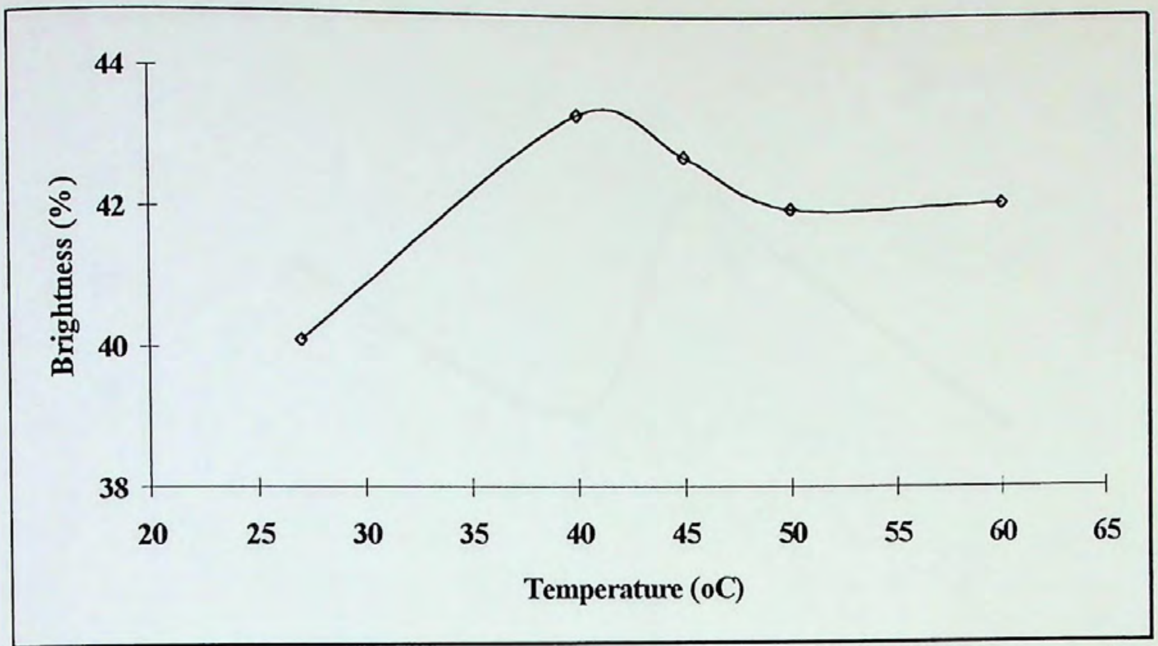

Fig 5.11 Effect of temperature on brightness using flotation cell for 15 minutes time

Brightness increases as expected by increasing the temperature, because the high temperature swells the fibers and peals off the ink particles from the fibers and changes viscosity of oil base vehicle of the ink. Then, further increase in the temperature, causes extra ink particles to be pealed off the fibers and left suspended in the pulp slurry, which would decrease the brightness value. It is therefore, reasonable to conclude that if for each temperature test point, more time was given in the floatation cell, brightness might have increased.

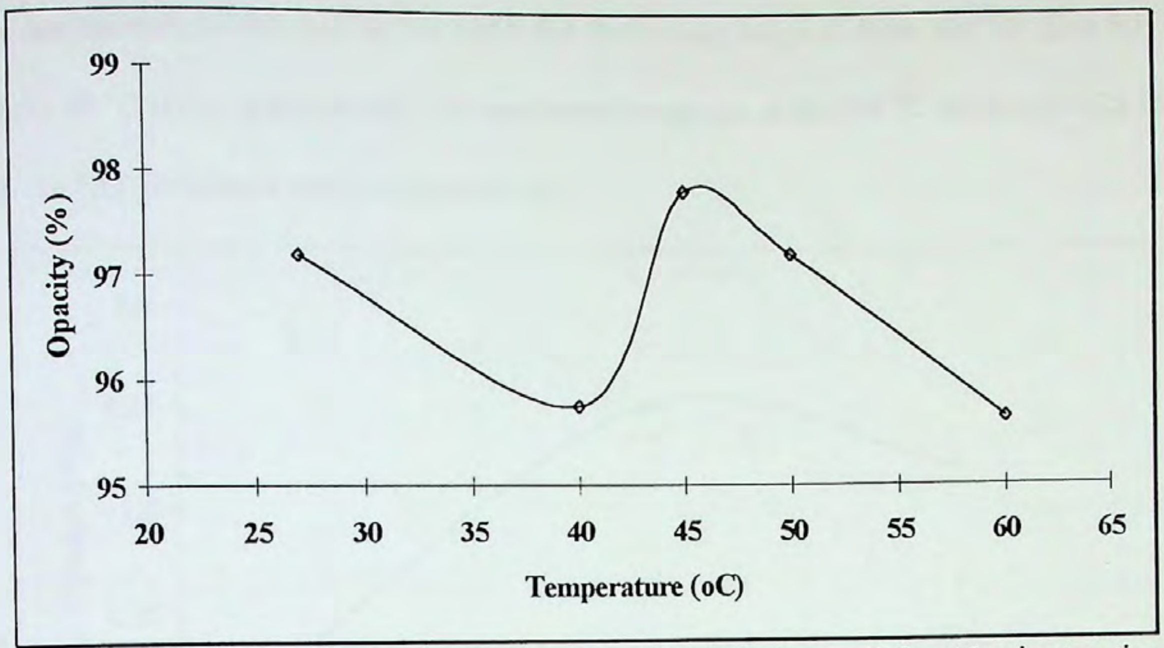

Fig 5.12 Effect of temperature on opacity using flotation cell for 15 minutes time

Opacity is expected to be opposite to brightness. As brightness increases, where ink is removed, the opacity decreases, since the ink particles are removed and light could pass through the fibers. The other parameter that affect the opacity results are the individual paper thickness, which is very difficult to control by the manual hand sheet forming process. Therefore, the trend of the brightness and opacity are not comparable.

5.4.2 Effect of Flotation Cell Temperature at 10 minutes

In order to optimize the equipment used through process time and temperature, which are reflected on energy consumption and cost minimization, the same procedure and tests were carried out at 10 minutes. The reason for choosing 10 and not 5 minutes is that the 5 minutes are not enough to control the system, even though they would have been more economical.

Figures (5.13) and (5.14) show that tension and tear almost had the same trend, which is increasing to a peak, then decreasing. The increasing range for both tension and

tear are between 27 °C and 40 °C, while the decreasing range is from the 40 °C to 50 °C. Where 40 °C is the turning point. The maximum points are at the 40 °C which are 1.25 N/m and 34 Nm for tension and tear respectively.

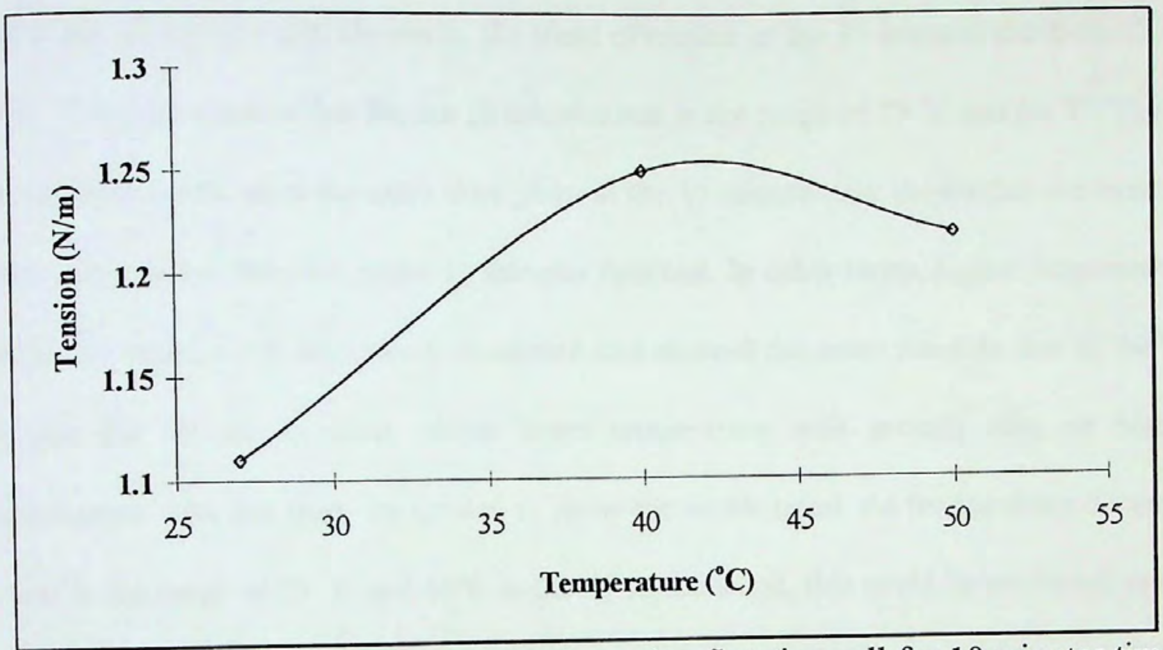

Fig 5.13 Effect of temperature on tension using flotation cell for 10 minutes time

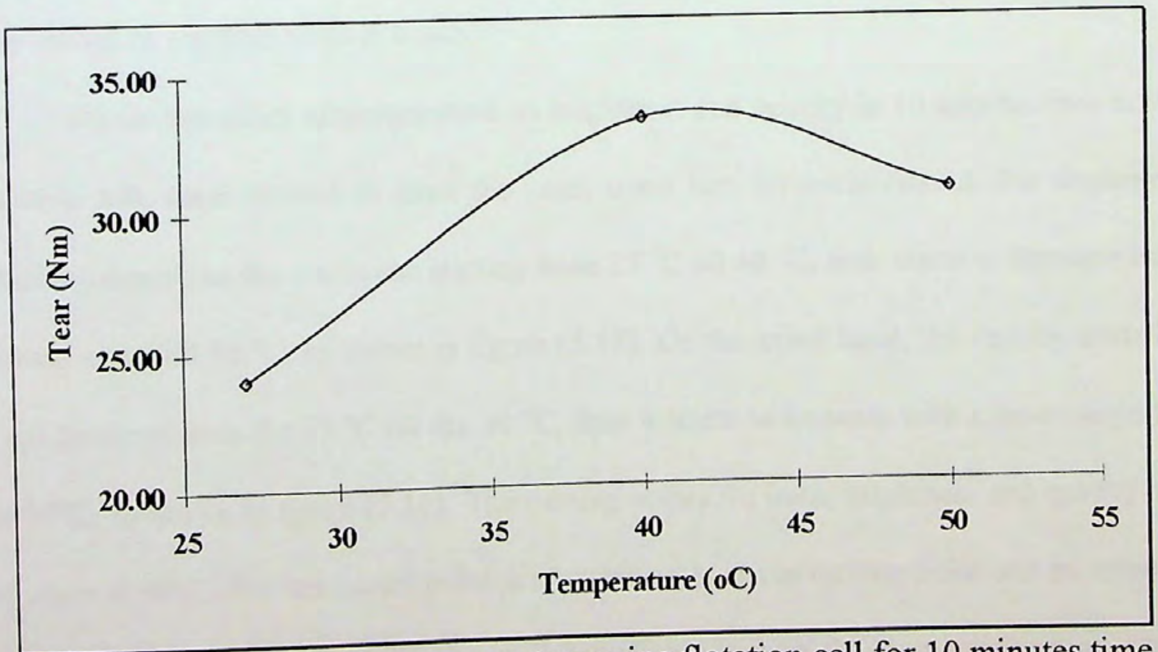

Fig 5.14 Effect of temperature on tear using flotation cell for 10 minutes time

Comparing the physical test results of the 15 and 10 minutes tests shows that the drop in tension in the 15 minutes test at the 45 °C does not exist in the 10 minutes test. This could be due to the fact that the number of data points in the 10 minutes test are less than that at the 15 minutes test. However, the trend of tension at the 15 minutes test from 27 °C to 45 °C are the same as that for the 10 minutes test in the range of 27 °C and 50 °C. This is a reasonable result, since the extra time given at the 15 minutes test shows that the trend at lower temperature than that of the 10 minutes time test. In other terms, higher temperatures for the 10 minutes test might have continued and showed the same trend as that of the 15 minutes but shifted. In short, either lower temperature with enough time, or higher temperatures with less time, are needed to show the whole trend. As for the sharp decrease in tear in the range of 27 °C and 45°C in the 15 minutes test, this could be attributed to the sensitivity of the test, where there might be defects in either the matrix, the fibers themselves, or the fiber to fiber bonds.

As for the effect of temperature on brightness and opacity in 10 minutes time in the flotation cell, these proved to have the same trend but, inversely related. For brightness increases sharply to the maximum starting from 27 °C till 40 °C, then starts to decrease with a lower slope till 50 °C, as shown in figure (5.15). On the other hand, the opacity starts by sharp decrease from the 27 °C till the 40 °C, then it starts to increase with a lower slope till the 50°C, as shown in figure (5.16). The turning points for both, brightness and opacity are the same at 40°C. The maximum point for brightness is at the turning point and its value is 43.5%. On the other hand the maximum point of opacity is at the least temperature tested (27 °C). Its value is 100%. Its turning point showed to be the minimum point which is at

40 °C with 96.5% value. The reasoning for the brightness trend is the same as that of the 15 minutes time.

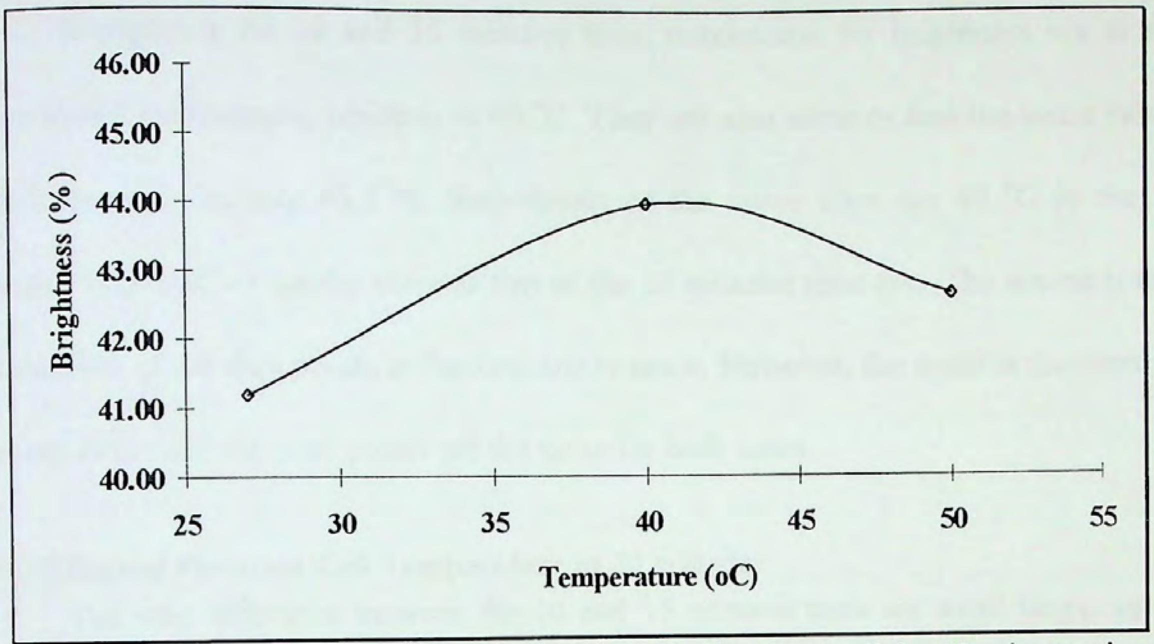

Fig 5.15 Effect of temperature on brightness using flotation cell for 10 minutes time

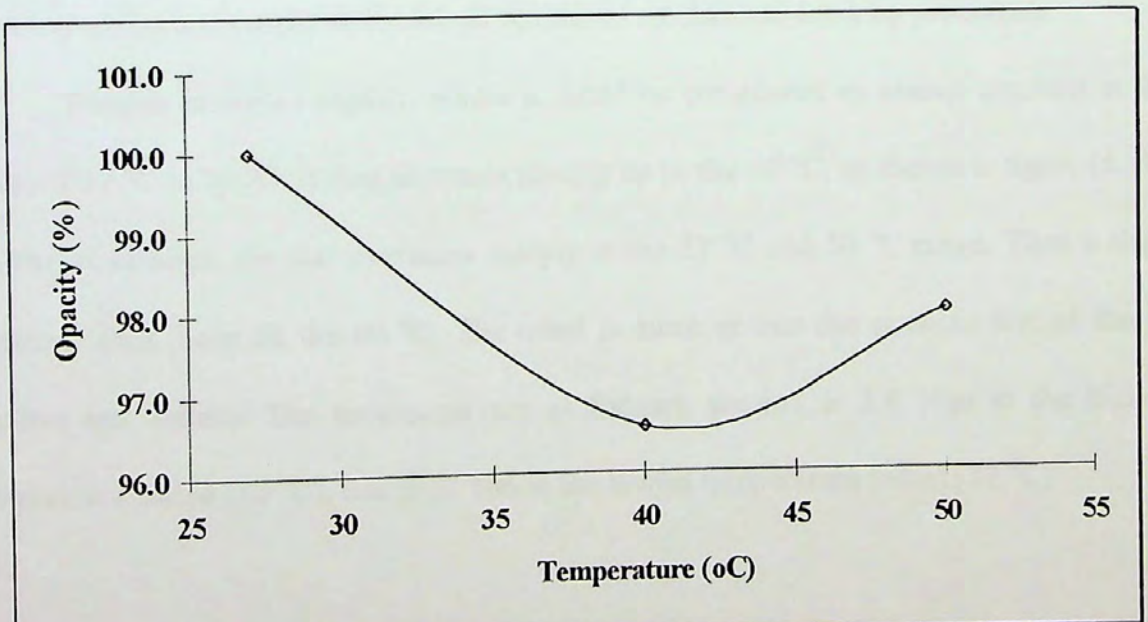

Fig 5.16 Effect of temperature on opacity using flotation cell for 10 minutes time

Opacity is expected to be opposite to brightness in trend. Since the presence of ink particles means higher opacity value.

Comparing the 10 and 15 minutes tests, maximums for brightness are at the same tested temperature, which is at 40 °C. They are also more or less the same value, which is approximately 43.5 %. Smoothness of the curve after the 40 °C in the 10 minutes time test are not the same as that of the 15 minutes time test. The reason is that the number of the data points in the first one is more. However, the trend is the more or less the same and the peak points are the same for both cases.

5.4.3 Effect of Flotation Cell Temperature at 30 minutes

The time difference between the 10 and 15 minutes tests are small range, so an extreme larger time is tested, which is 30 minutes. This is done in order to ensure the accuracy of the test results and reach an optimized mechanical deinking procedure.

Tension increases slightly, where it could be considered as almost constant in the range of 27 °C to 50 °C. It then increases sharply up to the 60 °C, as shown in figure (5.17). On the other hand, the tear decreases sharply at the 27 °C and 50 °C range. Then a slight increase takes place till the 60 °C. The trend is more or less the same as that of the 15 minutes test results. The maximums are as follows, tension is 2.8 N/m at the highest temperature tested (60 °C), tear is 32 Nm at the lowest temperature tested (27 °C).

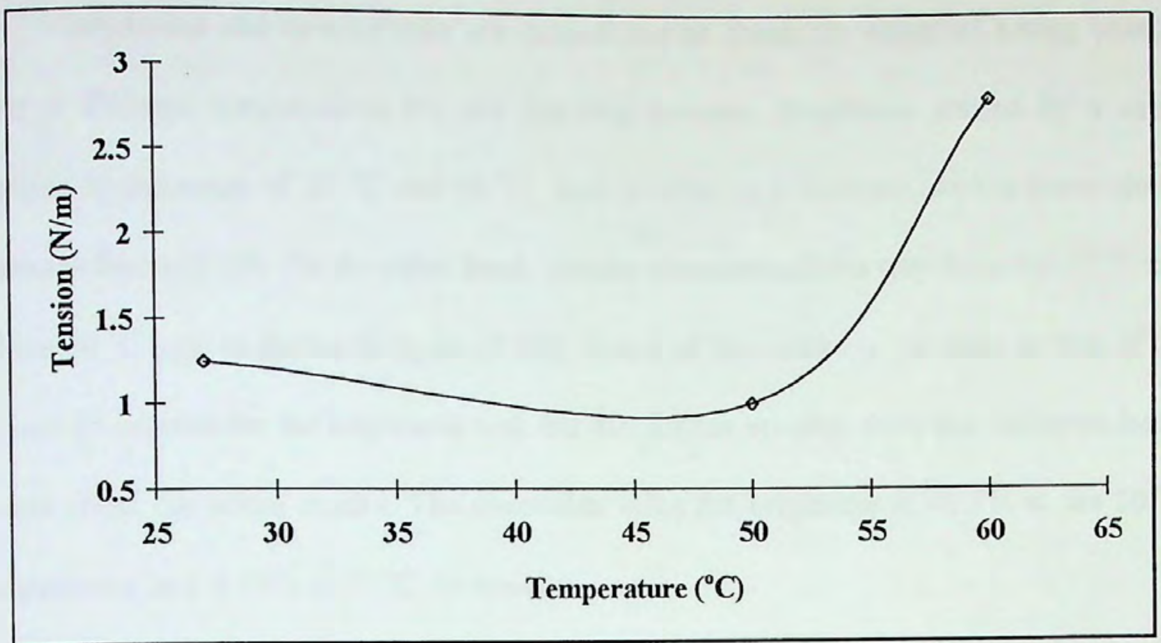

Fig 5.17 Effect of temperature on tension using flotation cell for 30 minutes time

Tension increase by temperature could be due to the fine pulp fibers that are formed and could act as fillers between the fiber matrix and binders. Tear has an opposite slope from tension which is generally decreasing, as shown in figure (5.18). The reason could be because tear reflects single fiber strength which is deteriorated with higher temperature.

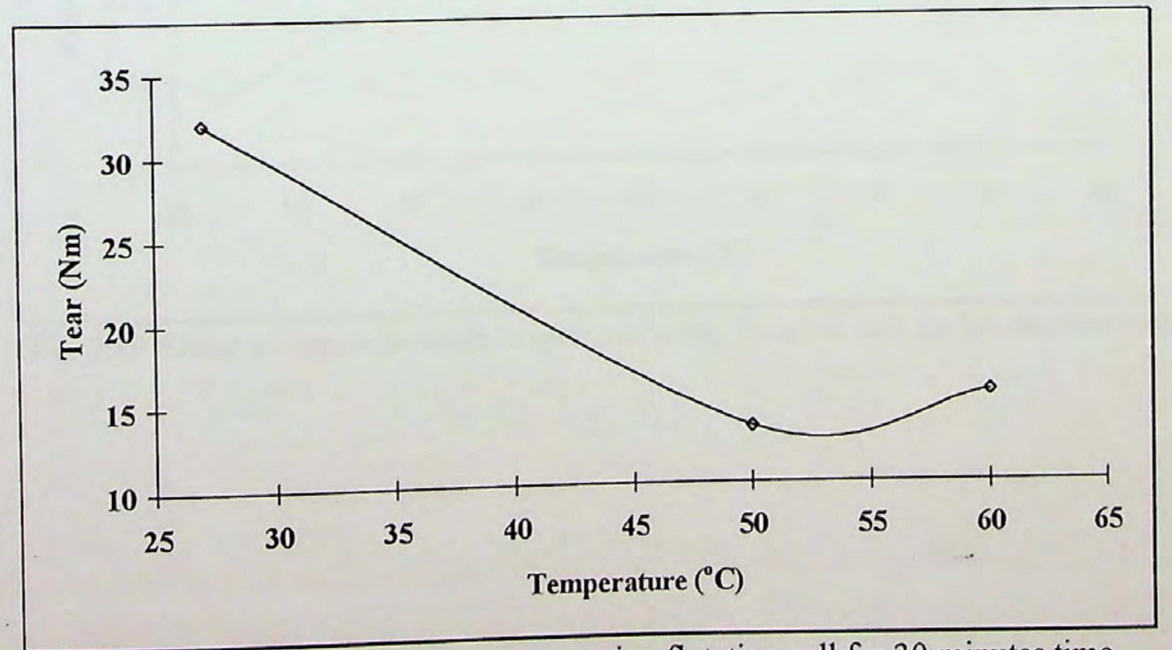

Fig 5.18 Effect of temperature on tear using flotation cell for 30 minutes time

Brightness and opacity tests are carried out to check the effect of having enough time at different temperatures for the deinking process. Brightness started by a sharp increase in the range of 27 °C and 50 °C, then it turns to a decrease, with a lower slope, shown in figure (5.19). On the other hand, opacity decreases all the way from the 27 °C test till the 60 °C test, as shown in figure (5.20). Trend of the results is the same as that of the 10 and 15 minutes for the brightness test, but not for the opacity, since the thickness factor would affect the tested results. The maximum value for brightness is 42.3% at the 50 °C temperature, and is 98% at 27 °C for opacity.

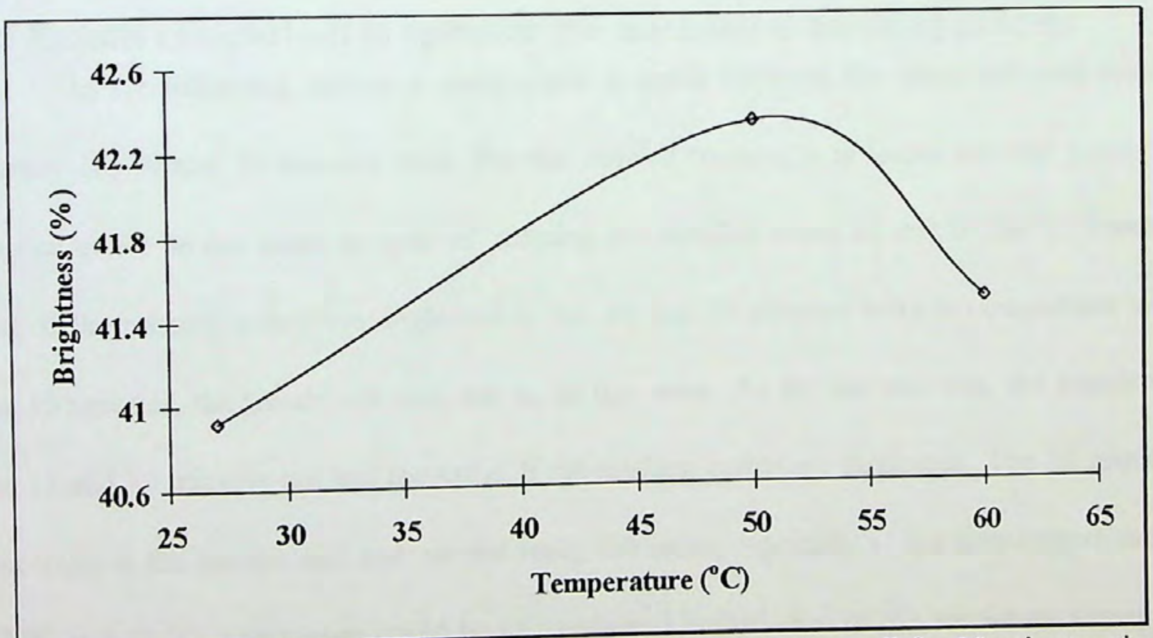

Fig 5.19 Effect of temperature on brightness using flotation cell for 30 minutes time

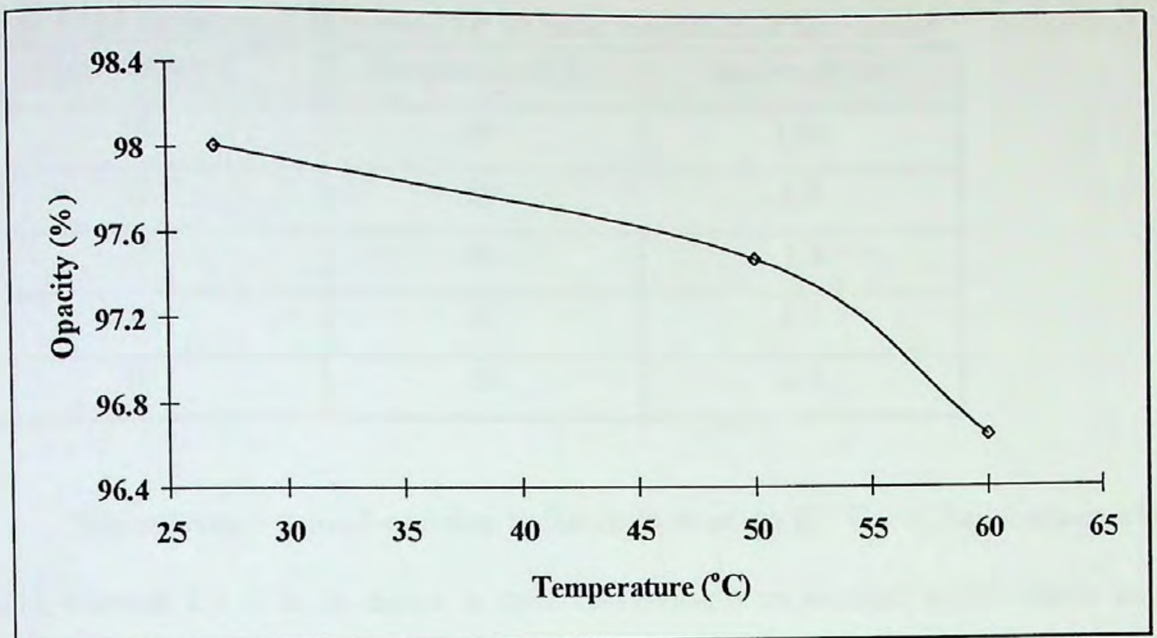

Fig 5.20 Effect of temperature on opacity using flotation cell for 30 minutes time

5.5 Results comparison to optimize the mechanical deinking process

In the following section a comparison is made between the three different results namely 15, 10 and 30 minutes tests. For the case of tension, it is found that the trends of tension could be the same, in spite of missing the detailed trend as that of the 15 minutes test. If the missing points are neglected at the 10 and 30 minutes tests in comparison with the 15 minutes, the trends will turn out to be the same. As for the tear test, the trends for the 15 and 30 minutes are still the same, if the missing points are neglected. The 10 minutes test trend in the tension and tear are not really the same, especially at the temperature range 27 °C and 40 °C. The reason could be as mentioned before, due to the sensitivity nature of the test. To get more comparable results for optimizing the process, maximums are tabulated for the different temperatures and times. The maximums are taken from all the experiments mentioned before.

Table (5.1) Maximums of tension for all time, temperature test results

Time (minutes)	Temperature (°C)	Tension (N/m)
10	40	1.25
10	50	1.2
15	60	1.3
30	27	1.3
30	60	2.8

The maximum value for tension is shown to be at the 60 °C test for 30 minutes test, which reached 2.8 N/m, as shown in table (5.1), that is an extreme value relative to the others tabulated. Even on the chart it showed to be an extreme value. Tension is affected by the thickness of each single sheet. This test might have had a couple of these thick sheets, so the results are not to be depended upon. On the other hand, the other results are more or less in the same range which are 1.2 to 1.3 N/m. Concentrating on the 40 °C test for 10 minutes and that of 60 °C test for 15 minutes, their values are 1.25 and 1.3 N/m respectively. So the 40 °C for 10 minutes result is the more time and energy conserving condition. As for the maximums of tear, it showed to be at the same conditions preferred for the tension, which are the 40 °C test for 10 minutes, where the value for tear is 34 Nm. See table (5.2).

Table (5.2) Maximums of tear for all time, temperature test results

Time (minutes)	Temperature (°C)	Tear(Nm)
10	40	34
10	50	30
15	27	20
30	27	32
30	60	32

Maximums for brightness, which is the most important factor to be tested in this research, since it is the reflection of amount of deinking took place, showed to have the maximum at the 40 °C for 10 minutes time (43.5 %). Also the 40 °C for 15 minutes showed to be the second highest brightness value (43.25 %). The difference is very little, as shown in table (5.3). As for the opacity the maximum results range is between 98 and 100 %. These are not tabulated, since as mentioned before, the results are sensitive to the thickness of each individual sheet of paper.

Table (5.3) Maximums of brightness for all time, temperature test results

Time (minutes)	Temperature (°C)	Brightness (%)
10	40	43.5
15	27	41.3
15	40	43.25
15	50	42.6
30	50	42.3

It could be concluded that the optimum results are the 40 °C test at 10 minutes. However, the difference between the 10 and 15 minutes at the same 40 °C temperature test could be negligible. Especially that the 15 minutes time is just enough to be able to control the system. So the 40 °C and 15 minutes will be the fixed parameters for the next experimenting stages from now on.

5.6 Effect of Washing of the pulp at different stages

According to the literature, washing was one of the important steps either in paper making or paper recycling. So the effect of washing was tested at three different stages

throughout the process using a sieve. The first stage is washing before the pulp is introduced to the flotation cell, in other words, washing after the beating stage only and then samples of paper are formed. This is noted on the chart in figure (5.20) as 'Pre'. The second stage was washing of the pulp after the flotation cell only, and this is noted on the chart as 'Post'. Finally, a third sample was done by washing the pulp after the beating but before the flotation cell and washed once more after the flotation cell. It is noted on the chart as 'Pre&Post'. Then the paper samples were tested for brightness and opacity, since the brightness is a reflection of the amount of deinking, results are shown in figures (5.21) & (5.22) The pulp was left in the flotation cell for 15 minutes at 40 °C temperature as mentioned before.

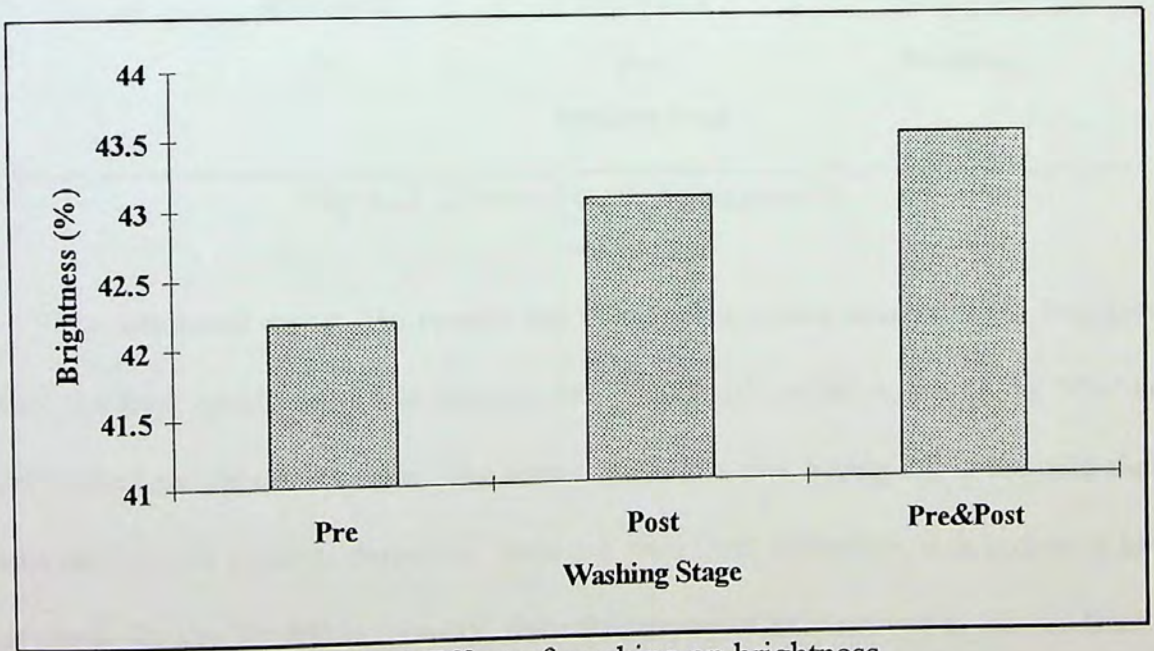

Fig 5.21 Effect of washing on brightness

The results of brightness are as expected, the highest value is for the Pre & Post washing stages, since good washing took place. So a good amount of ink is washed off with

the water. Also the 'Post' stage has a higher value than 'Pre' because in the post condition deinking took place in the flotation cell, so the ink particles are broken off the fibers and left suspended in pulp slurry and are washed off with the water. On the other hand, at the 'Pre' stage most of the ink particles are still sticking to the pulp fibers and could not be washed off well with the water.

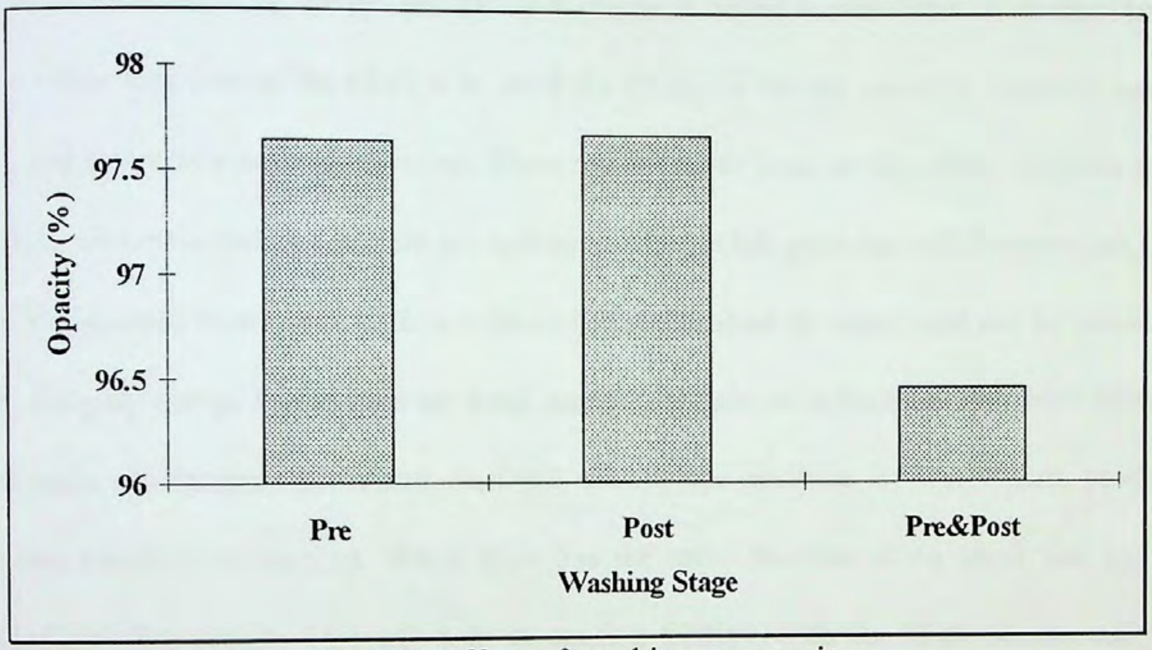

Fig 5.22 Effect of washing on opacity

As mentioned earlier, the opacity has a vice versa results relative to the brightness. Where the least opacity is shown through the 'Pre&Post' condition, where the 'Pre' and 'Post' values are almost the same. The reason for this is that having ink in the pulp slurry means the resulted paper is darker i.e. does not pass light. Therefore, it is logical to have least results for the 'Pre&Post' opacity, since the amount of ink removed at this condition is higher than the other two conditions.

5.6 Effect of Chemicals on the Deinking Process

One of the objective of this research is the efficiency of deinking. The deinking level is reflected by the degree of brightness of the paper. The reference recommended for the degree of brightness according to the standards is 55%, while the highest reached by the above mechanical process is 43.5%. Therefore, chemicals are added in the following stages to check their effect on the system. The first chemical added is some kind of an alkali base. The major functions of the alkali is to swell the fibers, so the ink particles could be pealed off, and to act as a saponifying agent. Since the ink is oil base, so the alkali will form soap with it, where the bubbles formed are hydrophobic. The ink particles will therefore stick to the bubbles and float to the surface without being dissolved in water, and can be skimmed off the pulp slurry. Two alkalis are used, namely, caustic soda (sodium hydroxide NaOH) and soda ash (sodium carbonate Na_2CO_3). Finally the addition of water glass (sodium silicate Na_2SiO_3) is checked. Water glass has the same function of an alkali, but has an added abrasive nature. This will help in causing friction with the fibers to increase the efficiency of removing ink particles from the fiber surface.

5.6.1 Effect of Caustic Soda (sodium hydroxide NaOH)

According to Dean and Dodson, sodium hydroxide is used for wood free secondary fibers, which are the ones used in newspapers. Its effect, as they suggest, is high concentration of Alkali with pH up to 11.5-12, which would saponify and / or hydrolyze some ink vehicles and swell the fibers to help in breaking up ink and coatings. Its high Alkalinity also prevents aggregation of small ink particles into larger ones that are difficult to wash, however, this aggregation is recommended for flotation. It has to be noted that the strong alkalinity would seriously attack the cellulose fiber, especially that a high area of

its surface will be exposed to the NaOH. According to the findings of Deand and Dodson [32], percentage recommended is 3-5% of dry fibers. If pH used is above 10, the pulp will be yellowish in color unless a bleaching agent is used.

To decide on the pH to be used some kind of calibration is recommended relative to the tap water used, so a fixed amount of the sodium hydroxide (0.5 gm) is added to a known volume of water (1 Liter) is used to measure the pH. An extra known volume of water is then added to dilute it and pH is measured again. Then pH reading verses water volume is plotted at a known weight of solid sodium hydroxide, as shown in figure (5.23). The recommended pH range of values to be used for three different tests are 9.5-10, 10.5-11, 11.5-12.

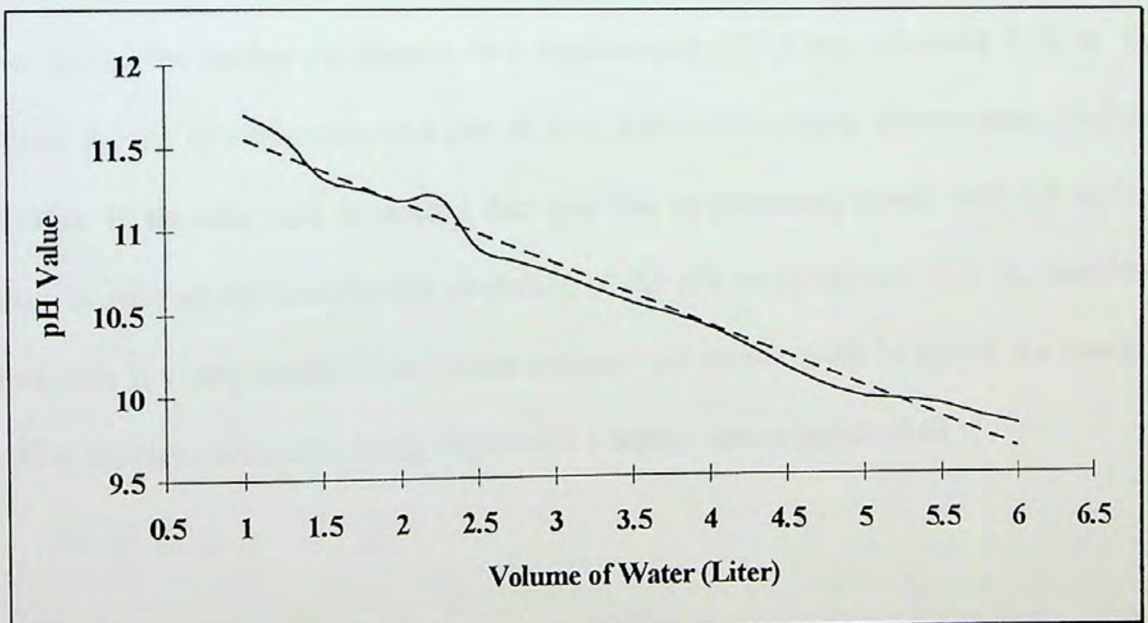

Fig 5.23 Concentration of sodium hydroxide reflected as pH value

Knowing the volume of slurry in the flotation cell to be 17 liter, so the mass of sodium hydroxide needed for the corresponding pH required is calculated by cross multiplication. For example for a pH range of approximately 9.5-10, 5.5 Liters of water are

required with 0.5 grams of sodium hydroxide so the total amount required for the flotation cell is as follows :

$$\text{mass of NaOH in flotation cell} = \frac{17 \times 0.5}{5.5} = 1.55 \text{ grams}$$

This calculation procedure is used for each pH required, then, the chemicals are added to the flotation cell when it reaches 40°C temperature and left in it for 15 minutes, based upon the optimized mechanical conditions of the process mentioned before. The pulp is then well washed from the chemicals. To check that no more chemicals are found in the pulp, a litmus paper is used, then samples of paper are produced and the different parameters are tested.

As shown in figures (5.24) and (5.25) the tension and tear trend are not really the same. As for the tension an increase to a maximum at pH of approximately 9.75, it then starts to decline to a minimum at a pH of 10.5, followed by slight increasement at higher pH value. In the tear case, it seemed that tear had an increasing trend with the high pH values, in spite of the interruption occurring at the pH range of and 10.5. As mentioned before, tear is a very sensitive test, so the difference in trends could be due to the change in the fiber characteristics after being exposed to a highly concentrated alkali

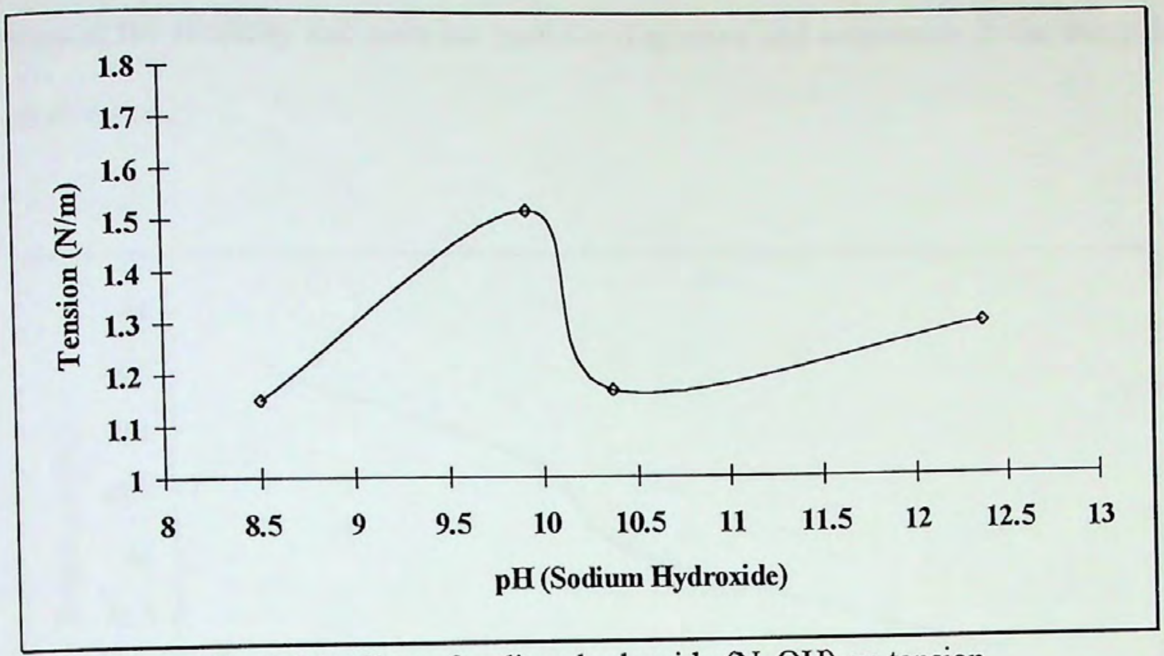

Fig 5.24 Effect of sodium hydroxide (NaOH) on tension

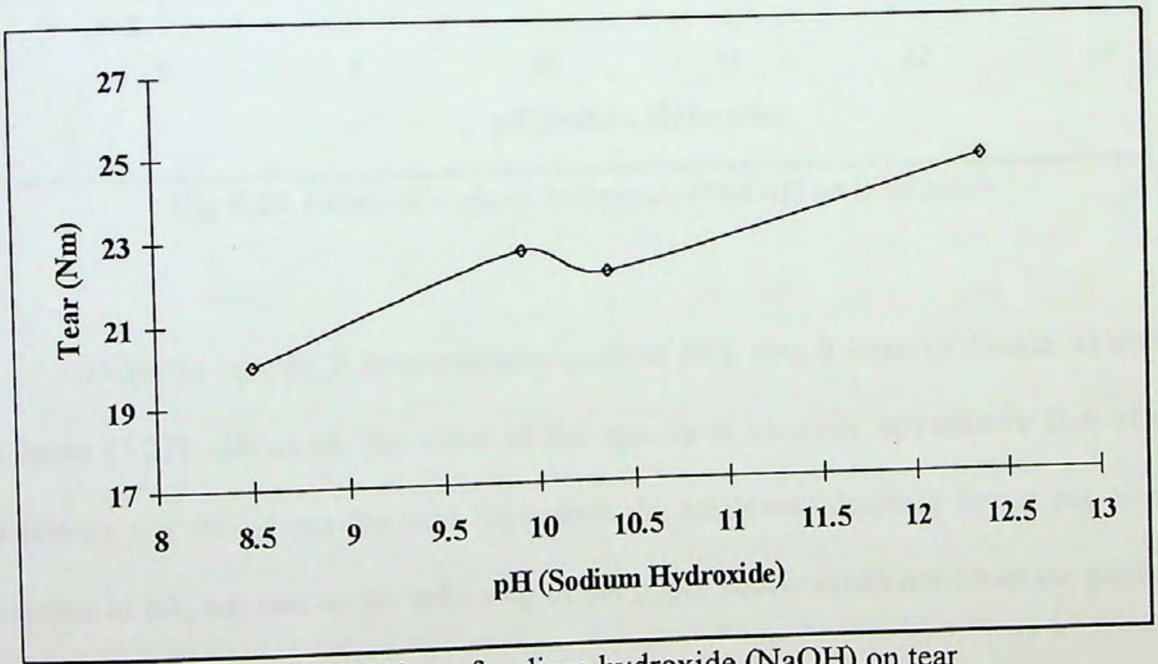

Fig 5.25 Effect of sodium hydroxide (NaOH) on tear

Checking the brightness with the addition of sodium hydroxide, can be seen in figure (5.26). The brightness is found to decrease by increasing the sodium hydroxide concentration. The reason for this could be the effect of yellowing that takes place by the

increase in the alkalinity and more ink particles dispersion and suspension in the slurry due to alkali action.

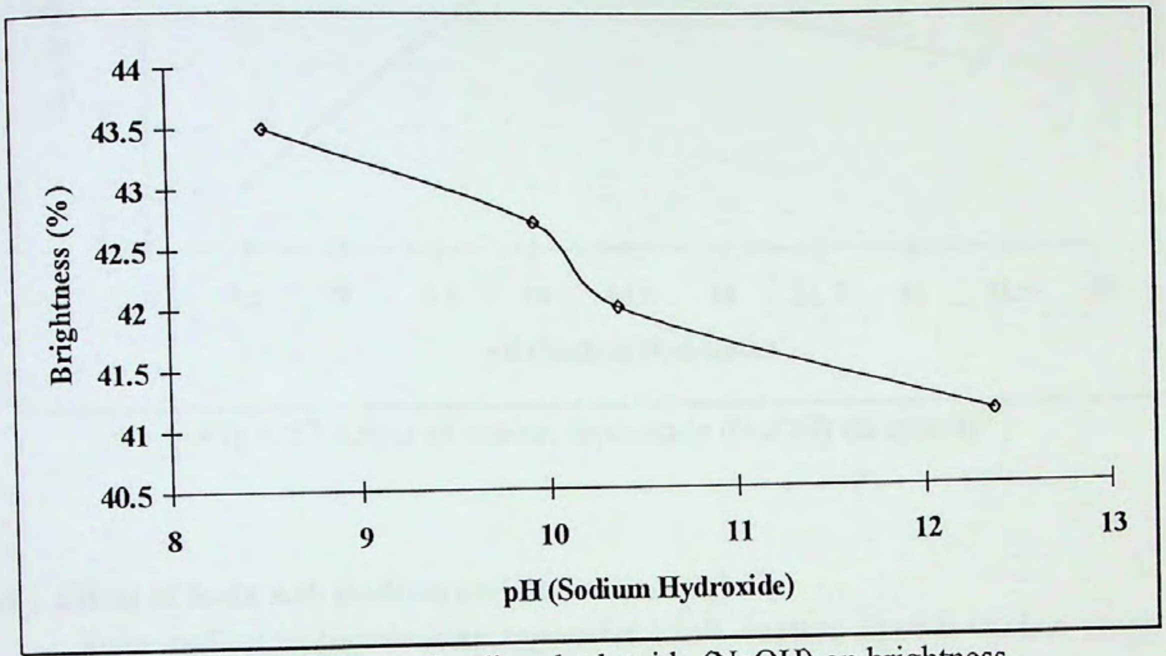

Fig 5.26 Effect of sodium hydroxide (NaOH) on brightness

As for the opacity, it increases up to a pH of 10.5, then it starts to decline, as shown in figure (5.27). Although, the trend of the opacity is naturally opposite to that of the brightness, yet this is not the case here since the brightness decrease is not due to the presence of ink, but due to the yellowing of the paper which would not cause the paper to be opaque.

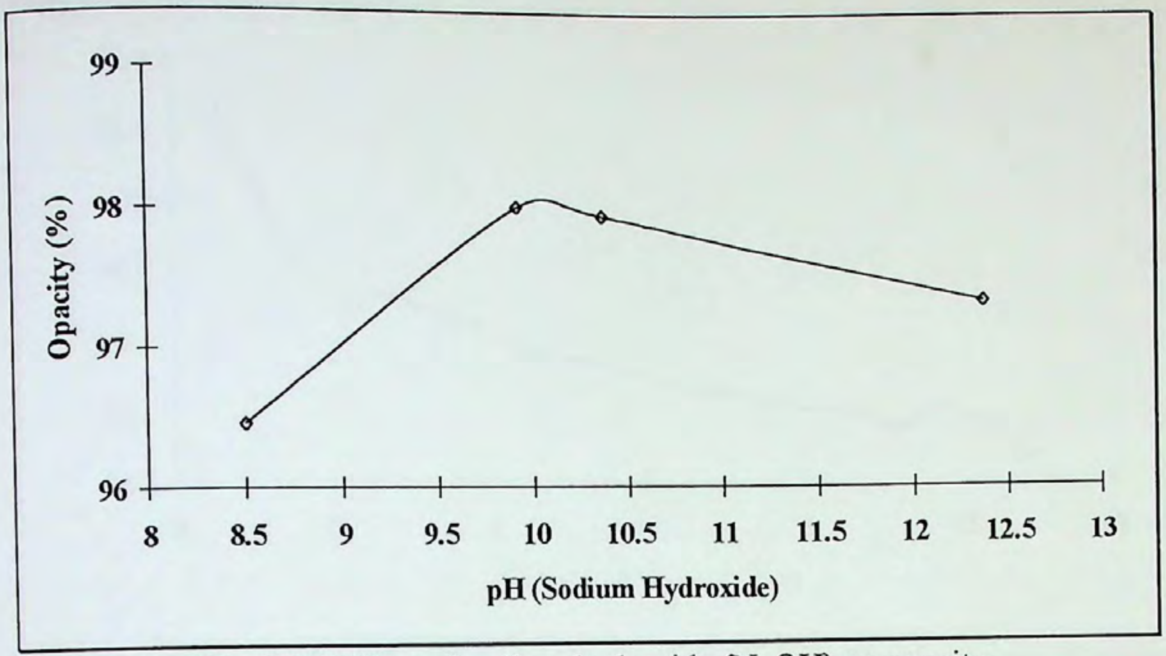

Fig 5.27 Effect of sodium hydroxide (NaOH) on opacity

5.6.2 Effect of Soda Ash (sodium carbonate Na_2CO_3)

Since sodium hydroxide is an aggressive alkali, another alkali is tried to check its effect, namely, the sodium carbonate. In the literature, it is said that this alkali is used partially to replace NaOH and Na_2Si_3[30]. Also used in conjunction with NaOH, since It cooks less harshly and produces a slightly brighter pulp than NaOH alone. It is, however, uncommon to be used alone due to slower cooking time although it provides the required alkalinity and buffers at a slightly higher pH than sodium silicate. Controlling its concentration is done the same way as that of the sodium hydroxide by reference to its pH, but it was done with two different masses to be able to reach the pH range of 9-10. The first one is 50 grams, see figure(5.28.a), while the other is with mass 0.5 grams, see figure(5.28.b).The same ranges of pH as that of the sodium hydroxide are chosen and samples of paper are prepared for testing.

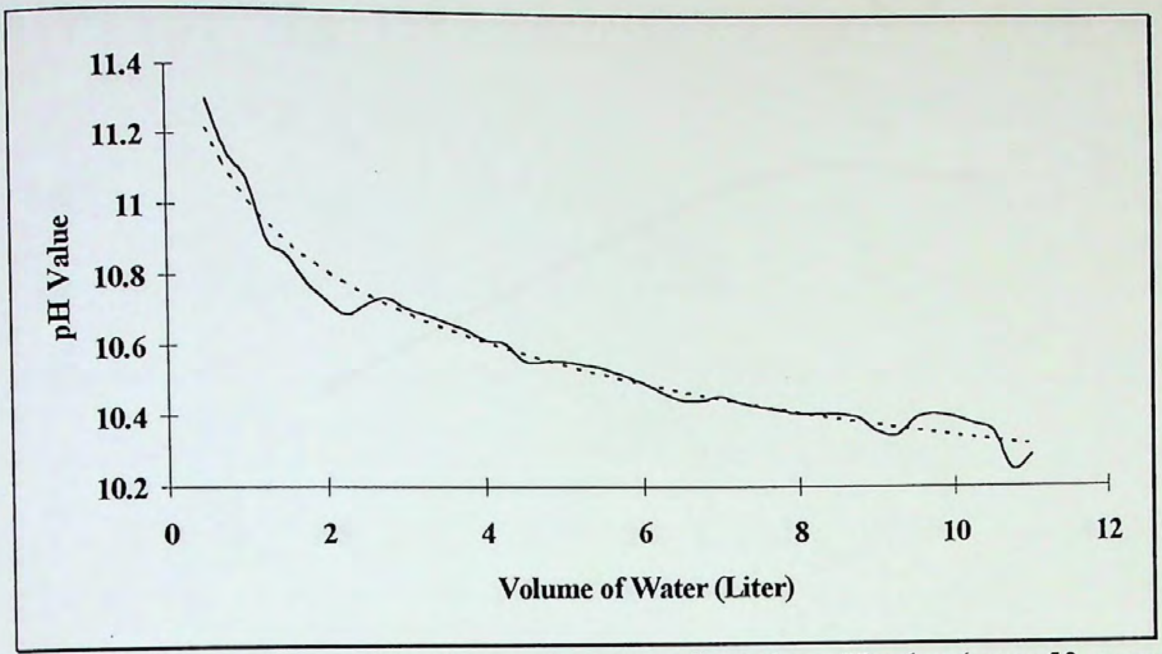

Fig 5.28.a Concentration of sodium carbonate reflected as pH value (mass 50 grams)

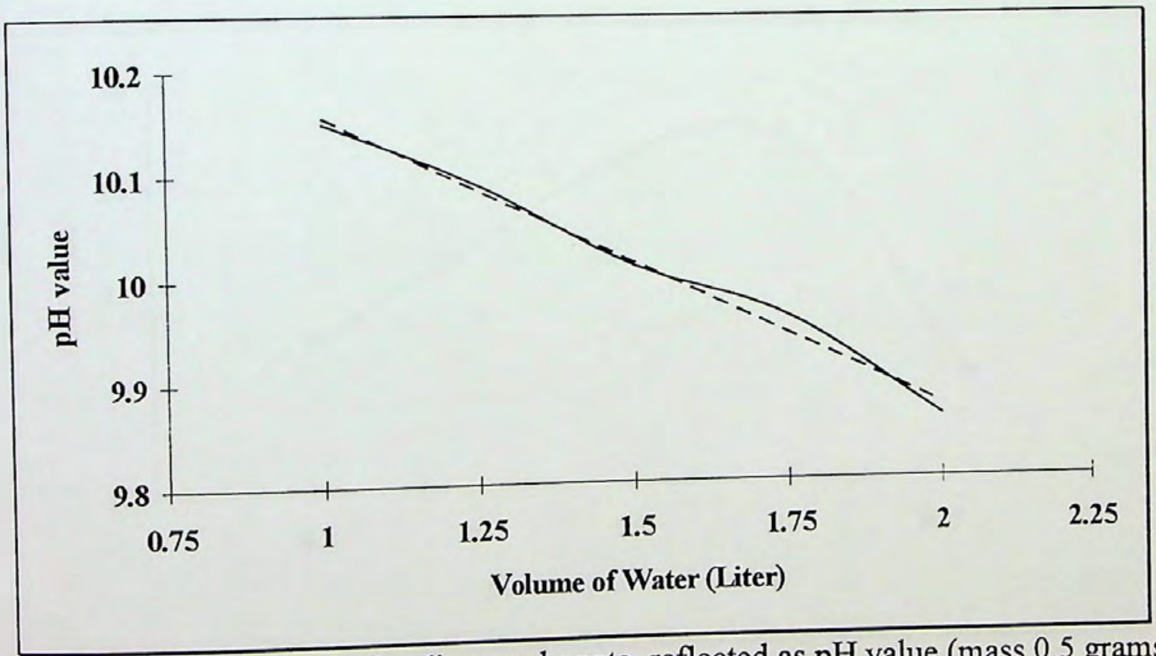

Fig 5.28.b Concentration of sodium carbonate reflected as pH value (mass 0.5 grams)

Tension showed to increase with a high rate at the pH range of 8.5-10, then it started to decrease but with a lower rate at pH range 10-11, see figure(5.29). The same trend is shown in figure(5.30) but the decrease in tear is with the same rate as that of its increase.

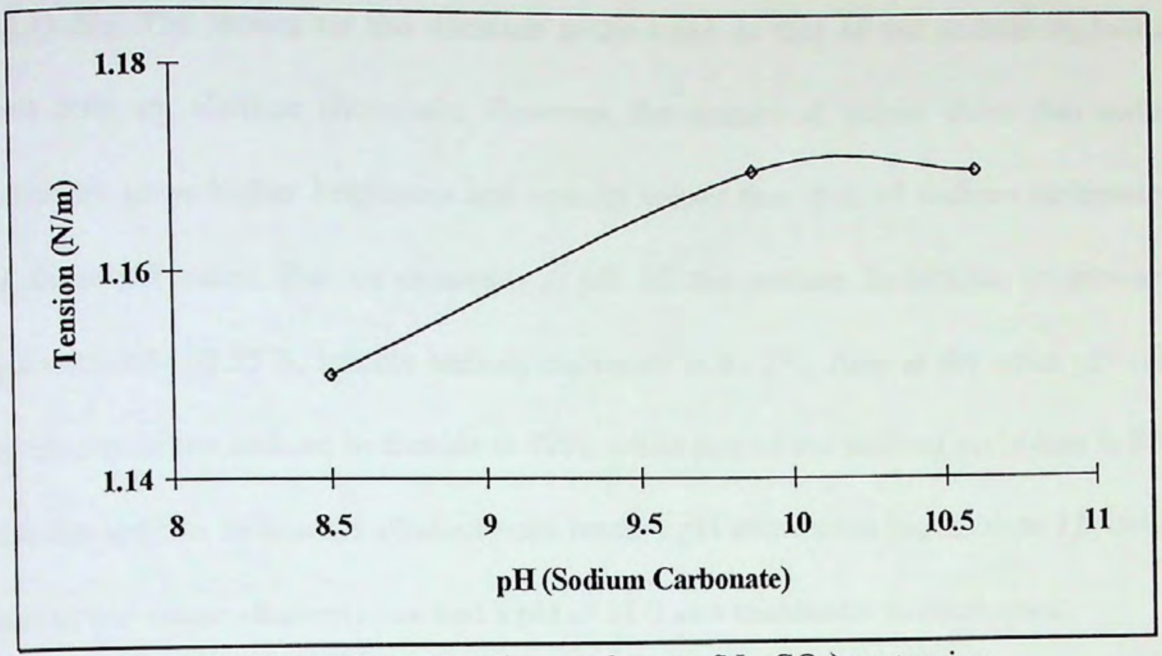

Fig 5.29 Effect of sodium carbonate (Na_2CO_3) on tension

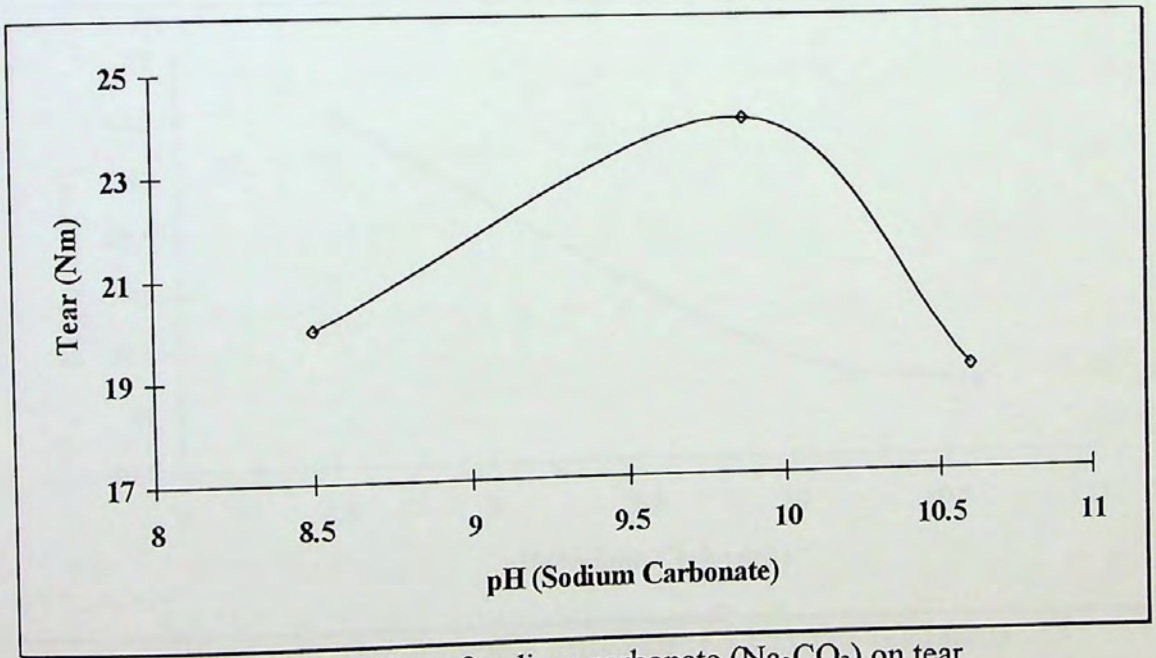

Fig 5.30 Effect of sodium carbonate (Na_2CO_3) on tear

The effect of addition of sodium carbonate concentration on brightness and opacity is more or less the same as that of sodium hydroxide. Both brightness and opacity decrease with the sodium carbonate concentration, as shown in figures (5.31)

and (5.32). The reason for the decrease is the same as that of the sodium hydroxide, since both are alkaline chemicals. However, the numerical values show that sodium hydroxide gives higher brightness and opacity values than that of sodium carbonate at the same pH value. For an example, at pH 10 the sodium hydroxide brightness is approximately 42.25%, but the sodium carbonate is 41.5%. Also at the same pH value the opacity of the sodium hydroxide is 97%, while that of the sodium carbonate is 98%. Also the sodium hydroxide alkalinity can reach a pH value even higher than 12, but the sodium carbonate alkalinity reached a pH of 11.2 as a maximum concentration.

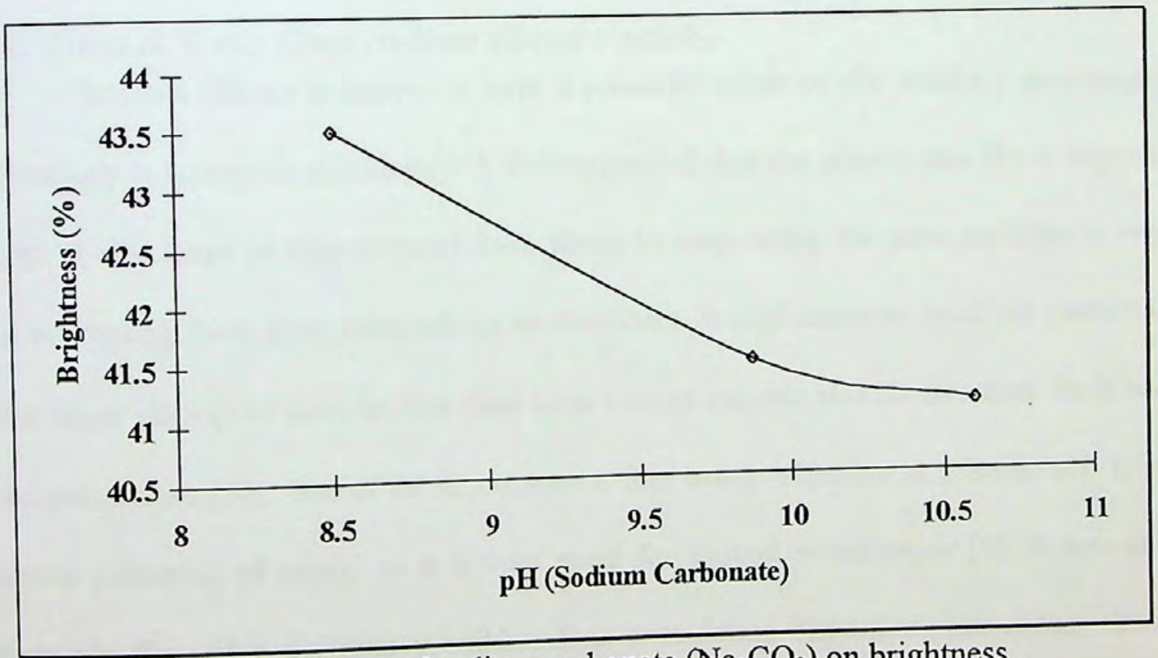

Fig 5.31 Effect of sodium carbonate (Na_2CO_3) on brightness

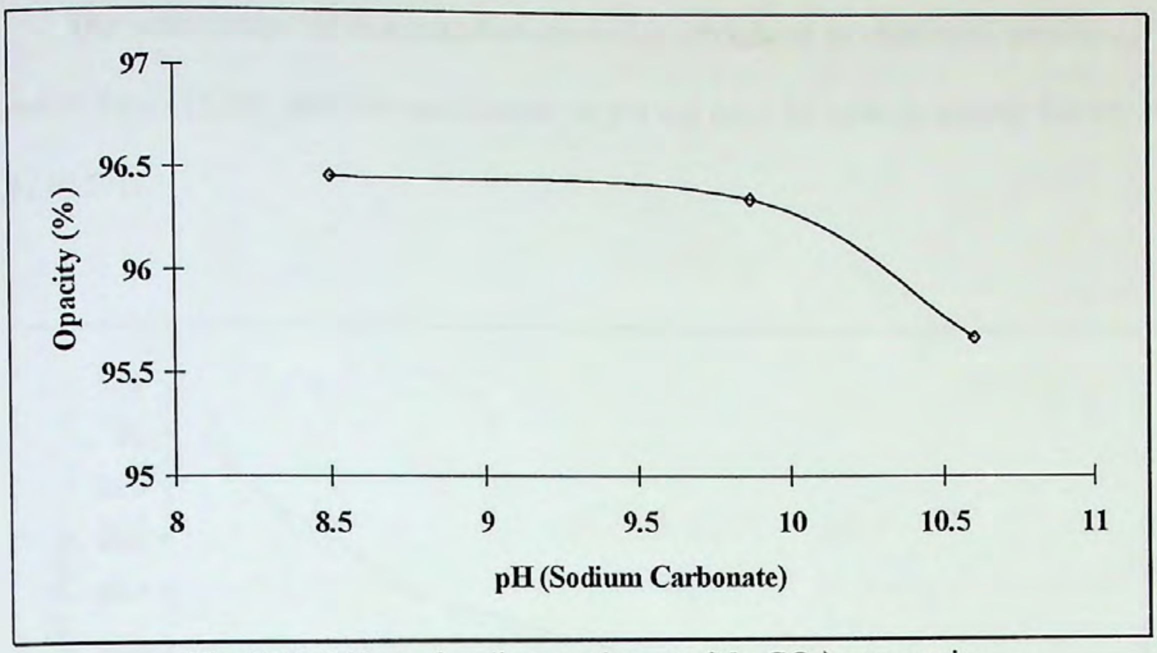

Fig 5.32 Effect of sodium carbonate (Na_2CO_3) on opacity

5.6.3 Effect of Water Glass (sodium silicate Na_2SiO_3)

Sodium Silicate is known to have a powerful effect on the deinking performance, particularly in newsprint deinking [30]. It is suggested that the silicate acts like a dispersing agent. It also helps to remove print from fibers by suspending the print particles in water and preventing them from redepositing on the fibers. It agglomerates small ink particles to form larger ones (>10 μm), so that they have a more suitable size for flotation. So it has a detergent action.[30]. One of its advantages is that being effective at a lower pH. It also prevent yellowing of paper, so it is very good for ground wood paper [7]. It acts as an alkaline buffer and a detergency builder. It is a moderate dispersant, can reduce the ink particle size which makes flotation more difficult [11]. Ink particle size decreases because of the friction action that is carried out by the silicate.

The same method of concentration control is carried out as mentioned previously, as shown in figure (5.33), and the same ranges of pH are used for testing, namely 9.5-10, 10-10.5, 10.5-11.

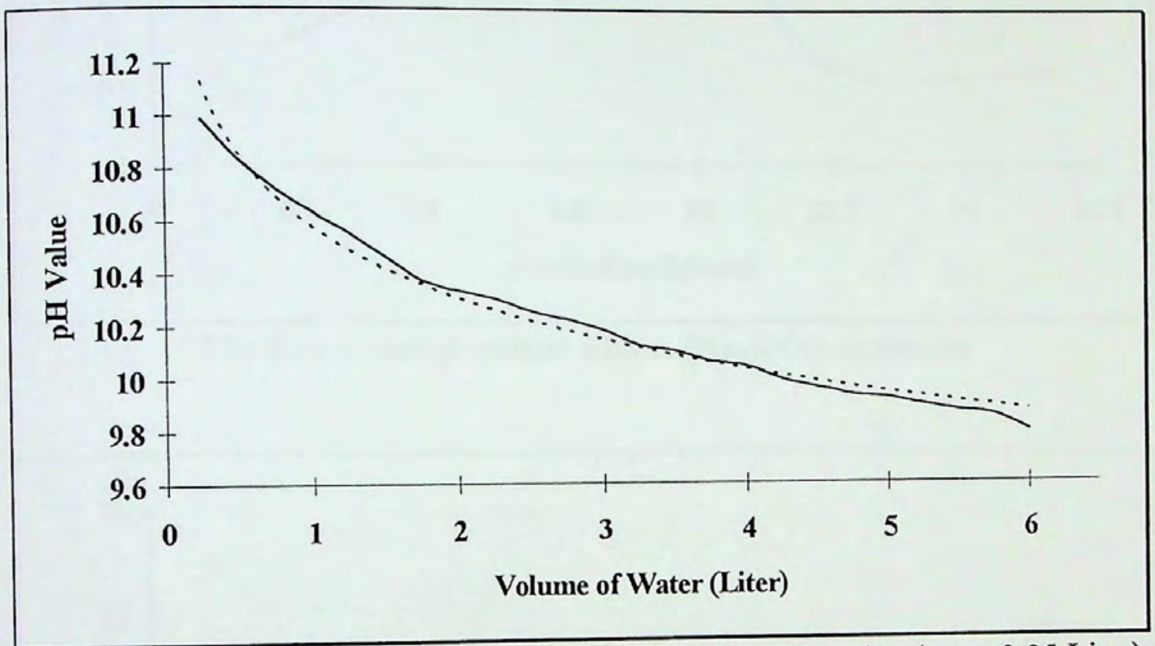

Fig 5.33 Concentration of sodium silicate reflected as pH value (mass 0.05 Liter)

Tension and tear values increase from tap water pH 8.5 up to 9.8. Then, a clear decline takes place up to pH 10.5 and tends to be constant at higher pH in the case of tension, as shown in figure (5.34). Tear, on the other hand, turns to increase sharply at a pH higher than 10.5, as shown in figure (5.35)

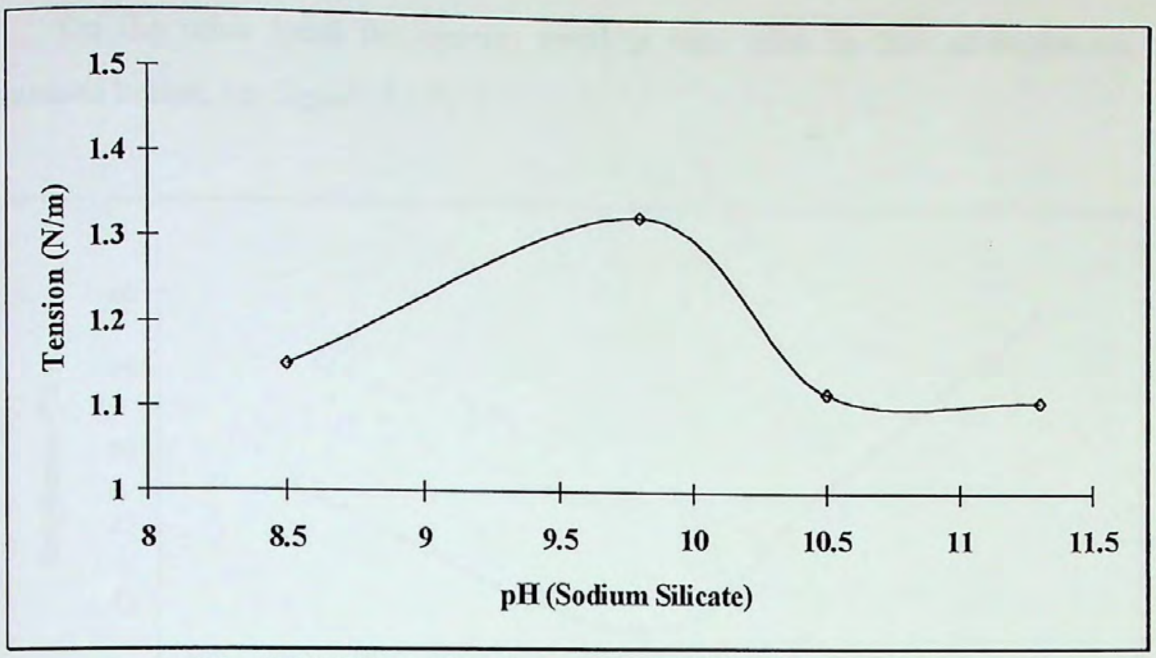

Fig 5.34 Effect of sodium silicate (Na_2SiO_3) on tension

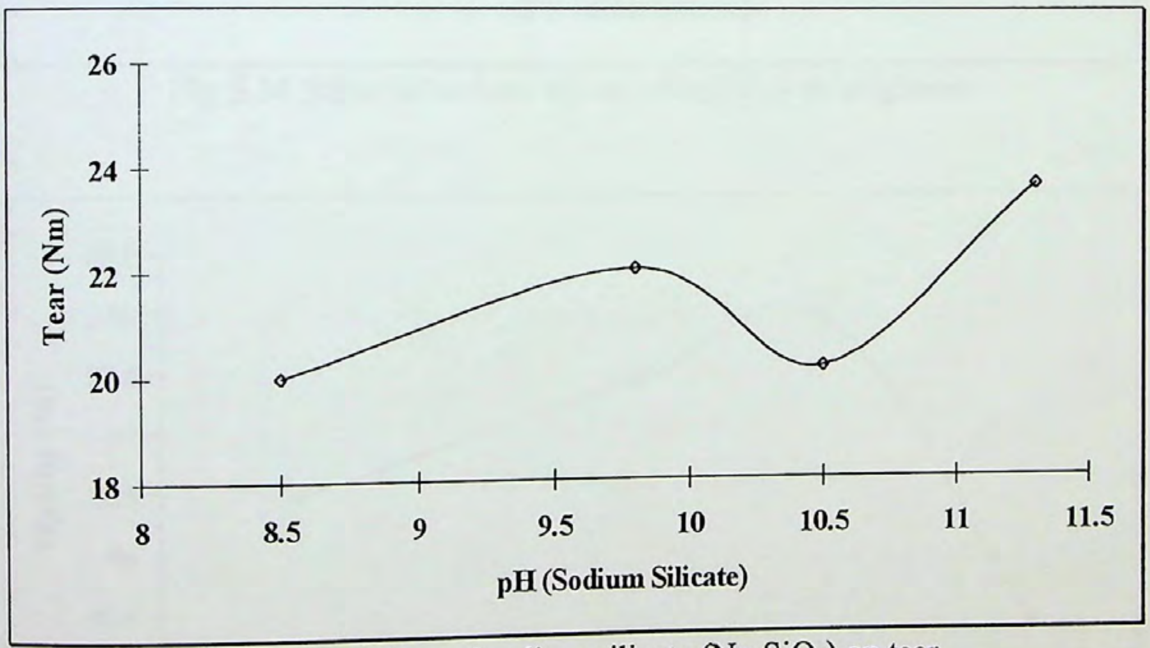

Fig 5.35 Effect of sodium silicate (Na_2SiO_3) on tear

Checking the brightness effect on sodium silicate concentration, showed that it decrease at the low pH, ranging from tap water pH value till approximately 9.75. Then it started to increase with a high rate at higher pH concentrations up to 11.5. Sodium silicate showed to be the most effective chemical used, see figure (5.36)

On the other hand the opacity trend is vice versa to that of brightness, as mentioned before, see figure (5.37).

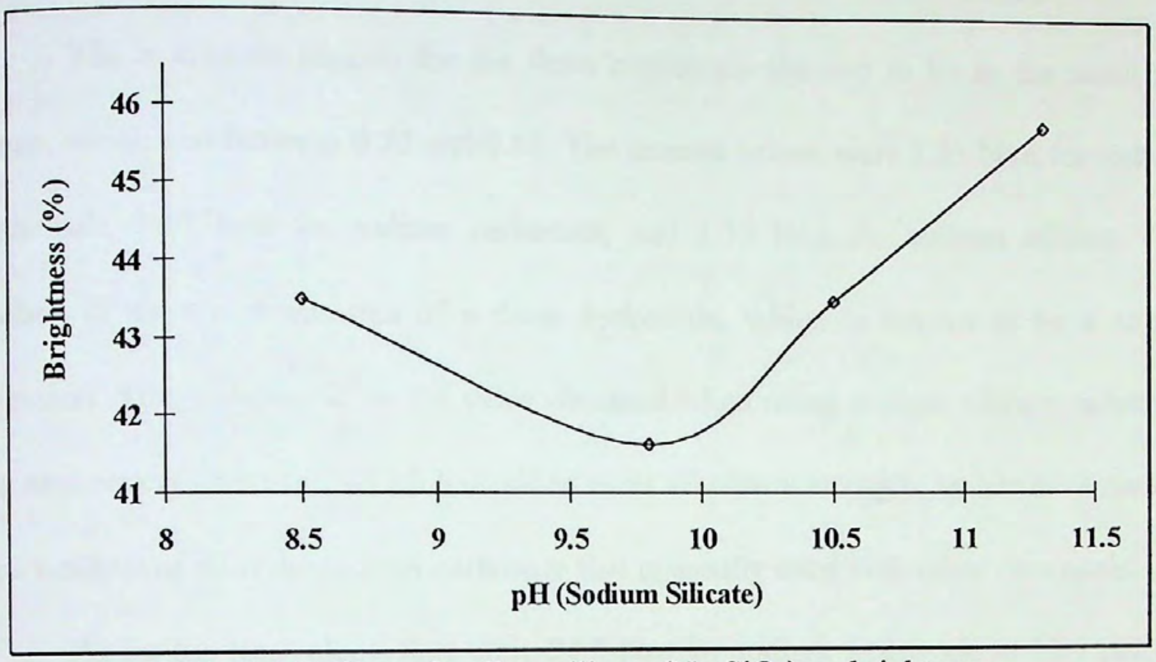

Fig 5.36 Effect of sodium silicate (Na_2SiO_3) on brightness

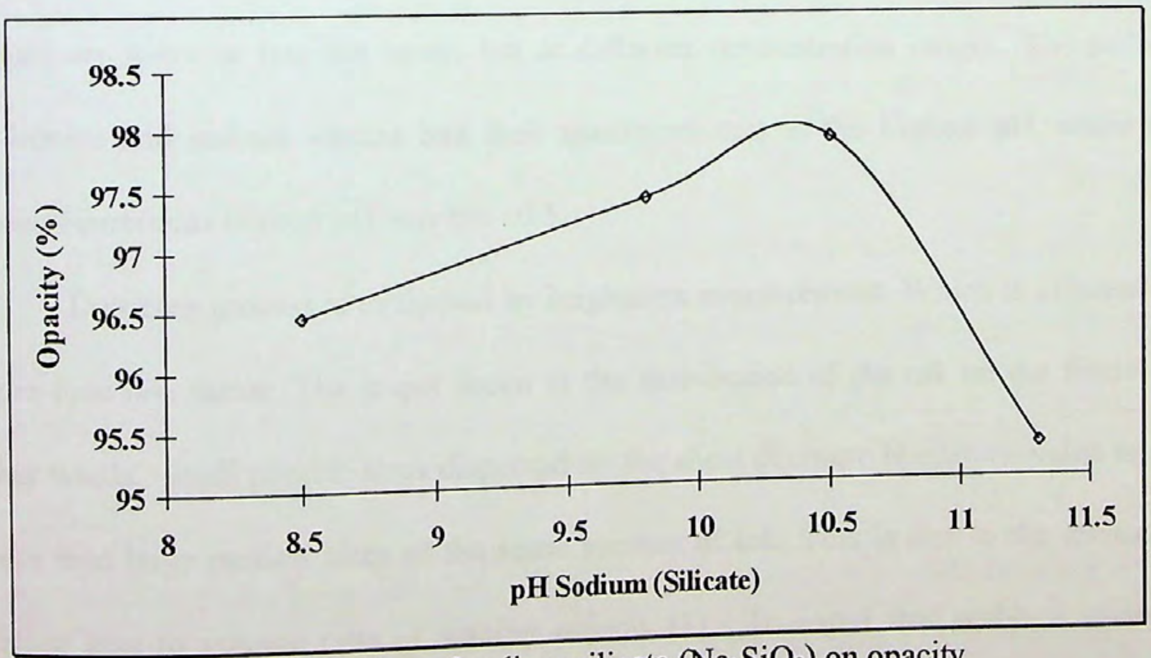

Fig 5.37 Effect of sodium silicate (Na_2SiO_3) on opacity

5.7 Results comparison to optimize the chemical deinking process

To decide on the best concentration and the best chemical used for the chemical deinking result, a comparison is carried out between the three chemicals used.

The maximum tension for the three chemicals showed to be in the same pH range, which was between 9.75 and 9.85. The tension values were 1.53 N/m for sodium hydroxide, 1.17 N/m for sodium carbonate, and 1.35 N/m for sodium silicate. The highest of the three was that of sodium hydroxide, which is known to be a strong chemical. This is followed by the value obtained when using sodium silicate, which is the next strong chemical, which has added to its alkalinity strength, an abrasive nature. The weakest of all is the sodium carbonate that is usually used with other chemicals.

As for the tear values, they were 24.5 Nm for sodium hydroxide at 12.5 pH, 24 Nm for sodium carbonate at 9.8 pH, and 24 Nm for sodium silicate at pH 11.5. Their values are more or less the same, but at different concentration ranges. The sodium hydroxide and sodium silicate had their maximum tear at the highest pH, while the sodium carbonate highest pH was the 10.5.

Deinking process is evaluated by brightness measurement. Which is affected by more than one factor. The major factor is the distribution of the ink on the fibers. In other words, small particle sizes dispersed on the sheet decrease brightness value much more than large particle sizes of the same amount of ink. This is due to the increased surface area to volume ratio of smaller objects [3]. To avoid this problem, modern computerized image analysis systems could be used. That counts the ink specks and their distribution can be determined, but this system is not available. So brightness is

used to evaluate the deinking system. Comparing the three chemicals, showed that the sodium hydroxide and sodium carbonate had more or less the same trend, which is decreasing all the way with the pH (chemical concentration). Ink particles are detached from the fibers due to their swelling and saponifying characteristic of the alkali. But they might not have enough time to be completely floated and removed from the slurry, so they are dispersed in the slurry. This is reflected on the decrease in brightness by the increase in alkalinity (chemical concentration). As for the sodium silicate, it starts by decreasing until pH of 9.75, then it starts to increase sharply. This shows that a pure alkaline material had the same way of deinking, but the presence of an abrasive material added to the alkaline nature of the chemical as that in the sodium silicate would change the deinking trend. The maximum values of brightness for sodium hydroxide and sodium carbonate were at the lowest pH (tap water, 8.5), which was 43.5% for both. As for the sodium silicate, it showed the highest brightness at the highest pH, which was 46.2% at 11.5.

On the other hand, opacity trends for the different chemicals were different from each other, and their range was very narrow for the three chemicals, i.e. between 95.5 and 98 %. This range differs according to the paper thickness as mentioned before. So their results are of no comparison, so of no importance.

It is therefore reasonable to conclude that the best chemical used is the sodium silicate, since it combines both the alkalinity effect and the abrasive material, that are needed for the best deinking results. Also, its tension value is intermediate relative to

the other two chemicals. Where the physical tests depend on the paper formation process. In industries, for example, sheets of paper are formed on mill. Therefore, they have direction of fiber orientation. It also have a controlled pressing and drying processes, which highly affect the final physical paper properties. However, the physical properties tests are carried out to give an indication on effect of the different parameters tested as time, temperature and chemicals on the fiber strengths and fiber to fiber bond strengths and not for comparison with standards.

Chapter 6

Conclusion

Waste paper recycling system was designed, manufactured and tested at the American University in Cairo. It was then tested, using 100% old newspaper for deinking and recycling. The first tested stage was mechanical deinking procedure and second was chemi-mechanical deinking procedure. For the mechanical system, the effect of beating time was tested. Visual inspection proved that paper fibers were defibered completely when the drum was raised at a relative high position for 15 minutes, then lowered to the minimum for 10 more minutes. The flotation cell, tested for different time, temperature and combination of both. The prepared sheets were then tested for physical (tension & tear) and optical (brightness & opacity) properties. The main property that reflects amount of deinking is the brightness, which is affected by the distribution of the ink on the fibers. In other words, small particle sizes dispersed in the sheet decrease brightness value much more than large particle sizes of the same amount of ink. This is due to the increased surface area to volume ratio of smaller objects [3]. To avoid this problem, modern computerized image analysis systems could be used. It counts the ink specks and their distribution can be determined, but this system is not available.

The results proved that the optimum acceptable value of tension was 1.25 N/m at 40 °C temperature and 10 minutes time. Although at higher temperature (60 °C) and for longer time (15 minutes) the tension value was higher (1.3 N/m), yet, the higher

temperature and time means no conservation of energy and time and the results difference are not really worth while. As for the tear test, the maximum value reached was at the same tension optimum conditions reached. Which are 40 Nm at 40 °C temperature and for 10 minutes time. The physical properties conditions are tested to check the effect of recycling on them. In industry these properties could be controlled by adding relevant additives as starch to enhance them. As for the optical properties tested, the results were confirming the same conclusion. Highest result for brightness was obtained at the 40 °C temperature and 10 minutes (43.5%). The second highest was at the same temperature but for 15 minutes (43.25%). The difference is negligible, which is 0.25 %. Out of experience with the system, the 15 minutes time are just enough to control the system. As long as the 5 minutes time difference will not really affect the results. Opacity are tested all the way through the testing stages. But their results are not of real importance, since they are affected by the single sheet thickness. Since the sheet thickness are not really controlled as recommended, due to the manual sheets preparation. So the results are not systematic with the testing conditions. Then effect of washing of the pulp was tested at different stages in the process. First before the flotation cell, then after the flotation cell and finally before and after the flotation cell. It proved that the more washing the better deinked pulp produced, which is reflected on the paper brightness results.

The second stage in testing was the effect of deinking chemicals if added to the system. Chemicals used were mainly alkali base, to saponify the oil base ink used in printing. Chemicals used are sodium hydroxide which is the strongest alkali, sodium carbonate which is a weaker alkali, and sodium silicate which is an intermediate alkali, but with an

abrasive nature. Tests were carried out at different concentrations of each chemical, with the optimized mechanical conditions mentioned before (40 °C temperature and for 15 minutes time). The tension showed maximums at the same pH range, approximately 10. The highest maximum of the three was that of the sodium hydroxide (1.53 N/m). The second highest is the sodium silicate (1.35 N/m). The third is the sodium carbonate (1.17 N/m). The maximums are directly proportional to the chemical alkalinity strength. As for the tear results, their value is the same (24 Nm), but at highest pH values. Where the sodium hydroxide was at 12.5, sodium silicate at 11.5 and sodium carbonate at 9.8. Tear is a sensitive physical test, because of the crack that is initiated at the start of the test. Brightness test showed that sodium hydroxide and sodium silicate had the same trend, which was decreasing with the increase of pH value. The alkaline material swells the fibers and saponify the ink. So the ink particles are detached from the fibers, but do not have enough time to float to the surface. So they are dispersed in the pulp slurry, and decrease the brightness value. The maximums are shown to be at the lowest pH (8.5), which is the tap water. Although at this pH value ink particles are expected to be still sticking to the fibers, but larger in size. As for the sodium silicate, brightness trend started by decreasing, then it increased sharply. The reason for this difference in trend is the abrasive nature of silicate. Its maximum 46.2 % is shown at the highest pH value 11.5. As for the opacity trend were not comparable, since the opacity is affected by the each paper thickness that is difficult to control.

Chapter 7

Recommendation for future work

7.1 Changes in Flotation Cell

7.1.1 Increase the distance between the jet pump and disc

The distance between the disc and the pump was constant in all the tests carried out, which was 3 cm. This distance controls the amount of air entertainment in the slurry during operation of the flotation cell. Also the presence of the disc facing the pumped slurry causes turbulent flow, which mixes the slurry with the air bubbles and causes friction between fibers. Amount of entrained air are unpredictable with the change of the disc position, either upwards or downwards. However, the turbulent flow of the pulp will increase by decreasing the distance, but will decrease with the increase of the distance.

7.1.2 Add a source of air to the system

The ink particles are supposed to stick to the air bubbles and float to the surface of the flotation cell to be skimmed off. The amount of entrained by the jet pump were not enough. So the idea of introducing extra air to the system to increase the air bubbles in the slurry might increase the amount of ink removed by the system. The source of air could be introduce either from the bottom or at side of the flotation cell.

7.1.3 Change the design of the system

One of the systems suggested in literature is the one designed by Beliot's Group.[24&38], to be horizontal. Where, the pulp is introduced from the left hand side with

aeration and mixing sections are in the same area. Then the slurry passes through a nozzle and faces a wider section suddenly, to increase the pulp velocity and cause a turbulent flow, for good extra mixing and foam formation. At this section the foam formed, which consists of air bubbles, sticked to it the ink particles will float to the surface. At the top section there is an air draft entering to direct the foam to its outlet section, where by vacuum it is drawn off. At the right section there is a weir for the deinked pulp to pass to its outlet direction, there is also a baffle to prevent the foam from re-mixing with the deinked pulp once more, see figure 7.1. This design have better aeration system, where air is imposed, and introduce from the bottom side corner in the system, so better bubbles are formed and directed upward through the slurry. This would help the ink particles to stick to the air bubbles and float directed to the foam collection zone.

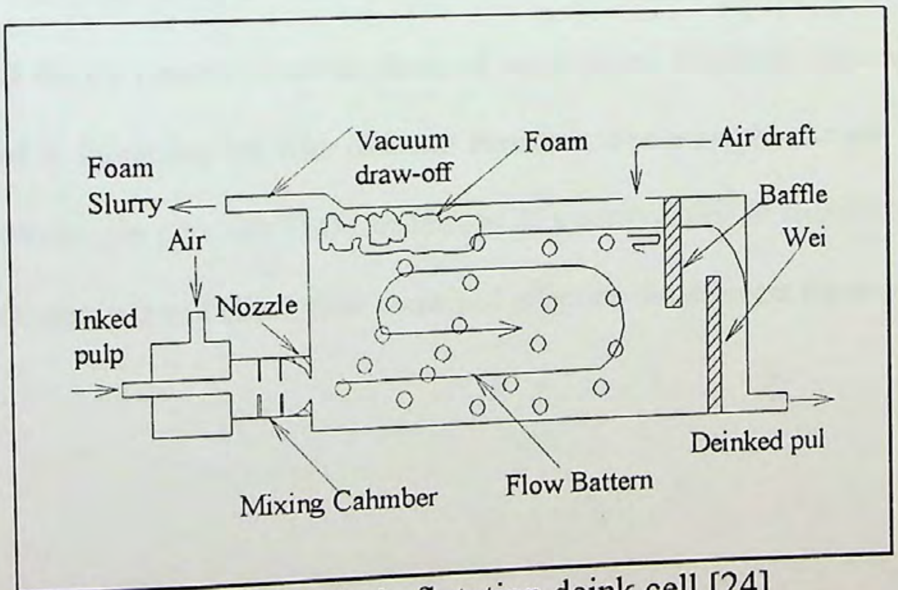

Fig 7.1 Beliot's flotation deink cell [24]

Also, the removing method of the inked foam slurry by vacuum at the top surface of the system is better than the present one, which depends on the flow of the foam over the weir. The presence of the baffle and weir at the collection section of the inked pulp prevents the re-mixing of the ink particles with the deinked pulp slurry.

7.2 Better Washing System

The system used is a manual with a sieve of ASTM 100. There are better mechanical washing systems available on industrial levels, such as screw presses, drum washers, sidehill screens, and belt washers [30]. None of these was available. It is expected that using a better washing system will increase the amount of ink removed from the slurry, since it was shown through the manual washing system used to be effective.

7.3 Use other chemicals

The chemicals used in this research were to check their effect on the system efficiency and the ink removal from the fibers of waste paper. However, there are others list recommended in literature, but with different functions. For example, the use of bleaching chemicals as hydrogen peroxide H_2O_2, or the use of a combination of chemicals together to optimize their amounts and check their combined effect on the different paper properties.

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Appendix A

Experimenting test results values tabulated for refrence.

Effect of flotation cell time

Effect of flotation cell at room temperature

Time (min.)	Tension (N/m)
5	1.08
10	1.11
15	1.12
20	0.31
30	1.25

Time	Tear (Nm)
5	25.33
10	24.00
15	25.60
20	17.33
30	32.00

Time (min.)	Brightness (%)
5	41.20
10	41.20
15	41.30
20	40.66
30	40.92

Time	Opacity (%)
5	100.0
10	100.0
15	100.0
20	98.82
30	98.01

Effect of flotation cell time at 50 °C

Time (min.)	Tension (N/m)
10	1.22
15	0.98
30	1.01

Time	Tear (Nm)
10	30.67
15	17.44
30	13.36

Time (min.)	Brightness (%)
10	42.67
15	41.46
30	42.34

Time	Opacity (%)
10	97.99
15	97.31
30	97.46

Effect of flotation cell temperature

Effect of flotation cell at 15 minutes

Temperature (°C)	Tension (N/m)
27	1.19
40	1.23
45	0.95
50	1.13
60	1.32

Temperature (oC)	Tear (Nm)
27	20.29
40	16.21
45	12.95
50	15.81
60	16.62

Temperature (°C)	Brightness (%)
27	40.11
40	43.36
45	42.77
50	42.01
60	42.08

Temperature (oC)	Opacity (%)
27	97.19
40	95.76
45	97.82
50	97.22
60	95.65

Effect of flotation cell at 10 minutes

Temperature (°C)	Tension (N/m)
27	1.11
40	1.25
45	1.22

Temperature (oC)	Tear (Nm)
27	24.00
40	33.33
45	30.67

Temperature (°C)	Brightness (%)
27	41.20
40	43.98
45	42.67

Temperature (oC)	Opacity (%)
27	100.0
40	95.56
45	97.99

Effect of flotation cell at 30 minutes

Temperature (°C)	Tension (N/m)
27	1.25
50	1.01
60	2.81

Temperature (oC)	Tear (Nm)
27	32.00
50	13.36
60	15.40

Temperature (°C)	Brightness (%)
27	40.92
50	42.34
60	41.48

Temperature (oC)	Opacity (%)
27	98.01
50	97.49
60	96.65

Effect of washing on brightness and opacity

Temperature (°C)	Brightness (%)
Pre	42.18
Post	43.06
Pre&Post	43.51

Temperature (oC)	Opacity (%)
Pre	97.64
Post	97.67
Pre&Post	96.46

Effect of chemicals on deinking process

Effect of caustic soda (NaOH)

pH	Tension (N/m)
8.5	1.15
9.92	1.52
10.37	1.17
12.37	1.3

pH	Tear (Nm)
8.5	20.00
9.92	22.67
10.37	22.13
12.37	24.81

pH	Brightness (%)
8.5	43.5
9.92	42.72
10.37	42.01
12.37	41.12

pH	Opacity (%)
8.5	96.46
9.92	98.00
10.37	97.94
12.37	97.33

Effect of soda ash (sodium carbonate (Na_2CO_3)

pH	Tension (N/m)
8.5	1.15
9.87	1.17
10.6	1.17

pH	Tear (Nm)
8.5	20.00
9.87	24.03
10.6	19.07

pH	Brightness (%)
8.5	43.5
9.87	41.49
10.6	41.11

pH	Opacity (%)
8.5	96.46
9.87	96.36
10.6	95.68

Effect of water glass (sodium silicate Na_2SiO_3)

pH	Tension (N/m)
8.5	1.15
9.8	1.33
10.5	1.12
11.3	1.11

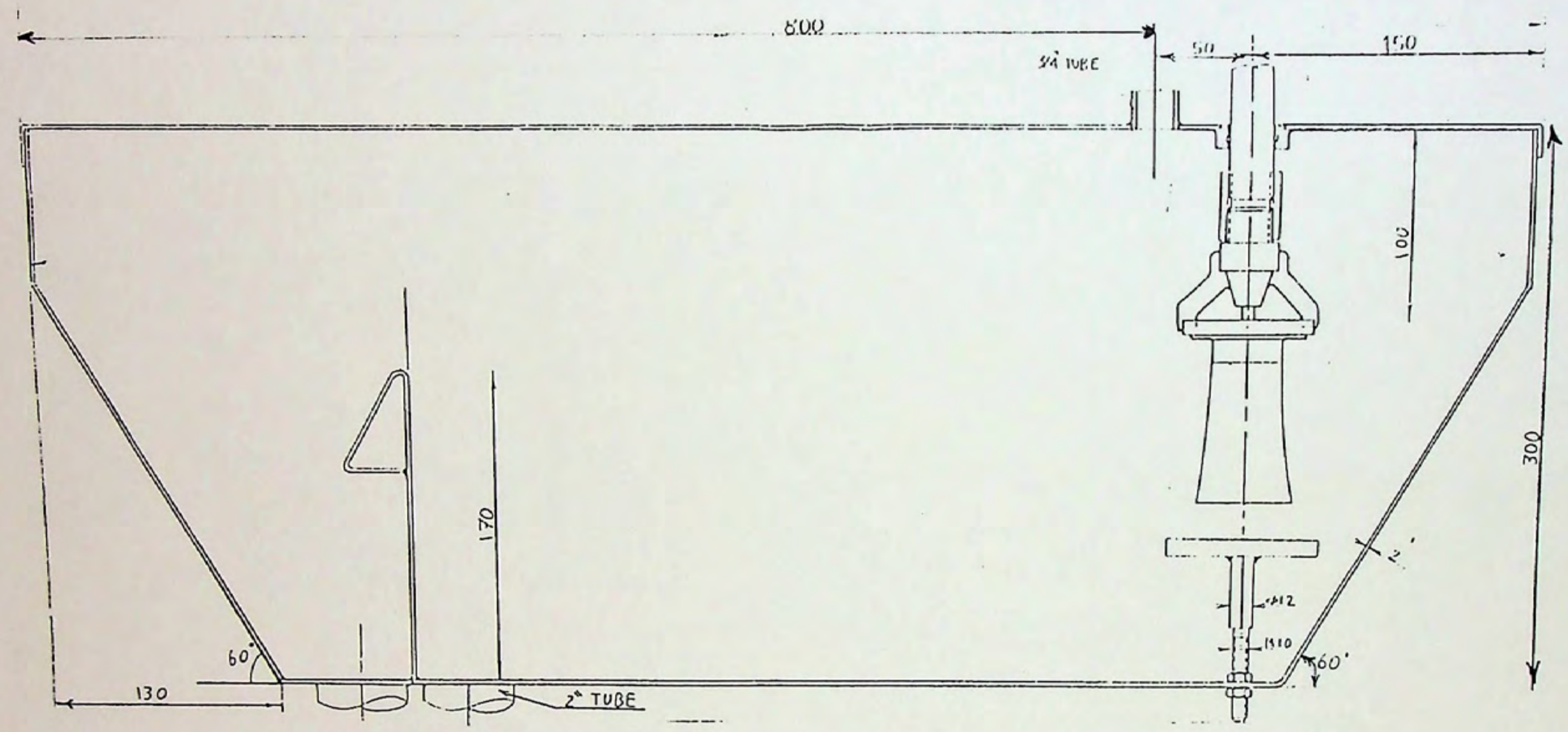
pH	Tear (Nm)
8.5	20.00
9.8	22.06
10.5	20.16
11.3	23.69

pH	Brightness (%)
8.5	43.5
9.8	41.63
10.5	43.52
11.3	45.81

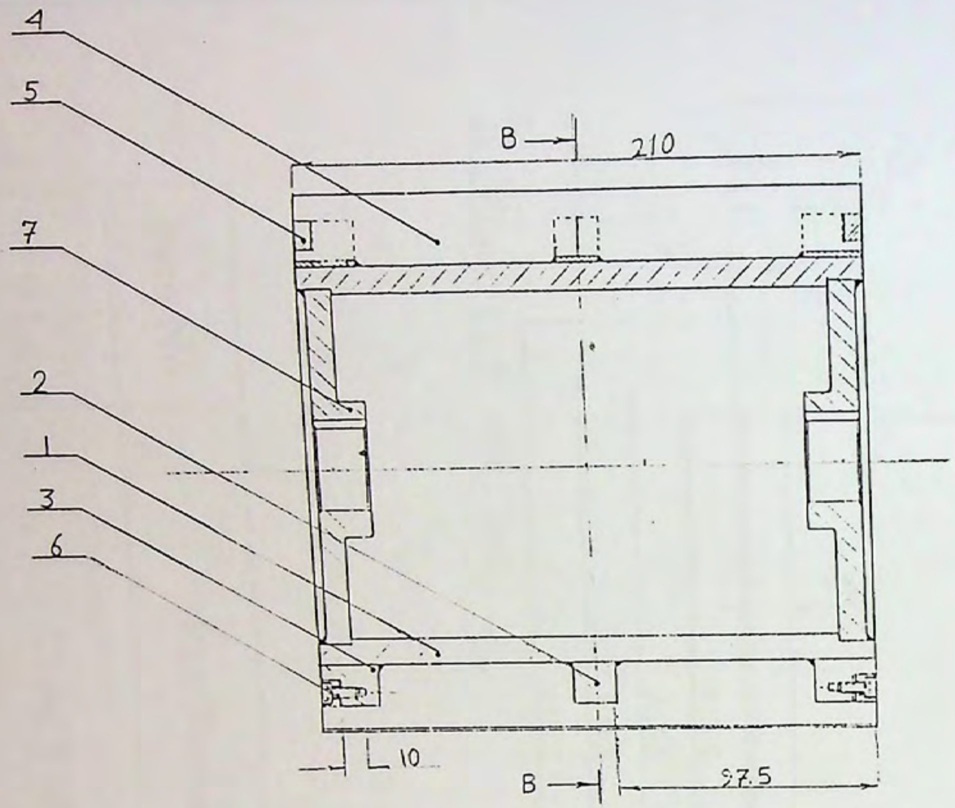
pH	Opacity (%)
8.5	96.46
9.8	97.41
10.5	97.91
11.3	95.29

Appendix B

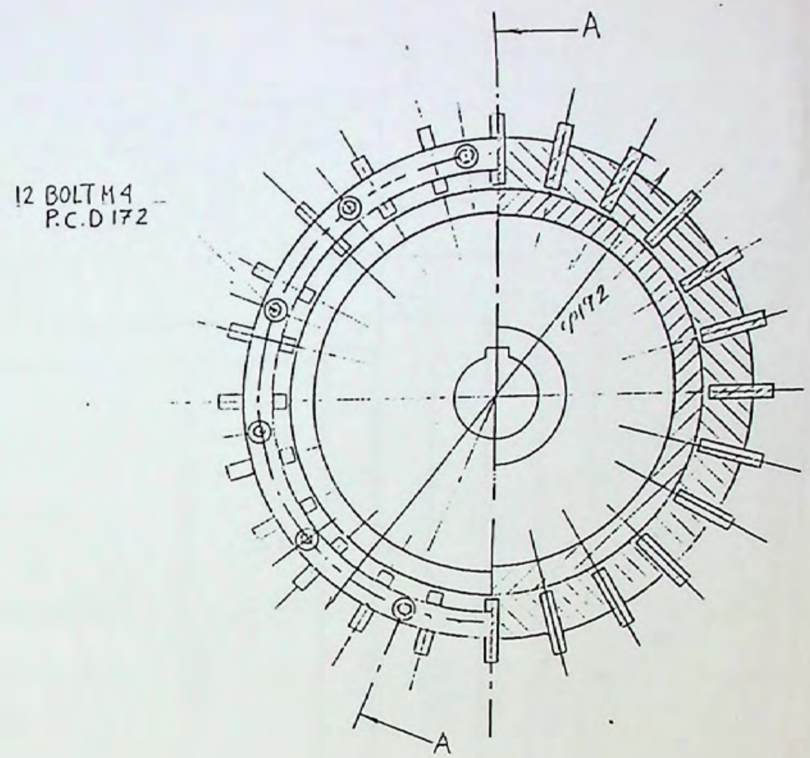
Design Drawings of Flotaion Cell and Beater machines



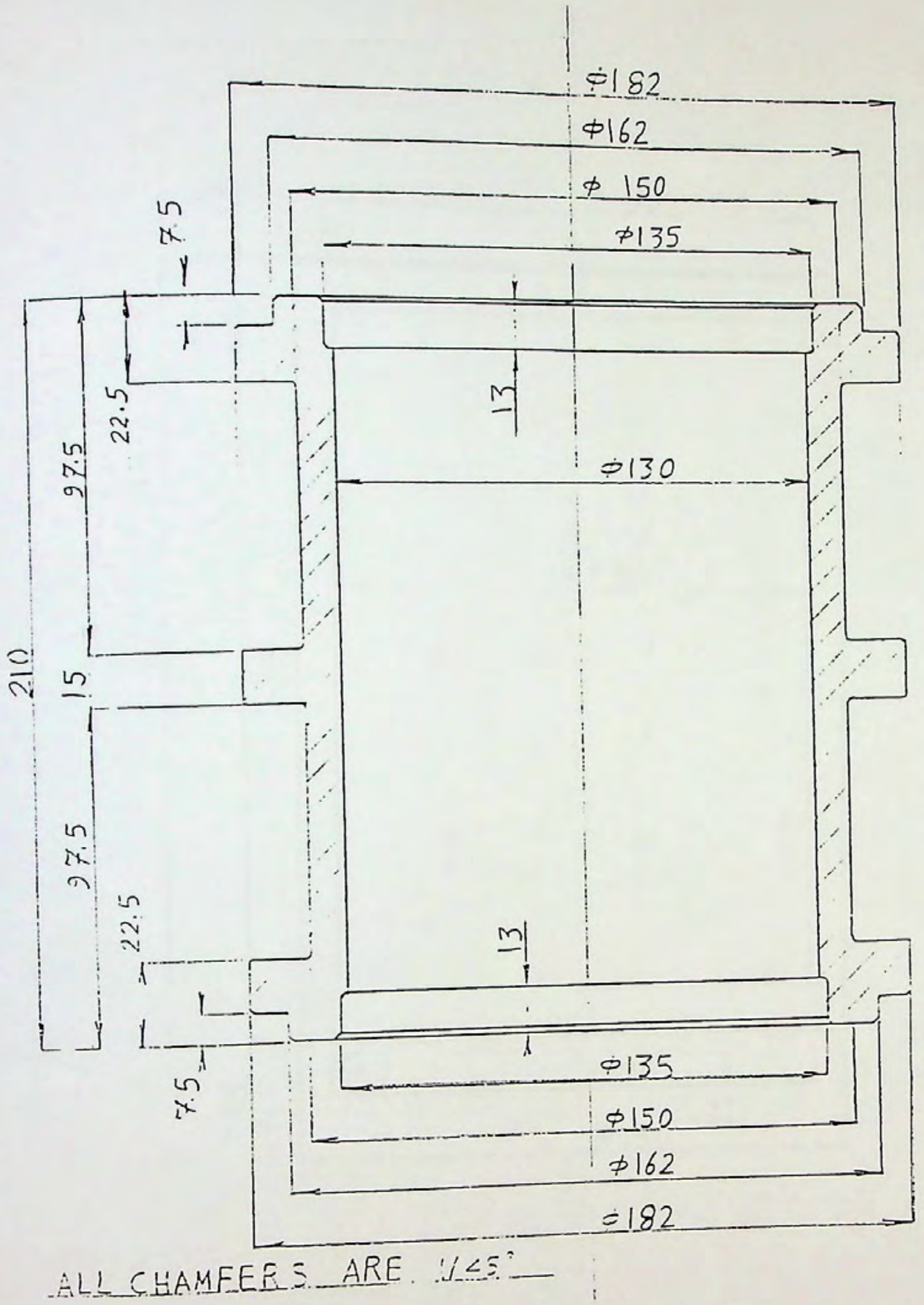
Design Drawing of Flotation Cell



Item No.	Part Name
9.1.a & b	Drum Body
9.2	Middle Blade Support
9.3	Blades End Support
9.4	Blades
9.5	Blades Lock Plates
9.6	Allin Bolts M 4x10 DIN 912
9.7	Drum Hubs

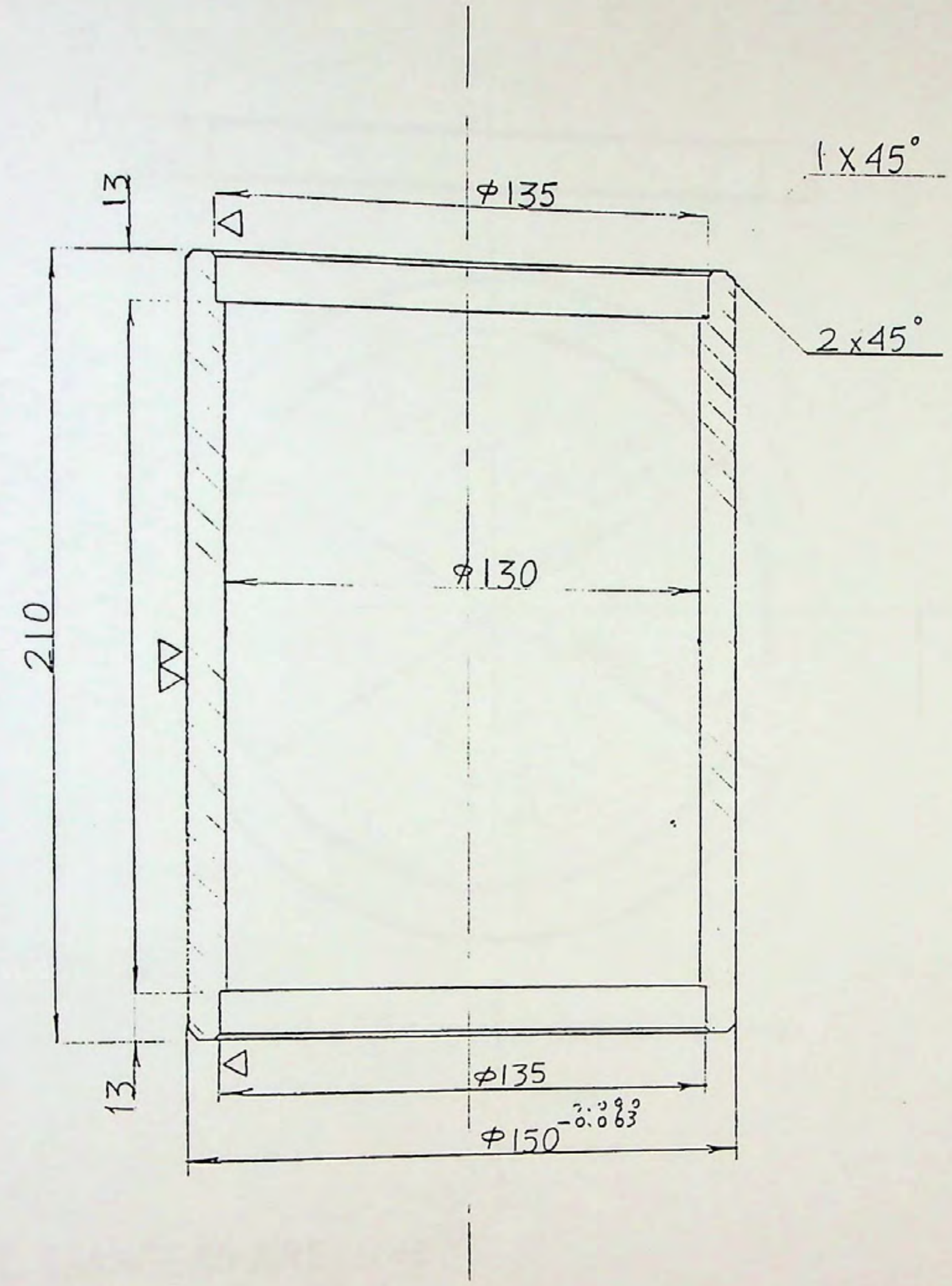


Item No.	Part Name
9	Drum Blades Assembly

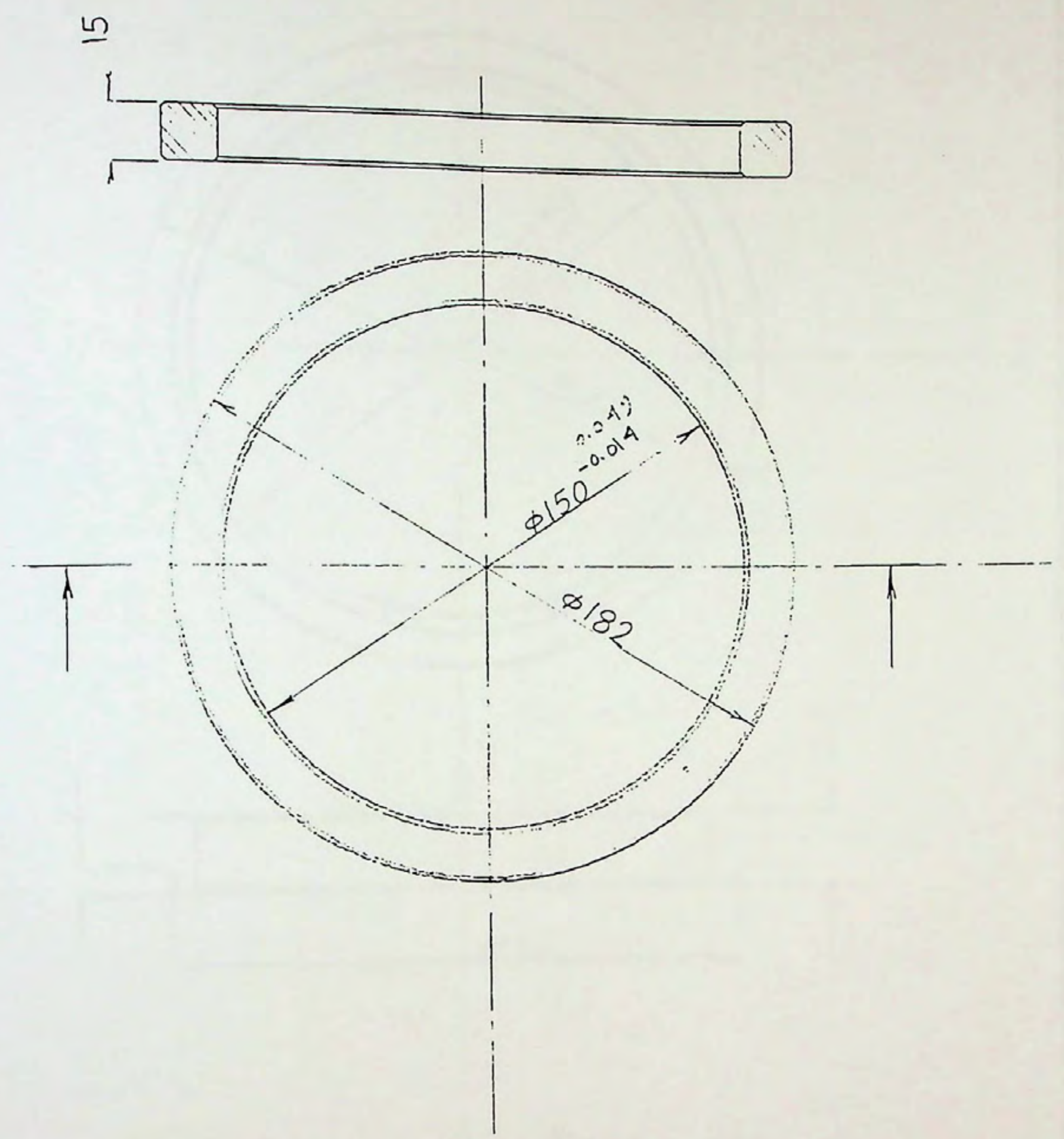


ALL CHAMFERS ARE 1/45°

Item No.	Part Name
9.1.a	Drum Body

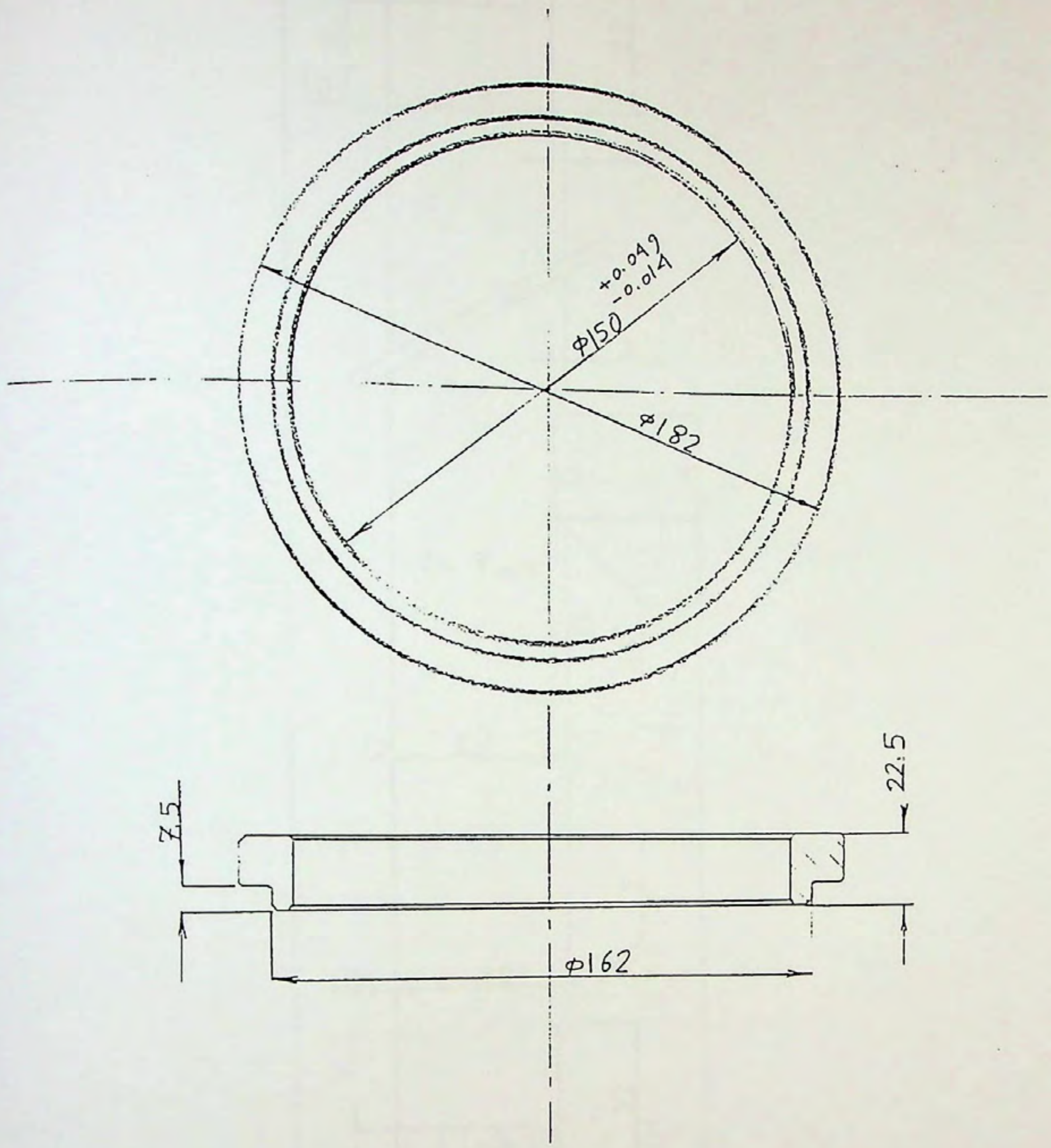


Item No.	Part Name
9.1.b	Drum Body



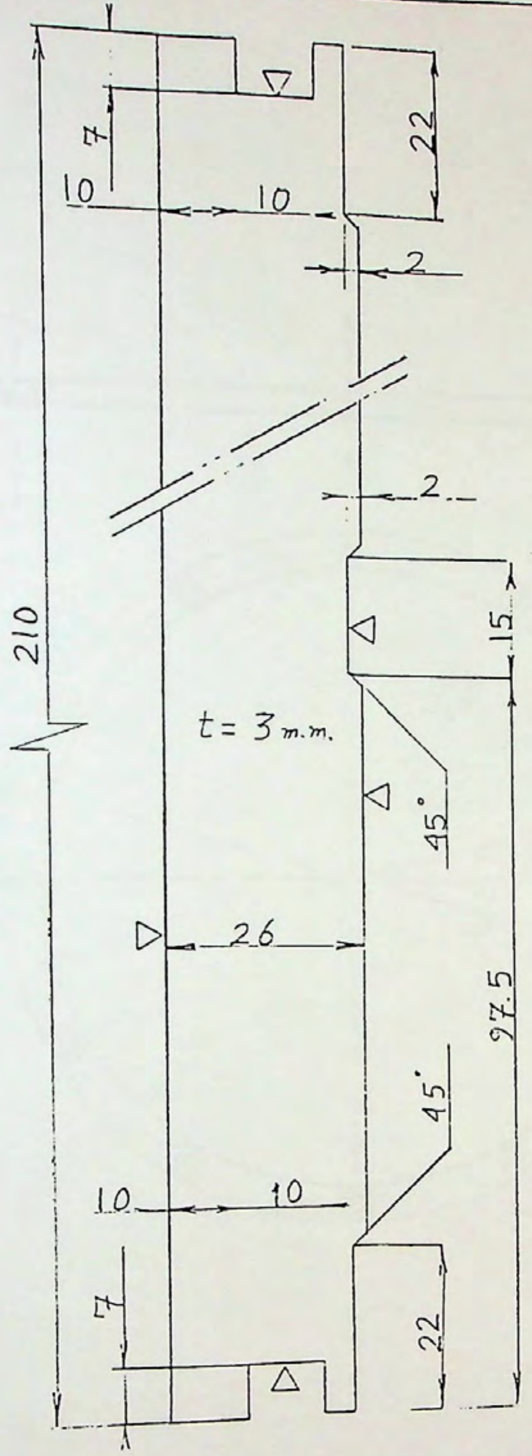
ALL CHAMFERS ARE 1/45°

Item No.	Part Name
9.2	Middle Blade Support

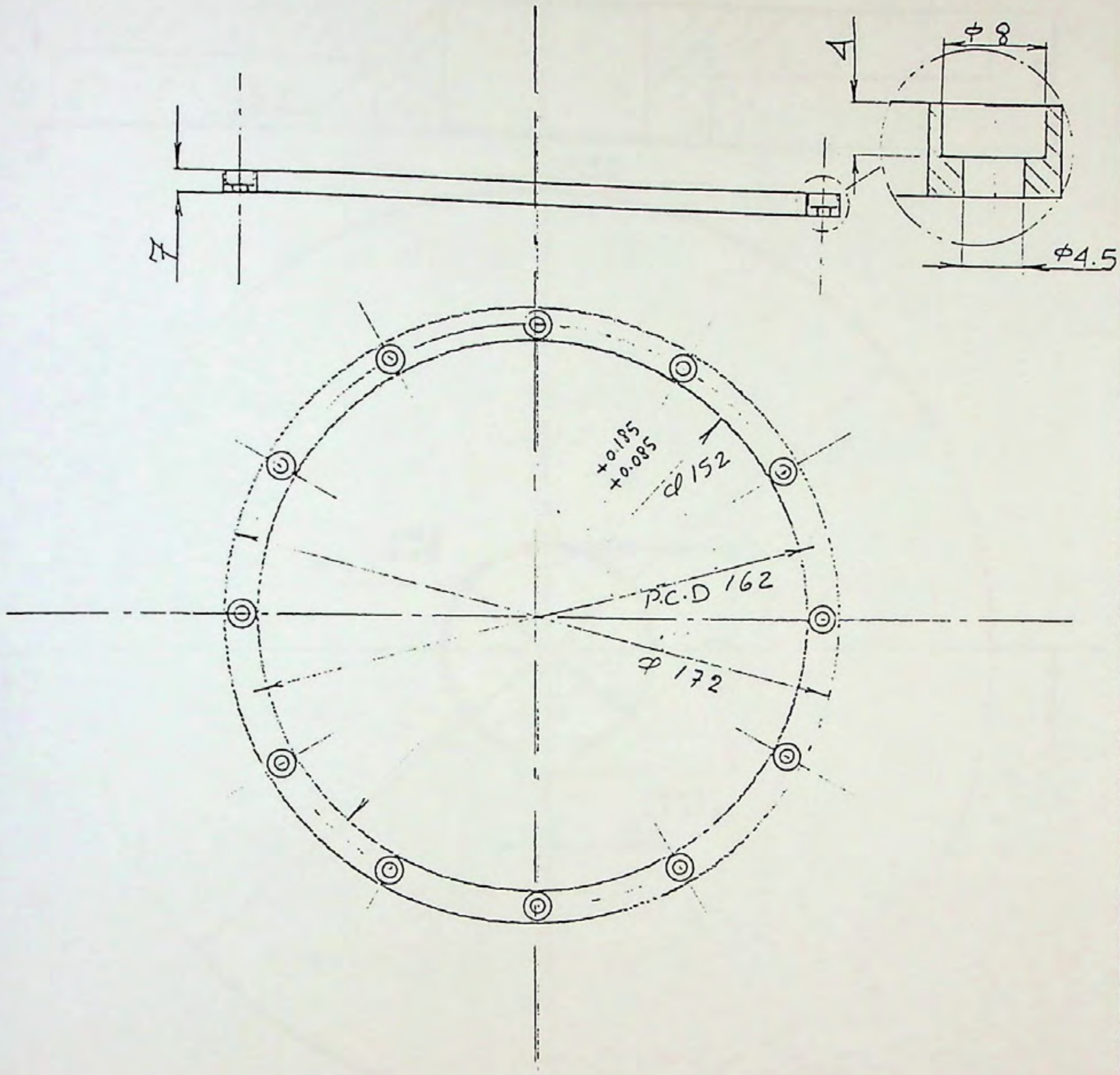


ALL CHAMFERS ARE 1/45°

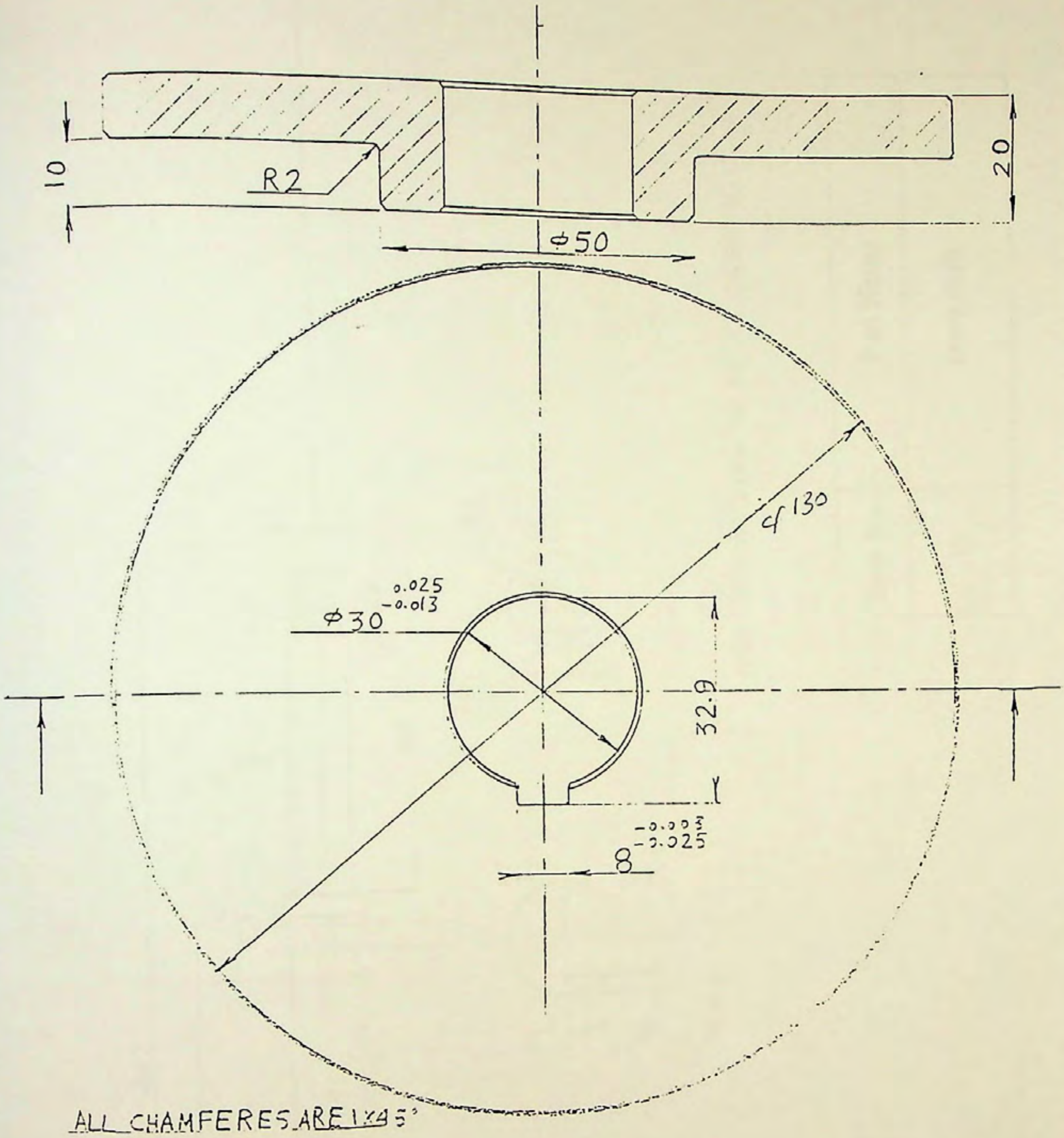
Item No.	Part Name
9.3	Blades End Support



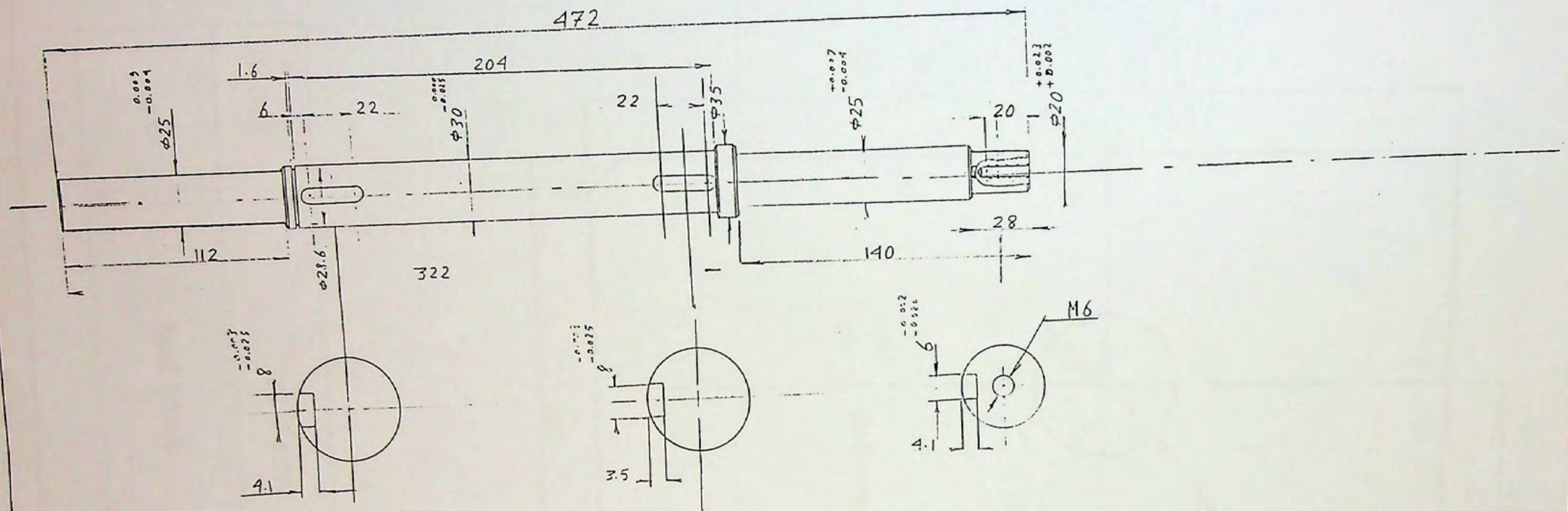
Item No.	Part Name
9.4	Blades



Item No.	Part Name
9.5	Blades Lock Plate

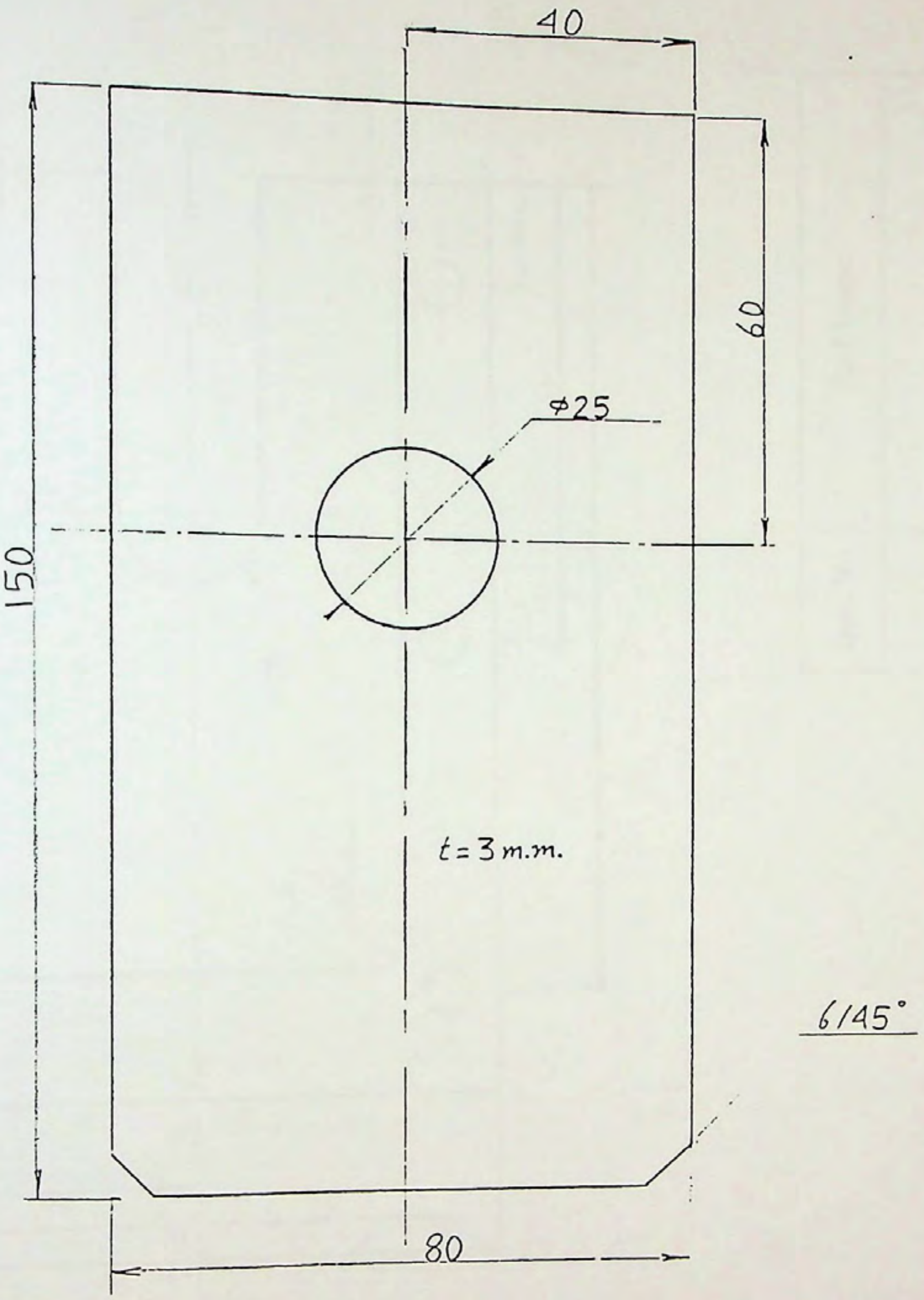


Item No.	Part Name
9.7	Drum Hubs

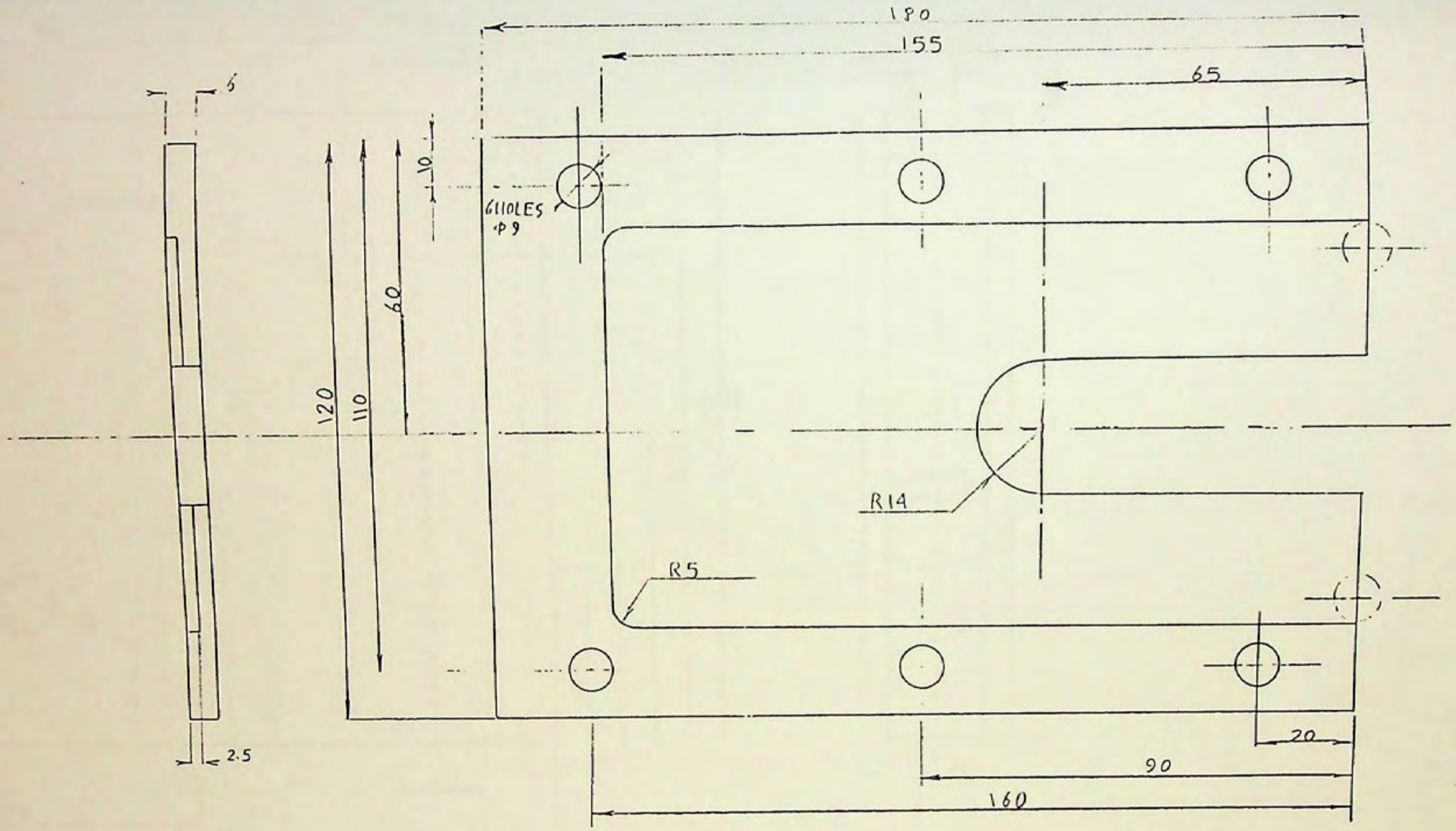


NON TOLERATED DIM. TO BE ACCORDING TO I.T. 10

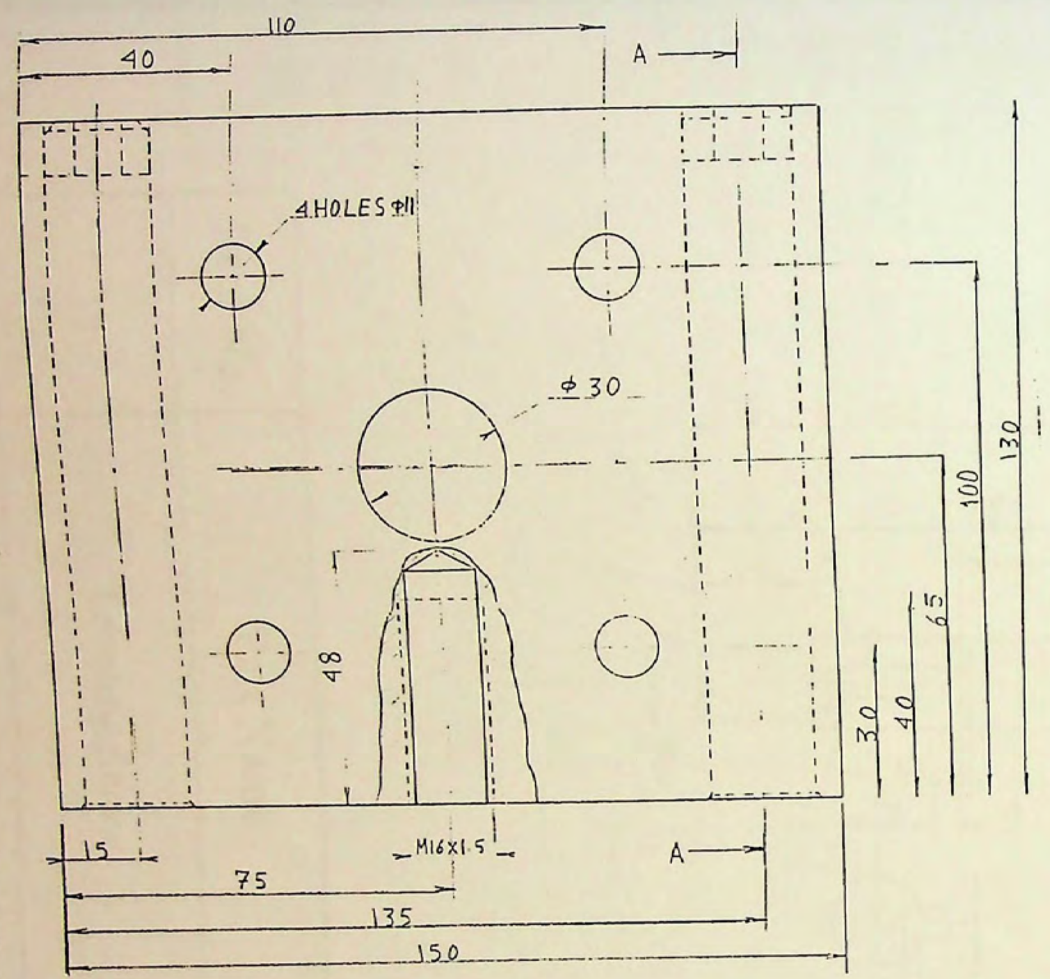
Item No.	Part Name
10	Drive Shaft

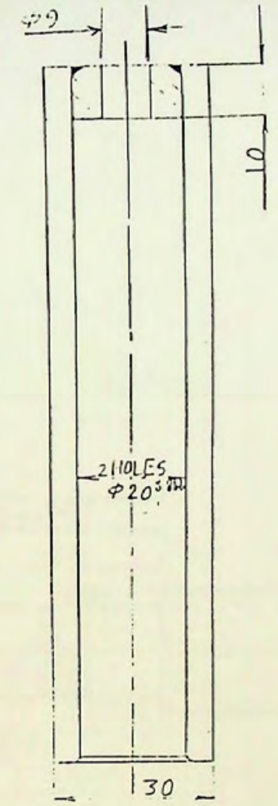


Item No.	Part Name
11	Seal Sheet

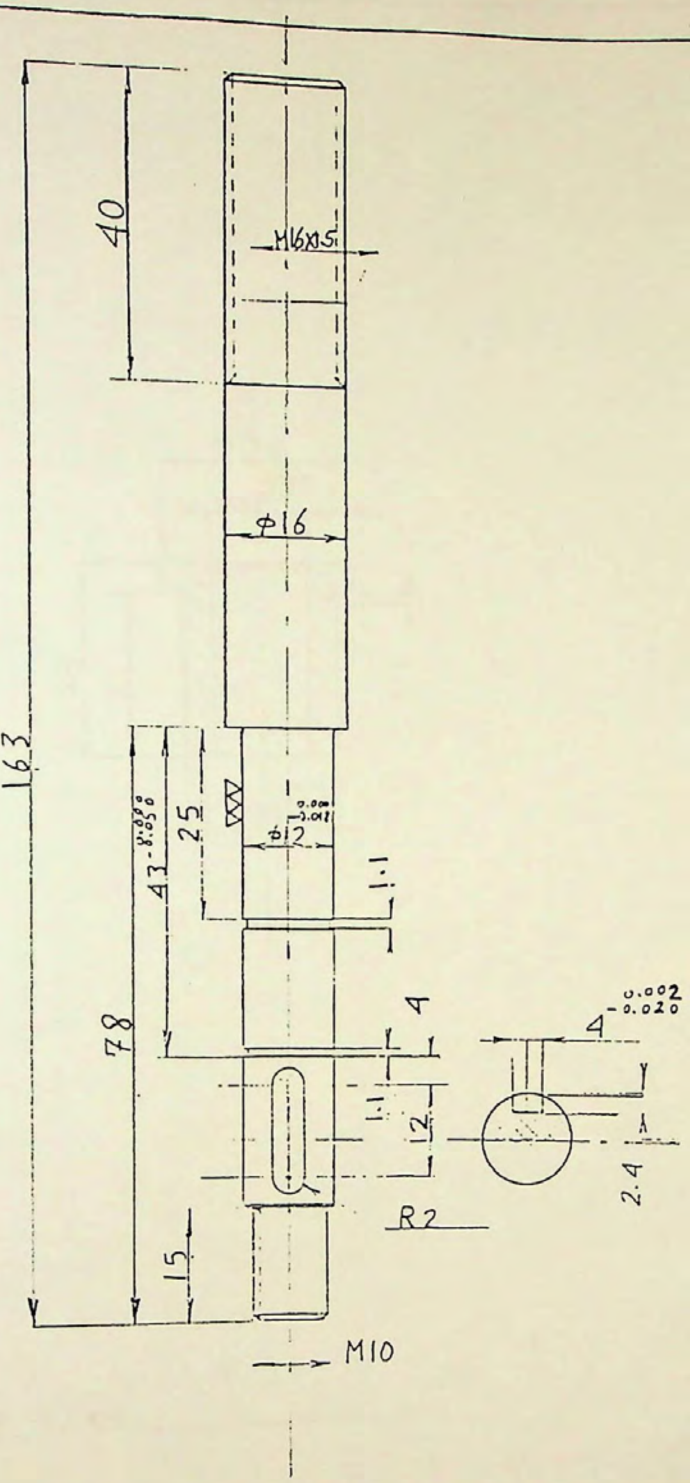


Item No.	Part Name
12	Seal Pressure Plate

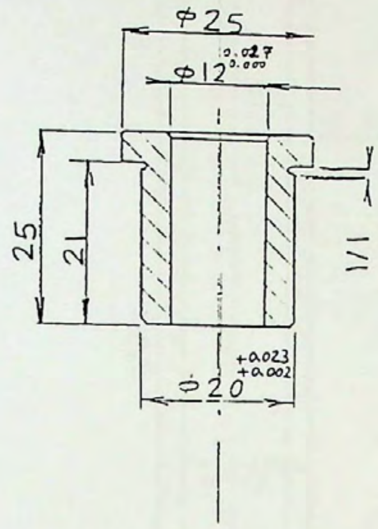




Item No.	Part Name
13	Bearing Block

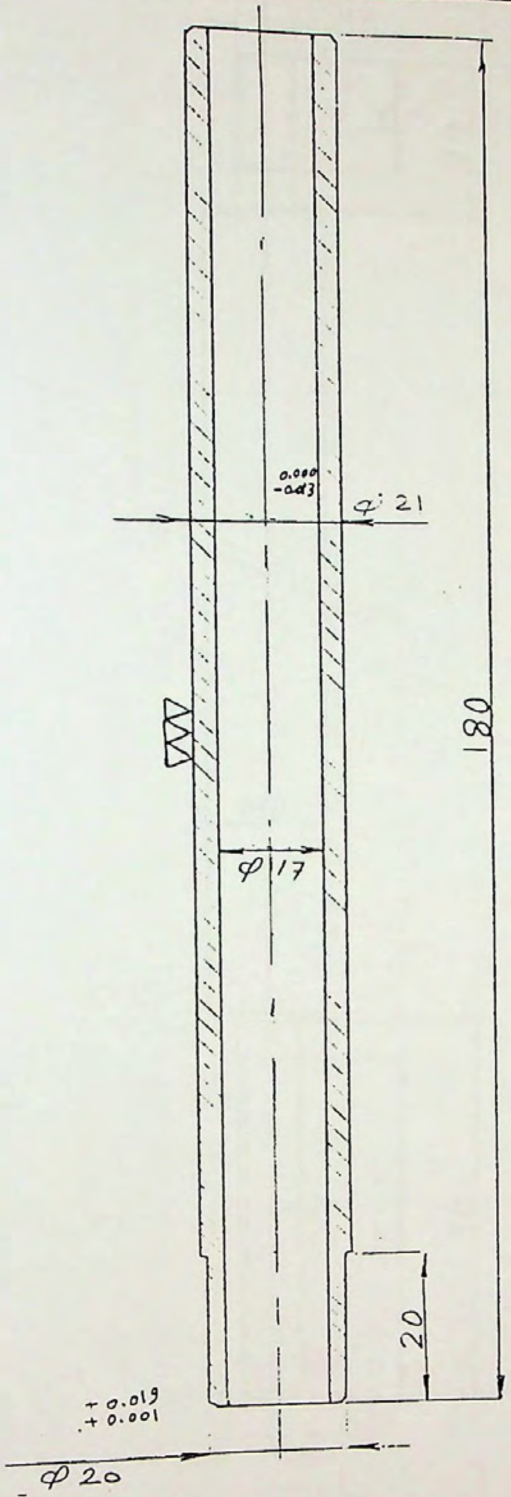


Item No.	Part Name
18	Leveling Screw

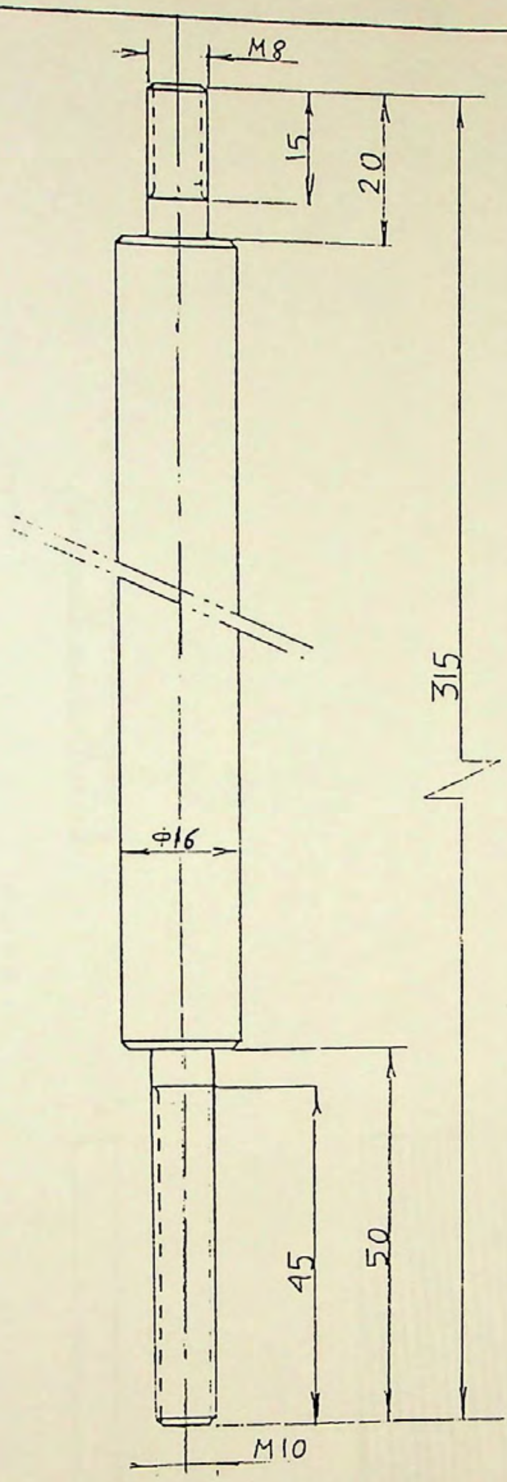


ALL CHAMFERS 1/45

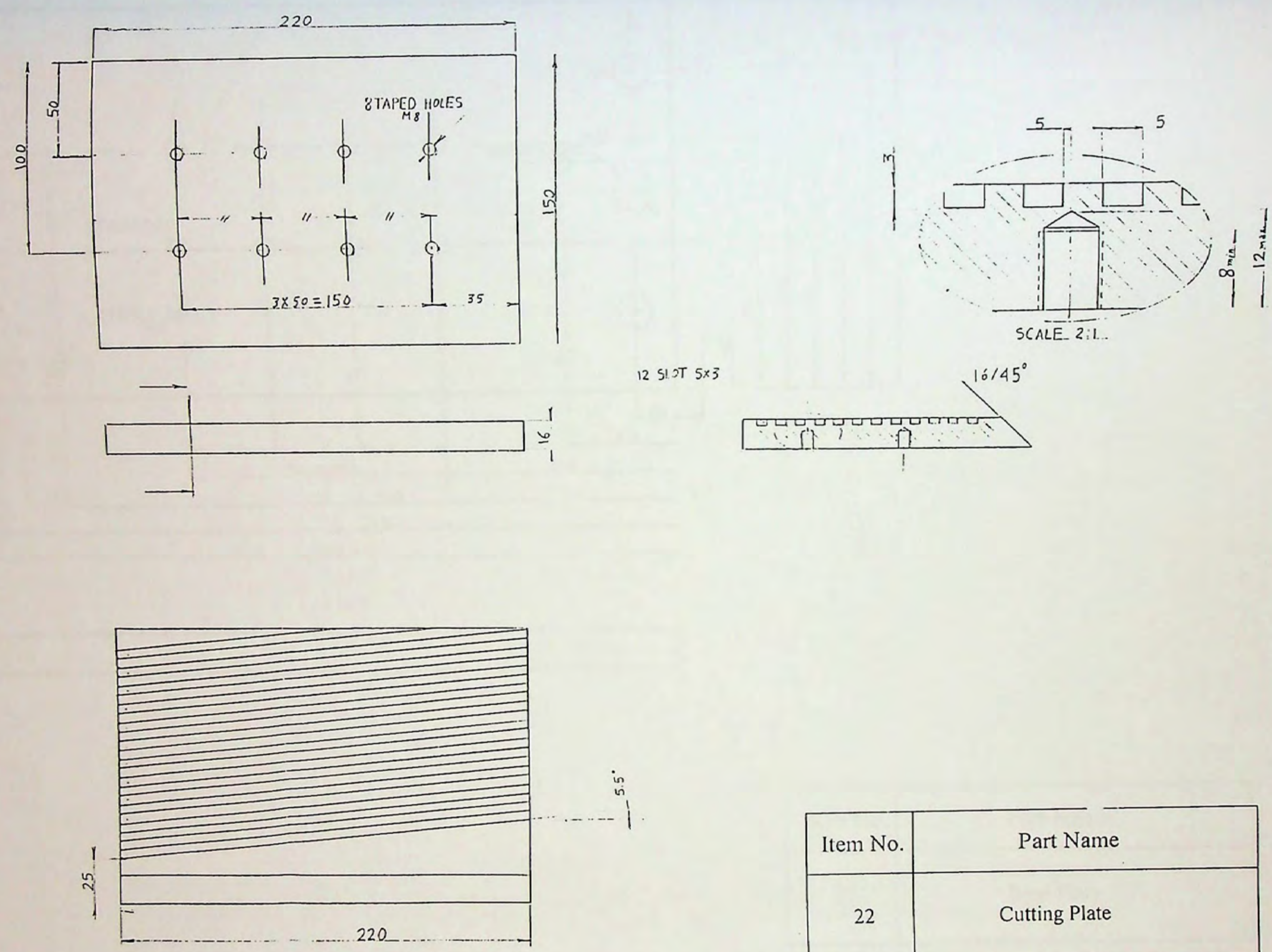
Item No.	Part Name
19	Screw Bush



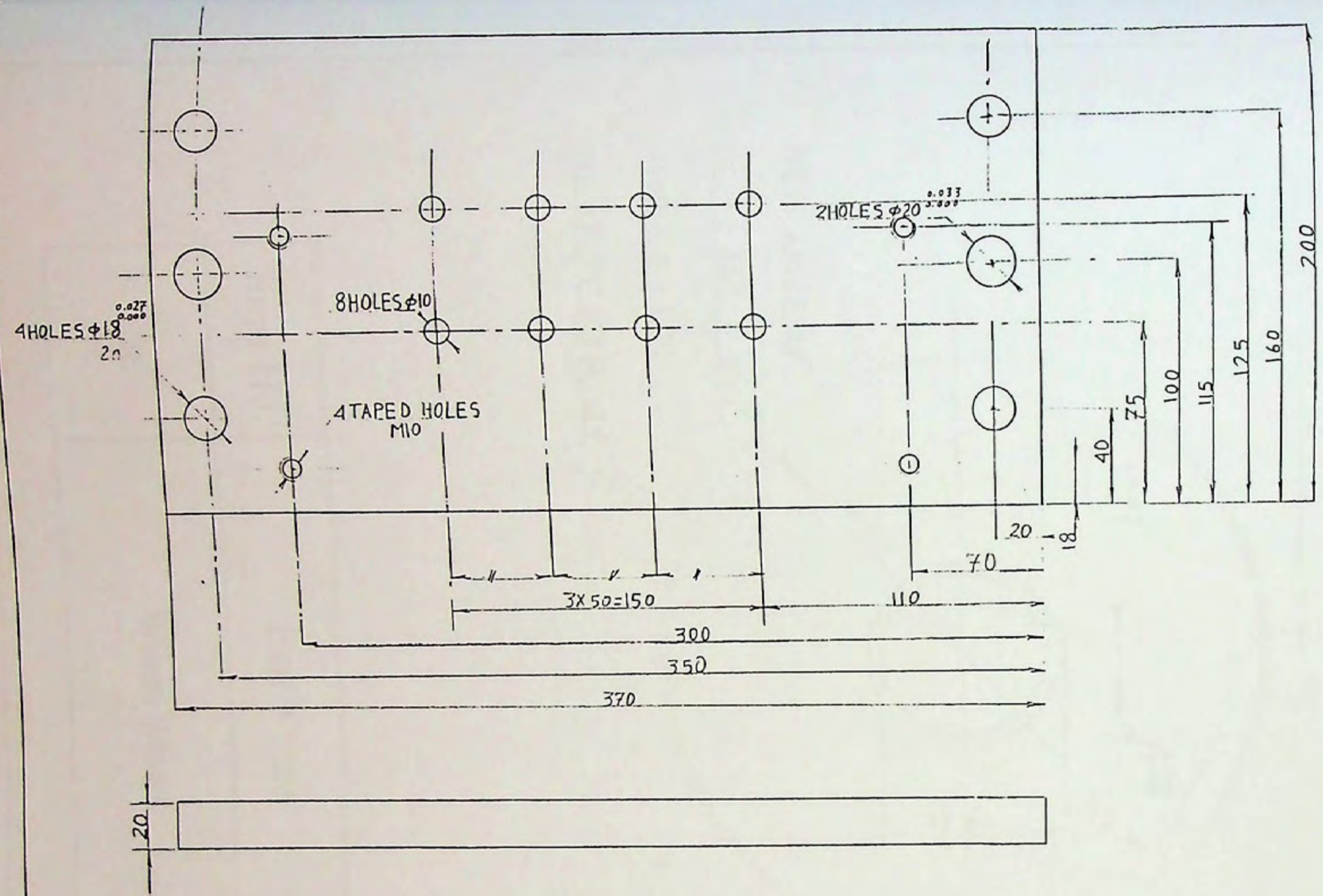
Item No.	Part Name
20	Guides



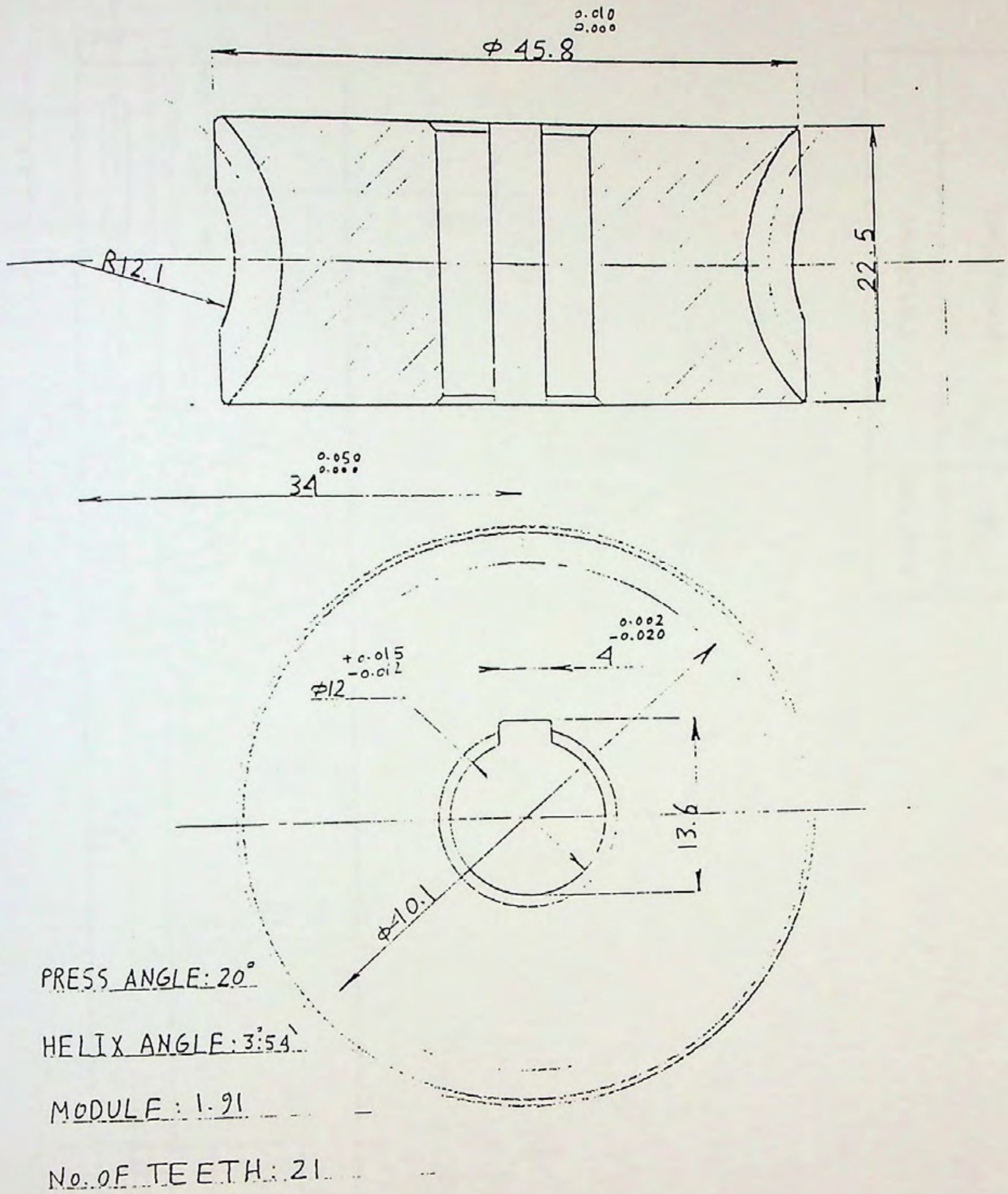
Item No.	Part Name
21	Motor Screw



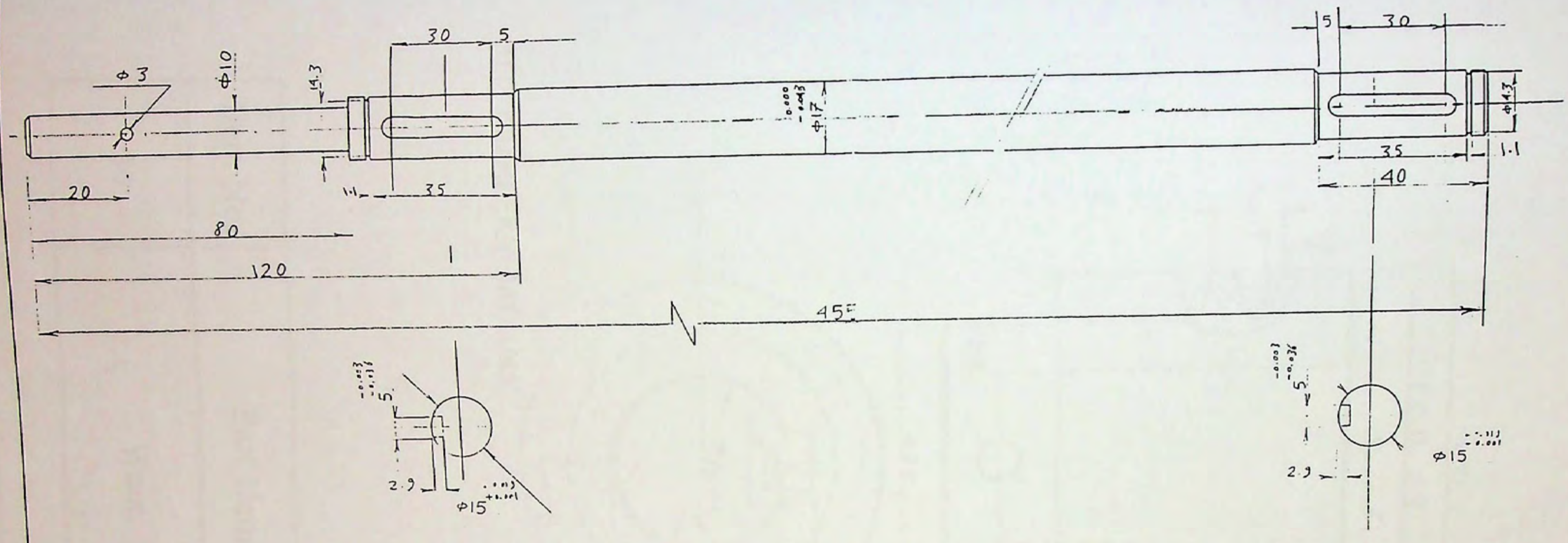
Item No.	Part Name
22	Cutting Plate



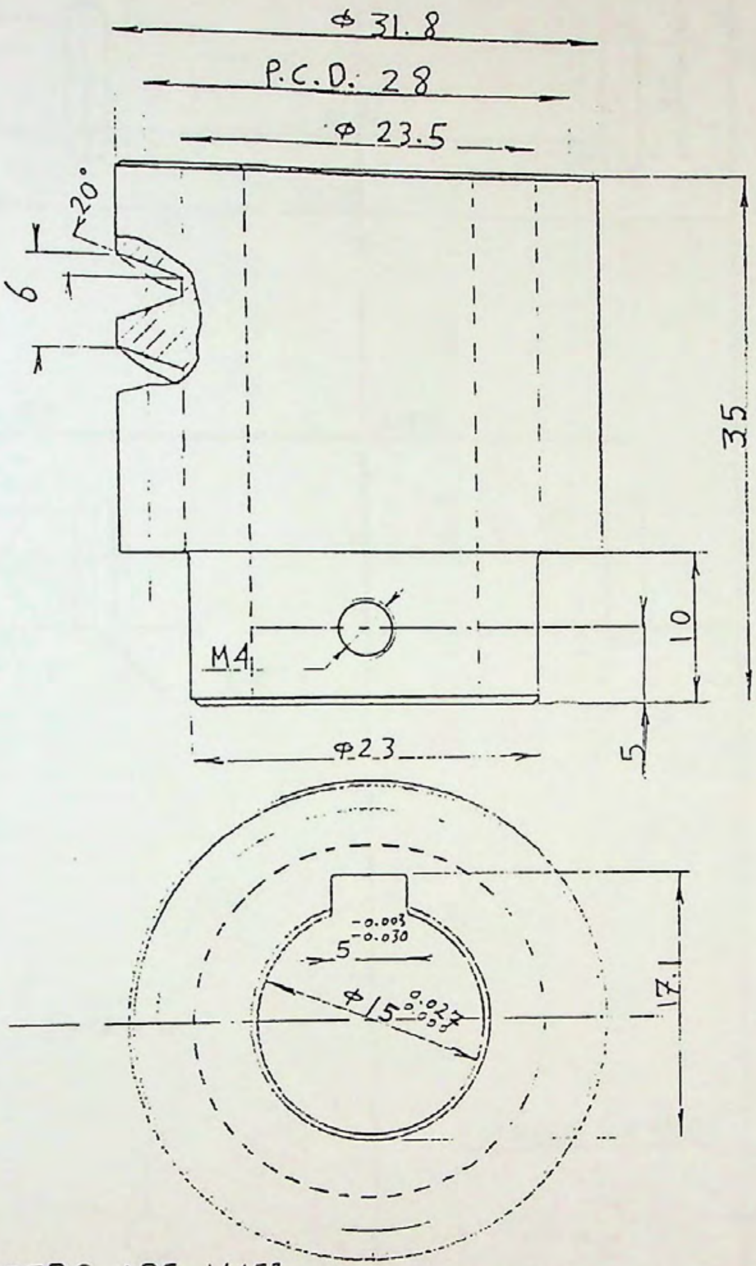
Item No.	Part Name
23	Base Plate



Item No.	Part Name
26	Worm Wheel



Item No.	Part Name
29	Leveling Shaft



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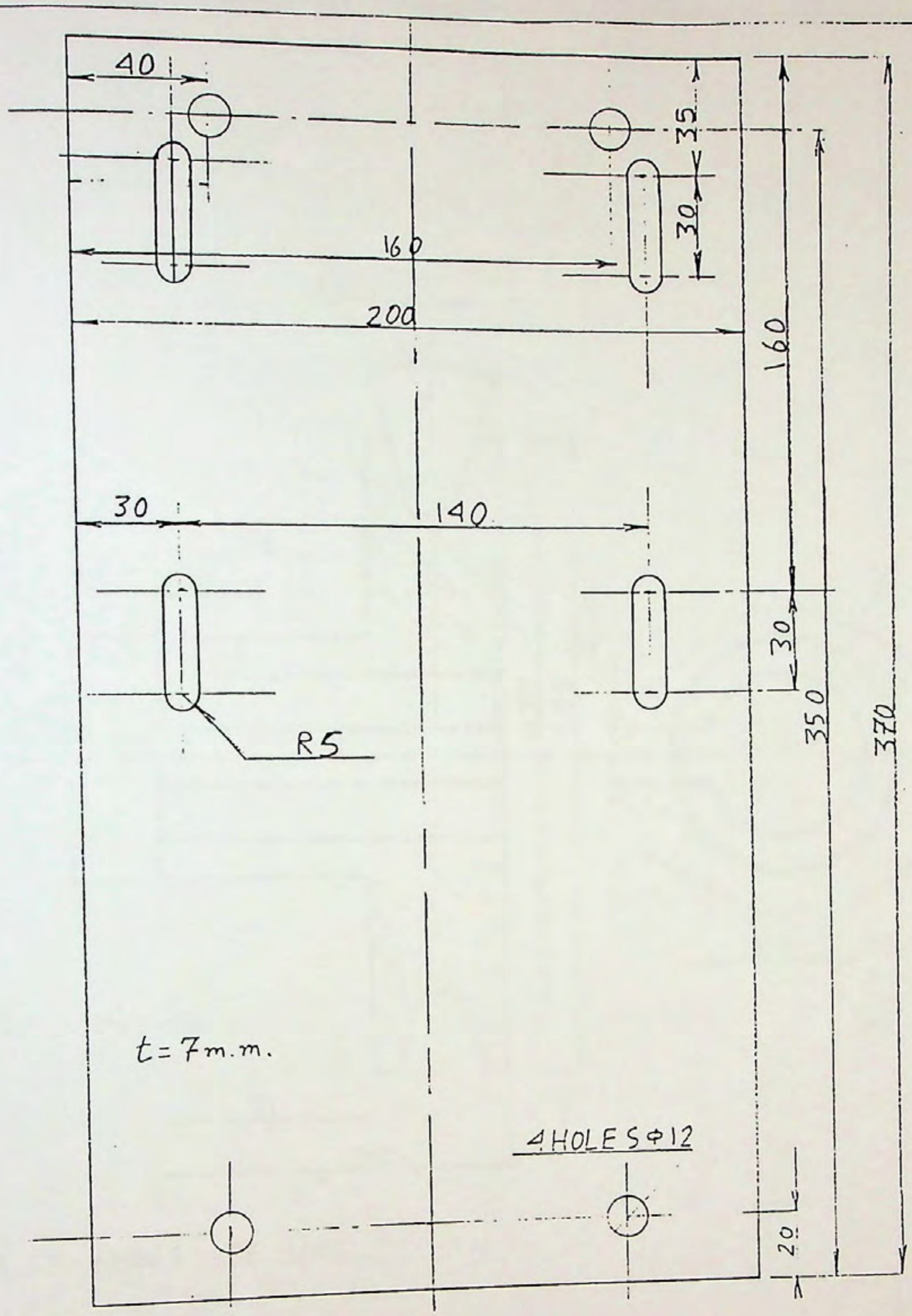
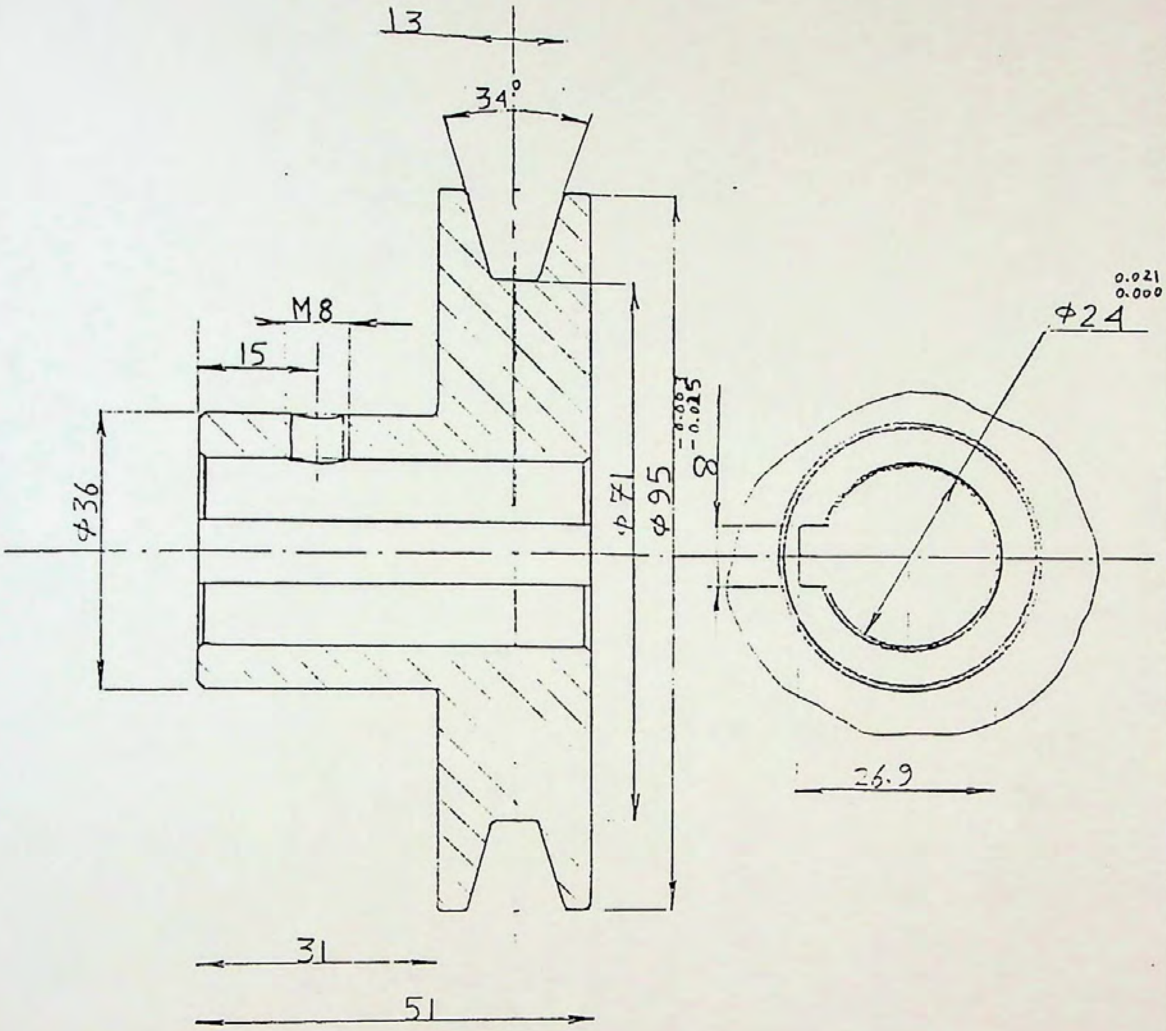
Item No.	Part Name
30	Worm



Item No.	Part Name
35	Motor Sub Plate



ALL CHAMFERS ARE 1/45°

Item No.	Part Name
37	Motor Pulley