CHAPTER 1

INTRODUCTION

1.1 Fibre morphology

Paper is manufactured from a pulp consisting of separated fibres, mainly wood fibres. The tree grows from the boundary layer between bark and wood, the "cambium layer". This consists of a thin layer of living cells, which divide and are thereby responsible for the growth of the tree. The cambium layer is protected by a thin bast layer, which in turn is protected by the bark. Old layers of bark are stretched out and break. The sap wood lies just inside the cambium layer, and serves to transport water and store nutrients. Towards the centre and bottom of the tree lies the oldest wood, called heartwood. Substances such as resins and tannins are enriched in the cells of the heartwood, which therefore has a darker colour. The heartwood is dead and stiff. In pines, the heartwood is preserved by the pinosylvin which is secreted. Rings, called the annual rings, can be seen in the cross section of the trunk, the inner, wider lighter part of an annual ring is formed in spring or early summer. During the next growing phase the darker and denser summerwood (late wood) is formed, which appear as a dark boundary around the springwood (earlywood). The width of the annual rings varies considerably, depending on the conditions available for growth. The more favourable the conditions, the wider apart the annual rings.

More than 90% of coniferous wood consists of tracheid cells. These are 3-5 mm. The length:width ratio often exceeds 100:1, which is the reason why they are so well suited for paper manufacture. The fibres are cylindrical and hollow spaces (lumen) in adjacent fibres communicate with one another by means of valved windows or pores. Water can be transported in a zig-zag manner through this inter-connected system of hollow spaces, from the root up into the tree.

The late wood fibres are smaller and have thicker walls than the early wood fibres. They grow more slowly. If a late wood fibre is dried, the cross section shrinks but it retains its form. If an early wood fibre is dried, it collapses. (Fig. 1).

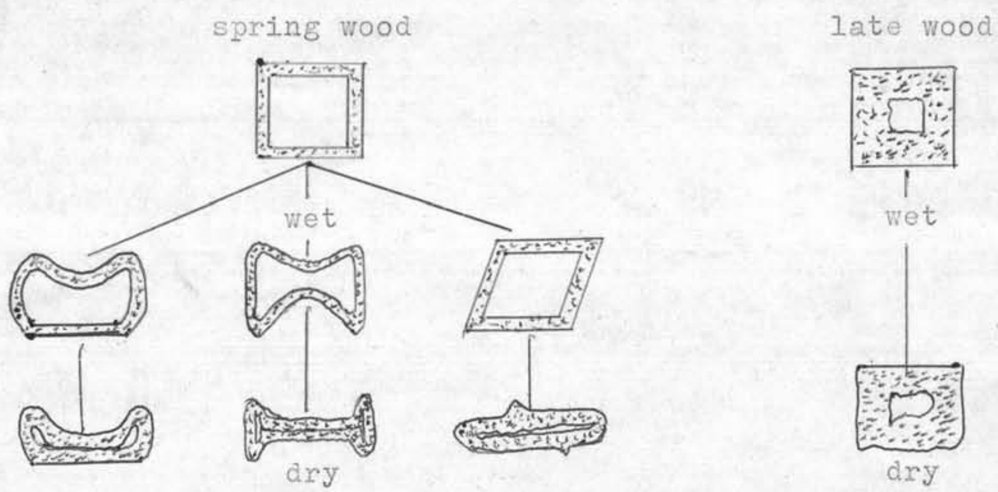

FIG. 1 Late wood and early wood fibres when dried.

The late wood fibres are harder and more bulky. They give, therefore, a porous sheet of low strength. Early wood fibres give denser and stronger sheets.

Broad-leaved woods (hardwoods) consist of librilform cells, vessels and pith ray cells. Librilform cells are 0.5-3 mm long with a mean length of c.a. 1mm. Like the tracheids they have a hollow centre (lumen). They account for 25-35 percent by volume of broad-leaved wood, but considerably more by weight. Broad-leaved wood contains about 50 % by volume of vessels, but only about 10 % by weight. These short cells with large hollow centres make up the building blocks for the vertical channels which transport water in broad-leaved trees. In this case, the water does not travel in a zig-zag manner as in the tracheids of coniferous woods. The pith ray cells account for 5-35 % by volume of broad-leaved woods.

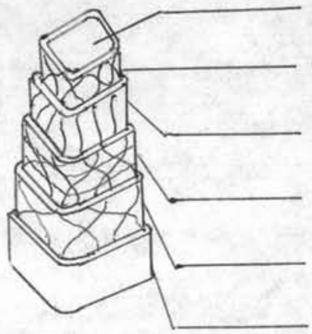

FIG. 2 The different layers of a cellulose fibre in schematic form

The structure of a tracheid fibre is shown schematically in fig. 2. The fibre is protected by a thin membrane, called the primary wall (P). Inside this, there is a so-called secondary wall which surrounds the lumen. It consists of a number of layers, numbered from the outside in as S_1, S_2, S_3. These layers are made up of spirals of fibrils, which lie at various angles to the length direction of the fibre. The fibrils consist of cellulose. The wood substance, or lignin, holds the fibres together in the wood. It is concentrated in the middle lamella, but also partially penetrate into the fibril layers. Lignin is made up of ring-shaped carbon compounds. D. Page and co-workers at the Pulp and Paper Research Institute of Canada have investigated the tensile strength of single cellulose fibres as a function of the fibrillar angle in the secondary wall S_2. All fibres had been produced by the sulphate method in a comparable manner. They found that the larger the fibrillar angle, the lower the tensile strength of the fibre, in other words, the more the fibrils are orientated along the axis of the fibre, the stonger the fibre. This is also what would be expected if the fibre is visualised as a tube which is reinforced by spiral-wound fibrils.

The investigation also showed that fibres with the same fibrillar angle in general had the same strength, irrespective of whether they were early wood fibres or late wood fibres and irrespective of the wood species. The fact that late wood usually has stronger fibres than does spring wood thus depends on the lower fibrillar angle in late wood fibres.

1.2 Types of pulp

Pulps used for manufacturing are classed as either mechanical pulps or chemical pulps. Mechanical pulps are those in which the fibres have been separated from the wood mainly by mechanical treatment, while in chemical pulps the fibres have been separated from the wood by chemical treatments.

1.2.1 Mechanical pulp

The basic principles of manufacturing mechanical pulp are simple, although the actual practice is quite complicated. It still remains an art rather than a science when compared with other methods of pulping. The basic operation consists of forcing by pressure a block of wood against a grind stone in the presence of water. The block is held against the abrasive surface of the revolving stone by such force that the wood is reduced to a fibrous condition while the water keeps the stone cool, cleans and lubricates its surface, and carries away the pulp.

Advantages of mechanical pulp.

1) Cost of production. In comparison with the chemical woodpulps, unbleached or bleached, and pulps from other vegetable sources, the most important advantage of mechanical pulps is their low cost. This is due chiefly to the fact that the yield of pulp is double that of mechanical woodpulps and to the lower cost of production achieved by the use of power instead of chemical and steam.

2) Use in printing papers. The use of groundwood of proper quality in the printing of paper has been found to improve printing results. In newsprint especially, it has long been known by experience and research that the printing quality of this important grade is improved in direct proportion to its content of groundwood.

When used in book papers and mixed with bleached woodpulps and a considerable amount of mineral filler, the groundwood must be of superior quality. Groundwood for this purpose is frequently given a bleaching treatment by the use of special chemicals in order to make the pulp whiter and brighter. The printing quality of these papers is excellent and vastly superior to the groundwood papers of the past.

3) Industrial papers. In other types of paper, such as toilet tissue, toweling, and many of the paperboard specialities, the chief and almost only advantage is in the lower cost of mechanical pulps in comparision with other pulps.

Limitations or disadvantages.

There are a number of disadvantages, the chief of which is the impermanence of paper containing groundwood. This lack of permanence is due to the reactivity of the noncellulose matter to oxygen of the air and other gases, besides being adversely affected in colour, strength, and durability by exposure to sunlight, heat, and air, also deteriorates more rapidly because chemical residues, such as sulphuric acid from papermakers'alum and sulphur dioxide when used in groundwood bleaching are harmful.

Besides the nature and induced lack of permanence, groundwood papers are characterized by low strength properties, low brightness and poor colour when compared with fully bleached chemical pulps. While the limitations of mechanical pulps can be removed in part by carefully selection of the wood and its preparation, as well as by better grinding techniques and bleaching methods, the drawback of impermanence is inherent in their chemical constitution.

1.2.2 <u>Chemical pulp</u>

1.2.2.1 <u>Sulphite pulp</u>

Outline of the sulphite process.

The sulphite process developed around the use of calcium for the formation of the sulphite mentioned in the Tilghman patent. Of all the alkali earths, calcium in the form of calcium carbonate (limestone) was the cheapest and most plentiful, and the sulphite process became, for the most part, synonymous with its use. To keep the calcium bisulphite in solution at elevated temperatures an excess of sulphur dioxide is necessary, and hence the pH of the cooking acid is low.

Sulphur dioxide in the acid is defined as follows:

Total SO_2. Determined by titration according to CPPA Standard J-1 or TAPPI Standard T-604 M-45 and expressed as percent total SO_2.

True free SO_2. The SO_2 present in excess of the amount required to form the bisulphite. This is equal to the total SO_2 minus twice the combined SO_2.

Mill free SO_2. The sum of the true free SO_2 plus one-half the SO_2 combined as bisulphite, determined by CPPA Standard J-1 or TAPPI Standard T-604 M-45 and expressed as percent free SO_2.

Mill combined SO_2. THe SO_2 combined with the base as monosulphite, determined by the difference between the total SO_2 and the free SO_2.

More recently strength and yield advantages of bisulphite pulps made with liquors containing little or no excess SO_2 have led to the increasing use of the more soluble bases such as magnesium, sodium, and ammonium. The pH of the resultant cooking liquor will vary according to the excess SO_2 present, and a variety of processes have resulted. To specify the type being used, a nomenclature based on the predominant ion concentration has been adopted generally. Over 50% HSO_3, the cooking liquor is called X bisulphite, where X is the cation used. The nomenclature and process definitions are given in table A.

TABLE A

Item	Nomenclature	Predominant chemical agent in cooking liquor	Approx. initial pH at 25°C
1	Acid sulphite	$H_2SO_3 + XHSO_3$	1-2
2	Bisulphite	$XHSO_3$	2-6
3	Neutral sulphite	$XSO_3 + XCO_3$ (XOH or none)	6-9+
4	Alkaline sulphite	XSO_3 + XOH (or Na_2S)	10+

Acid sulphite process. The process in which the cooking acid used contains a high percentage of free SO_2 (excess SO_2) and therefore has a starting pH as indicated above. The base is usually calcium but may also be a soluble base such as sodium, magnesium, or ammonium.

Bisulphite process. The process in which the cooking liquor used contains a predominance of bisulphite ion in the 2 to 6 pH range with little or no true free (excess) SO_2. The base must be more soluble than calcium, i.e., sodium, magnesium, or ammonium.

Neutral sulphite process. The process in which the cooking liquor used contains a predominance of sulphite ion in the 6 to 9 pH range. The neutral sulphite semichemical (NSSC) process is one in which wood, usually hardwood, is treated with a cooking liquor made up of a mixture of sodium sulphite and sodium carbonate or other alkali at pH 7 to 9 followed by mechanical fiberizing. Neutral systems are not in common use for a single-stage pulping because of the abnormally long cooking times or high temperatures that would be required to produce fully cooked chemical pulps. However, liquors of this composition are used as one stage in certain multistage systems and in certain single-stage chemimechanical pulping systems. Sodium or ammonium base may be used over the entire pH range; magnesium may be used only at the lower pH end because of solubility limitations.

Alkaline sulphite process. The process in which the cooking liquor used contains sulphite plus alkaline agents at a pH of 10 or higher. This process is likewise not in common use, except as it pertains to the multistage processes. The base used would be sodium.

1.2.2.2 Alkaline pulp or sulphate pulp

The term alkaline pulping includes all methods of pulp manufacture in which plant materials containing cellulose fibres are treated with aqueous alkaline solutions. These plant materials include the following:

1) Cotton or linen fibres or rags, which contain no lignin.
2) Fibres such as those of straw, bagasse, bamboo, and esparto grass, which contain between 11 and 20 % lignin.
3) Hardwoods, which contain between 16 and 24 % lignin.
4) Softwoods, which contain between 27 and 33 % lignin.

The sulphate, or kraft, process

In the kraft process a mixture of sodium sulphide and sodium hydroxide is used to pulp the wood. The sulphide accelerates the delignification; consequently, the chips are exposed to the hot alkali for a shorter time than in the soda process, and this makes it possible to produce a pulp of much greater strength than soda pulp. According to Strachan, experiments in England during the Napoleonic Wars (i.e., 1805-1814) established that the addition of sulphur and sulphides would accelerate the alkaline pulping of straw, but the first patents on the use of sulphides in the pulping of wood are those of Eaton in the United States in 1870 and 1871.

In spite of these, C.F. Dahl of Danzing Germany, is usually credited with the development of the kraft, or sulphate, process in 1879. He began to substitute sodium sulphate (salt cake) for the soda ash (sodium carbonate) used to replace the alkali lost in cooking straw. The results were at first unsatisfactory, however, and it was not until 1884 that Dahl obtained a patent. The process was soon applied to coniferous woods, and in 1885 the first kraft paper was produced at the Munkjö mill in Jönkoping, Sweden, apparently because, owing to an error, a digestor was blown before the chips were fully cooked. Instead of discarding the chips, the mill manager ordered them to be passed through a kollergang to make an inferior grade of paper. The resulting pulp made a paper which, though dark in colour, was far stronger than any paper hitherto known. It was given the name kraft, which is Swedish and also German for strength.

The sodium sulphate had, of course, been reduced to sodium sulphide in the recovery furnace. Sodium sulphate itself is incapable of pulping wood, yet the method came to be called the sulphate process because this salt has generally been used as a makeup to replace any chemical losses. The term sulphate pulp has also become standard, rather than the more distinctive kraft pulp, the latter term usually referring only to the strongest unbleached sulphate pulps.

1.3 Process of manufacturing household paper products in Thai Scott Paper Mill

The machine which is used in this paper mill is a Fourdrinier machine with machine size 2340mm. (fig. 3). The first operation of manufacturing household paper products, i.e. toilet tissue, facial tissue, paper napkins and etc., is that the pulps (long fibre, short fibre, mechanical pulp, etc.) have to be mixed with water in a pulper (1) until the pulps are disintegrated, which is called stock, at a definite consistency. Dyestuff and chemical are added at this point to produce tissue paper of required colour. The stock is pumped to be temporarily stored in the dump chest (4) in order to be subsequently pumped into the high density cleaner (2) to under go a thorough cleaning process. All dirts and foreign materials which are heavier than fibres will be extracted, clean stock will be passed into a deflaker (3) which will separate fibres from each other. All separated fibres will be pumped by the deflaker up to save all headbox (5). Part of stock will over-flow into a machine chest (10) to be ready for making paper. Other part will go into save-all (6) to catch small or short fibres which are in white water from couch pitch (18). The short fibres will be recovered at save-all and the clarified water will flow down from save-all into clarified water chest (7) and is pumped up to clean the fourdrinier wire (14) of paper machine or over flow out to the drainage. The recovered fibres will be scraped off the save-all couch roll and drop into the machine chest (10). The stock in the machine chest is pumped into a refiner (8) to be beaten to get a right freeness before it is passed into a consistency controller (11) where it is mixed with water according to a preset ratio. The stock after passing the consistency controller into a selectifier (12) for final cleaning. The above process is called stock preparation of paper manufacturing.

The clean stock with very low consistency will flow up from the selectifier into paper machine head box (13) where it forms a jet flowing through the lips of the head box with the same speed of the fourdrinier wire (14). The fibres will form as a wet paper sheet on the wire while water will be removed by gravity, deflector blades, foils, and vacuum. At the end of the wire part, the sheet will be kissed off by pick-up felt and is taken along to be pressed and vaccuumed to remove water before passing to touch yankee dryer (15) for drying. The sheet will be removed from dryer by means of doctor blade before being calendered and reeled, at this stage one-ply paper is obtained. If two-ply paper is required, two reels of paper must be rewound on the rewinder and slitted at the desired width before send-

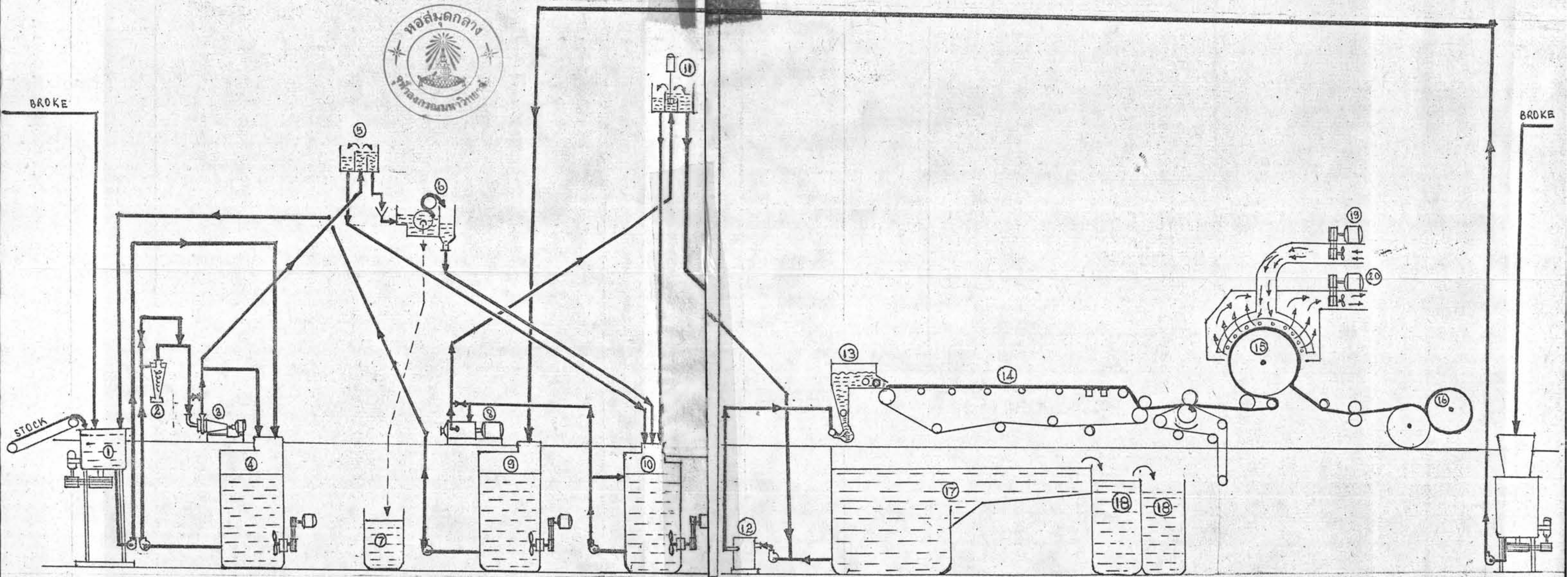

FIG. 3 FOURDRINIER PAPER MACHINE.

(1) PULPER
(2) HIGH DENSITY CLEANER
(3) DEFLAKER
(4) PAPER DUMP CHEST
(5) SAVE ALL HEAD BOX
(6) SAVE ALL
(7) CLALIFIED WATER CHEST
(8) REFINER
(9) BROKE CHEST
(10) MACHINE CHEST
(11) CONSISTENCY CONTROLLER
(12) SELECTIFIER SCREEN
(13) HEAD BOX
(14) FOURDRINIER WIRE
(15) YANKEE DRYER
(16) REEL
(17) WIRE PIT
(18) COUCH PIT
(19) SUPPLY FAN
(20) EXHAUST FAN

ing to convertor plant for final finishing.

At the Thai Scott Paper Mill, four kinds of household paper products (each kind of them are produced by different furnishes) are manufactured namely: toilet tissue, facial tissue, napkins, cellulose wadding. In manufacturing these tissue papers the manufacturer encounters a problem, especially on napkins. The problem is that the ratio of machine direction tensile strength to cross direction tensile strength is too high which causes the tissue paper to be torn easily on one side. The present investigation attemps to establish the factors which govern the ratio and subsequently attemp is made to lower the ratio without drastic reduction of the tensile strengths. As the ratio is lower, the quality of the tissue paper is improved, and the tissue paper can be made almost equally strong on both directions. The ratio of tensile strengths of the tissue paper may be lower by changing the orientation of the fibres (chapter 2, 2.2 Page's theory), by reducing the weak zones in the cross direction (chapter 2, 2.3 Statistical distribution of paper properties), and by changing the quality of furnish. Therefore, four factors are believed to have strong influence upon the ratio, namely:

(1) The relative velocity between jet of stock at the slices and the fourdrinier wire (or between head box level and theoretical head). As the stock leaves the slices onto the wire, most of fibres are orientated in the machine direction which cause the machine direction tensile strength to be much higher than cross direction tensile strength, consequently the ratio is high. If the fibres are orien-

tated more in the cross direction the ratio will be reduced. This may be achieved by changing the jet velocity of stock while wire velocity is set constant.

(2) Freeness (Canadian Standard Freeness) of stock in the head box. As the pressure between two discs of the refiner is increased the freeness is lower. The fibres in the refiner are beaten and fibrillated which increase surface and flexibility of the fibres, a greater degree of bonding takes place when the sheet is dried. The fibrillation along the side of the fibres are more than the width and the fibres are usually orientated in the machine direction, this may cause the paper to have less porosity in the cross machine direction and increases the tensile strength in the cross direction more than in the machine direction.

(3) Consistency of stock in the head box. Stock containing large chumps of the fibres can not produce paper with good and even formation due to poorly deflocculated stock suspension in the head box at high consistency. For uneven formation there are many weak points along the cross machine direction of the paper, when the paper is tested for the cross machine direction tensile strength the value of tensile strength is from the weakest piont. As the consistency of stock in the head box is lower the paper is more even formation, less weak points across the machine direction of the paper with higher cross machine direction tensile strength.

(4) Mixture ratio. The mixture ratio of the long and short fibres influences tensile strengths of the paper in both directions,

so it is expected that it also influences the ratio of the tensile strengths.