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PRACTICAL EXPERIENCES IN THE USE OF MIXED TROPICAL HARDWOODS FOR THE PRODUCTION OF PULP AND PAPER 1/

by

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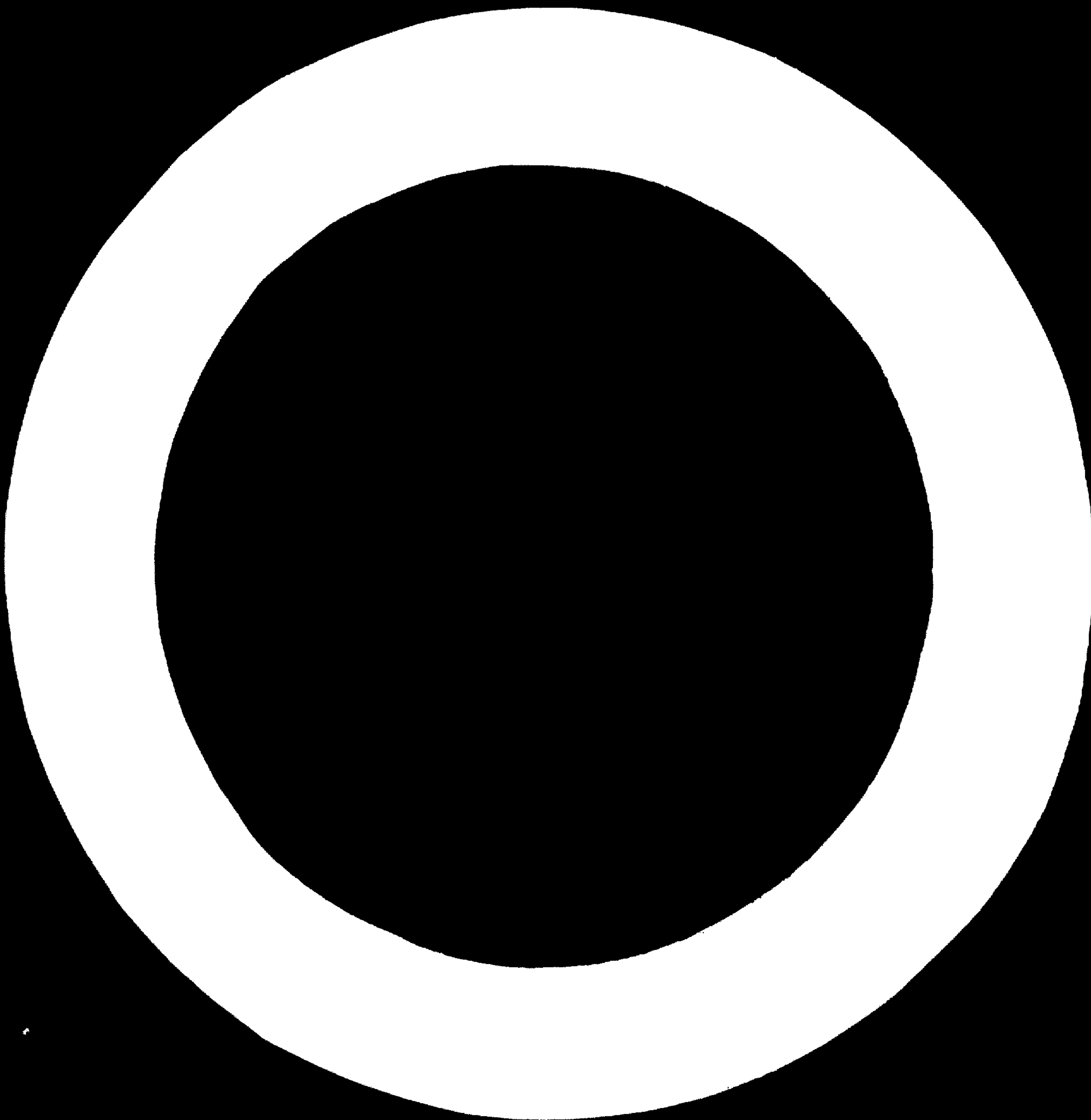

Introductory Background

The production of pulp and paper from the tropical hardwood forests of the world presents a tremendous challenge. This arises for three main reasons. Firstly these forests cover a considerable area of the earth and are available in large quantities; secondly, they occur in parts of the world where there is often no alternative source of raw material for the manufacture of pulp and, from it, of paper. Thirdly, and perhaps most important of all, these woods do not lend themselves readily to the normal pulping processes used for making good grade pulps (and especially bleached pulps) for use in paper manufacture.

The past 50 years has already seen a phenomenal increase in the consumption of paper and paper products throughout the world. This is bound to continue in the future 30 years of this century, and the rate of increase will obviously be very much greater in those countries whose paper consumption per head of population is at present relatively low. If one takes the United States having the highest per capita consumption of paper of all nations, namely 230 kilogrammes per annum and compares this with some of the smaller developing countries whose paper consumption is only a few kilogrammes per head per annum, it will be appreciated that the magnitude of the gap can involve serious drains on the fibrous raw materials now available. Added to this is the fact that the high per capita consumption of the United States may well increase further, although this is by no means certain. If however it does so, not only does the present gap between the smallest and the largest consumer have to be filled, but the top limit can become even higher.

It must be admitted that hitherto the increase in the consumption of paper and paper products, great as it has been during the past few decades, has not been greatly hindered by lack of availability of fibrous raw materials. The problems rather have been those of production (i.e. mill capacity) and of price and distribution. The reason for this is that, up to the present at any rate, the world resources of conventional paper making tree forests, and in particular the coniferous woods, have proved adequate for the world's requirements. In addition the increasing use of the hardwoods from the temperate zones has supplemented the supplies of coniferous woods, and indeed has even created a specific demand which did not exist before. This latter is based on the intrinsic qualities of the hardwood pulps, modern methods of pulping, and the utilisation of pulps which enable these qualities and methods to be used to the best advantage.

This tendency will no doubt continue in the future, but the time will come when existing supplies of hardwood pulps will also be exhausted or depleted. In view of their relatively long growth rate in the temperate zones, and especially in the northern parts of these zones, the question of replacement will become a problem. Some of the species are relatively fast-growing; eucalyptus is an example. These species no doubt will replace many of the conventional hardwoods at present being used for pulp. The work carried out in Australia in particular on the utilisation of eucalyptus, has played an important part in this connection.

In the past the majority of papers were made of coniferous wood with a small proportion of hardwood pulp but the tendency now is for the reverse to apply, namely the use of as much hardwood as possible with the minimum amount of coniferous softwood consistent with obtaining paper of the right quality. However, there is a limit to which this tendency can be forced, because the coniferous pulps are more versatile than the hardwood pulps. This may be summarised briefly, if inadequately, by the dictum that one can make long fibres into short fibres, but one has to adopt devious methods to obtain the effect of a long-fibred pulp from short fibre material; additives to the paper are one example, but they do not produce the same all-round effect.

These introductory remarks are desirable in order to place the position as regards the tropical hardwoods in its correct perspective. If the tropical hardwoods could be used to produce pulps of the same quality, price and general characteristics as those produced from the temperate hardwoods, then the future of raw material supplies for the paper industry would appear to be assured for a long period, because the amount of tropical hardwoods available is so very vast.

Unfortunately up to now this has not proved to be the case. Tropical hardwoods have often proved intractable to the normal pulping processes and moreover, they have certain inherent disadvantages as compared with the conifers and temperate hardwoods, many of which are referred to below. At present they can be described as no more than a possible but unattractive raw material for the manufacture of ordinary pulp and paper. If to this is added the facts that they are located very often in inaccessible areas of the world from the point of view of the main markets of paper pulp; that they are as a rule difficult to harvest and handle; and most important of all that they are very mixed in character, then it will be appreciated that all these factors tend to make them unpopular in the sense that they will only be used as a last resort or when it is possible to make pulp from them at an extremely low price.

An interesting feature of the tendencies recorded above is the increasing use of local raw materials for the manufacture of paper pulp in countries in which there is a developing industry of this nature. This is quite understandable in countries which have supplies of local woods already known to be suitable, examples being coniferous woods in South Africa. It also applies to non-woody materials such as bamboo in India, and to eucalyptus in numerous parts of the world and in particular Australia.

It should however, be noted that in the majority of cases the product is pulp for manufacture into paper in the countries which make it, and not pulp for export. One exception of this nature is esparto grass in North Africa, which is made into pulp for export purposes. Bagasse derived from sugar cane is another outstanding example, since it is in use in a wide variety of areas throughout the world where sugar cane plantations exist. . A pulp industry based on tropical hardwoods is likely to be in an analogous position to these non-woody fibres in countries which do not have adequate supplies of coniferous trees. On the other hand, a country which has both hardwoods and one or other of these alternatives to coniferous woods is more likely to choose the latter, because existing methods have shown that a better pulp is obtainable, and generally speaking, the capital cost of the plant to produce the pulp is lower.

It will be seen from the above general remarks that the use of tropical hardwoods for the conventional types of paper and board suffers from some important inherent disadvantages. The purpose of this Paper is to examine these and to endeavour to indicate to what extent, if at all, they can be overcome in the light of practical experience to date. The trees dealt with are those which are exclusive to the tropical areas, and it is estimated that these comprise some 50% of the forest areas of the world; the magnitude and importance of the problem may, therefore, be gauged from this fact.

The subject is treated under the following main headings:-

A. Characteristics of tropical hardwood forests.
B. Location of the forests.
C. Uniformity of the species.
D. General properties of the woods.
E. Species survey.
F. Pulping methods.
G. Investigational approach.
H. Uses for tropical hardwood pulps.
I. Examples.
J. Conclusions.

A. Characteristics of Tropical Hardwood Forests

It is reasonably fair to state that the only feature which all tropical hardwoods have in common is their lack of common features! They vary tremendously in type, location and species, and such variation is the basic cause of many of the problems involved. Some possible methods of overcoming them are dealt with below. Some of the various factors which go to make up this lack of common growing pattern are indicated in the following paragraphs.

B. Location of the Forests

From their very nature these forests are in tropical areas and these are very often difficult and indeed, inaccessible areas from a geographical point of view. Moreover they are often unhealthy areas, although under modern operating conditions this is a factor which can be largely eliminated from a health point of view. It nevertheless counts from an amenity point of view, especially from that of those who have to work under the conditions concerned.

Probably the mangrove illustrates this point as well as any species. There is a wide variety of species of mangroves offering abundant material for paper pulp, although none has ever been used successfully as such. Probably they could be if they were not located in such difficult terrain, because, as is well known, most of the true mangroves grow in swampy areas where harvesting is difficult - quite apart from the ultimate pulping process. The importance of accessibility is a point which is appreciated only with difficulty by those accustomed to the conventional forests and agricultural residues used for pulp manufacture.

The writer made a study in the upper reaches of the Amazon some hundred miles upstream from Manaus, where there were vast areas of magnificent virgin forests which were completely unexploited. The only means of access was by launch, followed by the use of canoe through the smaller side streams of the main river. Obviously the exploitation of these resources would require a considerable road building programme before the trees could even be brought to the riverside. From there they would have to be transported on fairly large vessels; and even then there would be the minor problem of the vessels returning empty upstream against a strong current for further supplies. It is extremely unlikely that, under these conditions, such forests could be of economical value for the manufacture of paper pulp, quite apart from the question whether the trees themselves are really suitable for that purpose. In this particular instance it was found that a lumber industry was likely to prove more promising but even then the preliminary steps to be taken to solve the transport problem involved a considerable initial capital cost. A rather similar position existed in another study made by the writer in the lower Congo area. However, there is little doubt that in the course of time these isolated areas of the world will be opened up by roads, railways or water communication, and the usage potential of the tropical forests will thereby be greatly increased.

Certain inherent disadvantages will however, remain. Tropical forests imply rain, indeed heavy rain, and operating under such climatic conditions is always difficult, although not impossible with modern developments in machinery and road making. However, it must always cost more to work under wet conditions than under dry conditions, and to this extent the disadvantage remains. An excellent case in point was seen in a study made in the Benin area on the south coast of Nigeria where logging operations under wet weather conditions are carried out on a major scale. This, however, refers principally to sawn timber wood, where the problems are rather different, and perhaps rather less exacting since whole trees have to be handled.

Tropical forests differ from a conventional coniferous forest in other important respects. With the latter the trees are usually cut during the winter period and floated down the rivers at the time of the thaw. This is a very convenient method of solving the handling problem. In many tropical areas the rivers are either inadequate, or they flood, and in any case they fluctuate very rapidly in width, depth and speed. Most important of all, many of the tropical hardwoods will not float, and so this very convenient method of transport is eliminated in areas where there are no proper roads.

C. Uniformity of Species

Apart from the question of physical characteristics, the most important single feature of tropical hardwood forests is their heterogeneity. This means that a small forest or a small area of such trees can contain numerous species having widely different pulpwood characteristics. It is not unknown for some 5,000 different species to be identified in comparatively small areas, and of these as many as 150 can rank as principal species, ie., species that deserve consideration from a pulping point of view and because of their frequency of occurrence. At the other extreme it is possible to find areas where 15 major species, or even less, will comprise 80% of the total tree population in terms of number.

It should be understood that the pulping characteristics of trees of different species can vary considerably, although it is not outside the bounds of possibility to evolve a process which will be satisfactory for them all in the sense that it will reduce the pulp to a common denominator. However, each tree can give rise to individual problems such as those of resinous matters, tannins, high silica content, and so on, so that the problem of obtaining a uniform tree mixture by clear cutting is by no means easy to solve, and in many cases it is even impossible.

In addition to this, trees in these forests vary tremendously according to their size, shape and volume. Tall trees of narrow girth and short trees of wide girth can grow together, and the proportions of one or other or intermediate grades can alter considerably from place to place in the same forest. It is indeed astonishing how selective the tree population is in taking advantage of a particular set of favourable growing conditions supplied by Nature - purely by accident in many cases.

Problems arising from lack of uniformity are much more accentuated in secondary forests as compared with virgin forests, as might be expected. In the virgin tropical forests the competition for air, light and soil nutrients has reached an equilibrium, but in secondary forests more species foreign to the original tree population have managed to establish themselves and the struggle for survival is much more acute. This means that there are fewer trees of the virgin type and a large number of species which are naturally stunted, or which by reason of their struggle for existence have not been able to maintain the uniform method of growth that one associates with virgin forests and which is favoured by the forest user, as well as by the pulp manufacturer. Secondary forests also contain, of course, a much larger proportion of trees which are unsuitable for pulping by virtue of their physical condition. In some respects this can be an advantage, since their separate removal gives more room for manoeurvre in cutting the better types of tree. On the other hand, what is removed has to be disposed of, and the labour involved in doing this is virtually wasted. If the forest is clear-cut, then on re-growing it contains a large proportion of these poorer grade growths.

This question of uniformity or otherwise among the tropical hardwood forests is discussed further below, and a case study involving a species survey made in the Congo is also referred to.

Again for reasons of location, the possibility of using waste wood, branches, etc. from tropical forests would be much less than in conventional wood pulp practice. On the other hand when there is an existing large saw mill there will be plenty of off-cuts available, which could form the raw material for a pulp mill. This possibility has been investigated in Southern Nigeria and elsewhere, but the type of offcuts obtained from the tropical woods (in the regions studied, at any rate) are such that they could not be economically made into pulp for the better grades of paper owing to their varied nature, and the presence of a large proportion of bark, dirt, decayed wood, etc. Indeed the rapidity with which wood is attacked by insects under tropical conditions once it is felled can influence the whole method of approach to pulping problems in tropical countries. The wood must be used as soon as possible and stock piling, either in log or chip form, is often ruled out unless special precautions are taken.

D. General Properties of Tropical Hardwood Trees and Wood

The only method of defining tropical hardwoods in the present context is to refer to them as those trees of the hardwoods (as distinct from the softwood) species, which grow under tropical conditions. This is not quite the same as growing in tropical regions, because some tropical regions have the climatic qualities of temperate zones. The forest lands of Kenya, for example, are virtually on the Equator but, by reason of their altitude, they resemble more closely the forests of the temperate zones of the world. Incidentally most of the forests exotic to that country are coniferous; they have been planted and are, therefore, quite alien to the normal type of tropical area. However, even true tropical climate can vary between place and place according to the altitude, prevailing winds, surroundings, soil, etc. These can affect the duration and intensity of the rainy periods, and all these subtleties of climate are reflected in the nature of the tree growth. The definition of tropical hardwoods given above, therefore, is an extremely wide one.

However, it is possible to draw attention to a number of features of woods from these climatic areas which are common to many of the species, though not necessarily to all; or to all to the same extent. Perhaps the best way of discussing them is in relationship to what one normally finds in the tree woods (soft and hard) of the temperate zones. The properties in question maybe summarised as follows:

1. Hardness

The trees are known as hardwoods and as a rule this is not literally a misnomer. The wood is physically hard and this very often is due to a high content of silica or other mineral matter. This has a noticeable effect on throughput during felling and subsequent chipping, although it does not pose an insuperable problem.

Of more importance perhaps is the influence of the hardness effects on the pulping process used. In the first place this can influence the degree of penetration of the chemical into the chips, although not necessarily so; secondly the presence of large quantities of silica, if it is dissolved by the black liquor, can give rise to troubles in the subsequent washing of the pulp and in the soda recovery process, where such a process is used. An extreme example of a difficulty of this kind, especially that due to silica, arises in the case of rice straw. Here it is virtually impossible to operate a soda recovery process when the alkaline procedure is used for making rice straw pulp. Rice straw is, of course, not a wood, but there are species of tropical hardwoods which have a silica content of the same order, although such woods are not at present pulping species.

2. Moisture Content

In general the moisture content of the tropical hardwoods is higher than that of the woods of the temperate and northern zones. However, the most important feature of this property is the great variability from one species to another, and even from one season to another for the same species. Thus the moisture content can be up to 40% in some species especially where these contain a high proportion of sapwood and particularly when they are felled during the rainy season. At the other extreme figures of nearly 200% have been reported. Such a high moisture content is advantageous in some respects but disadvantageous in others. One of its advantages is that certain of the species are more easily barked in the moist state. However, much of the moisture has to be transported with the trees and this can appreciably affect the transport costs, especially where, as in many cases, the wood has to be carried some distance owing to the location of the pulp mill with respect to the forests.

In some countries, transport costs due to high moisture content can be reduced by allowing the logs to dry out before they are transported. However, it must be remembered that the tropical hardwoods grow in the tropics, and here high humidities are normal, and the capacity to dry-out is correspondingly less.

A high moisture content can also be undesirable in that it increases the vulnerability of the wood to attack by insects and especially by fungi. Here again there are big variations in the resistance properties of the wood to attack. Some species are very resistant to biological and bacteriological attack, but others are extremely vulnerable and attack can be quite rapid. A possible method of dealing with this problem is by treatment with a preservative, such as pentachlorophenol. This method is quite widely used with commercial woods, such as those used for plywood, veneers and furniture. It could no doubt be applied equally well to pulp wood for cellulose production, but the cost is likely to be high and handling difficulties are likely to arise. It must be remembered that the conventional method of dealing with pulp wood is to chip it and store it in the form of chip piles; in this form the surface presented to attack is much greater than in the case of logs, especially where these retain their barks. It seems highly probable that treatment of wood which has to be stored in chip piles would be much more expensive than the treatment of wood in log form especially in relation to the value of the ultimate end-product.

5. Fibre Dimensions

It is, of course, well known that the fibre lengths of the hardwoods found in temperate zones are generally less than those of the conifers. This same generalisation applies also to the tropical hardwoods. Here again, however, we find examples of the diverse properties of such woods. Even one species itself can vary greatly in fibre dimensions. As an example, teak can vary in fibre length from 0.4 to 1.6 mm and in width from 14 to 44 microns. Taking the whole range of tropical hardwoods within the writer's experience, the dimensions range from 0.25 to approximately 5 mm in length, and from 15 to 55 microns in width; most are between 20 and 30 microns in the latter dimension. An interesting example of outstanding interest is Musanga smithii, since fibres of up to 75 microns in width have been recorded. There are also variations in the radius and in the average thickness of the fibre walls, namely from 3 to 10 microns; and the important ratio of this thickness to the radius can vary between 0.22 and 0.90. The percentage of wood substance in the fibres also varies, and although data are incomplete, the recorded range (namely, 25 to 80%) is very wide.

It is possible that the wide variations recorded above could give some lead as to the most efficient method of utilising tropical hardwoods. Thus it is reasonable to suppose that the heterogeneous nature of the forests which yield these species will give a mixed cellulose pulp in which long and short and thick and thin fibres are to some extent balanced. In this way it should be possible to simulate, to some extent at any rate, one of the great advantages of softwood cellulose pulp which a single species of hardwood pulp cannot realise; thus it should be possible to achieve a balance between the thin-walled spring fibres and the thick-walled autumn fibres. These fibres as such, do not occur in tropical hardwood, but a combination of the varied types of fibre found in such hardwoods might produce something approaching the same effect from the papermaker's point of view. Whether this is possible depends on the heterogeneity of the forests and on the uniformity of the heterogeneity over a wide area. Unfortunately one does not always find this degree of uniformity. There can be patches of one particular species and, some distance away, a stand (which may be large or small) in which another species predominates. Elsewhere, and perhaps also not far away, there can be stands consisting of mixed species. In other words it is very difficult to rely on obtaining a completely uniform mixture even if all the trees are cut and ultimately mixed together.

4. Non-Fibrous Constituents

In view of what has been written above it is not surprising that these constituents are also varied, and that they differ in character from those of the softwoods. Of the mineral constituents silica has already been mentioned as liable to introduce difficulties on chipping and interference with the soda recovery process if an alkaline process is used (see 1). Among the organic constituents the variety is even greater. Thus the oils and resins which one associates with the conifers are less in evidence with the tropical hardwoods. Their place is taken by tannins and colouring matters which are difficult to deal with where production of a pulp of good colour is involved. On the other hand, some of the dark-coloured tropical hardwoods are surprisingly easy to bleach if suitably digested beforehand; others perhaps paler originally, are extremely difficult to bleach and for no apparent reasons. There is little doubt that, given a sufficient variety of cooking facilities, it would be possible to cook a tropical hardwood so that it could be bleached to a good white colour. However, this might involve a sophisticated chemical process which is both complicated and costly, and the ultimate effect would only be to degrade the fibres from the strength point of view. Mangrove and other woods are well known sources of tannin, and it may be possible to combine tannin extraction with a pulp producing process; thus the wood would be extracted for tannin recovery in the first instance and when this objectionable constituent is removed the residue would be ready for the pulping process. Processes of this kind have been operated on hardwoods (as chestnut) from the temperate zones of Europe. On the other hand wattle is less promising in this respect.

As in the case of softwood, lignin is one of the most important non-cellulosic constituents of the tropical hardwoods and, as may be expected, it shows great variations in amount. For instance, contents of approximately 32% have been found, which is well above the average for the hardwoods of the temperate zones. On the other hand some species give very much lower lignin contents, so that here again generalisations cannot be made.

5. Specific Gravity

The difficulty of transporting many of the tropical hardwoods by flotation in rivers has already been mentioned. However, the basic substance of the cell wall is very similar for all woods, and it is the weight of wood substance per unit volume (which is related to the specific gravity of the wood) which is the useful indication of these properties. Specific gravity values recorded range from 0.2 to 1.0 although most of the species fall within the range 0.4 to 0.8. The temperate hardwoods are usually lighter, ranging from 0.3 to 0.6. Although the wood substance may have a specific gravity lighter than that of water, a log of it will still fail to float because of its high moisture content, which reduces the specific gravity to that of water so that the log ultimately becomes waterlogged and sinks.

6. Reproducibility

A feature of tropical hardwood forests, and indeed of many forests throughout the world, is the difficulty of predicting what will happen when the forest has been cut and it is allowed to re-grow of its own accord. Actually the virgin forests of the world are now reduced very considerably either by the ravages of man, fire, insects or failure to adjust over a long period to local climatic conditions. Once a virgin forest is destroyed then the forces of nature battle for the ground which is freed, and other plant species which may have been struggling for existence in vain hitherto have a chance to develop. The original trees then either become extinct, or comprise a much smaller proportion of the population. In general it may be said that the trees which grow as a result of this type of development, (i.e., secondary forest), are often of relatively little use for pulping. Once the equilibrium set up by nature has been disturbed by cutting or destruction otherwise of the virgin forest, the struggle for existence which then takes place usually appears to favour the rapid growth of small bushes, palms, mangroves and lianas as distinct from large-girth, tall, straight trees.

This emphasises an important feature of all industries based on tropical hardwoods, namely the essential nature of a preliminary study of reafforestation conditions before the project is embarked upon. The primary object of such a study would be to establish which species of trees grow best under the new conditions, i.e. after the virgin forest or existing forest has been cut; and whether it will be possible to eliminate the unwanted resistant species. Local climatic and geographical conditions will determine very largely the results of such a survey, and these results will undoubtedly differ from one tropical forest to another. The only safe course is experimental plantations which should be established as soon as possible after the primary forest is cut, and especially if the forest area defined by the survey is not large. Fortunately tropical forests have a high growth rate and indeed, 8 to 12 years often suffices for many tropical pulp wood trees to grow to a sufficient girth to be used for pulping; an approximately 2.5 cm. increase in average diameter per annum has been recorded. This rapid rate of growth assists reafforestation experiments.

Such experiments might, of course, suggest that it would be more advantageous to plant an entirely different type of crop; bamboo or sugar cane for instance. These are useful agricultural materials in their own right, and their residues can be used for paper making. Bamboo is a good source of cellulose pulp, and has a longer fibre than the hardwoods; it is widely used in India in substitution for the softwoods. Sugar cane would yield not only sugar, but bagasse for paper manufacture. The ground available after cutting primary forests is usually favourable for alternative crops of all kinds, but only experiment can decide which is the best to plant; and the indications will not be the same in all cases.

The problems of accessibility have already been mentioned under Location (above), but these are also important in connection with reafforestation experiments. Often the virgin forests are inaccessible by reason both of the lack of communications and the secondary forests surrounding them, and these forests are in many cases the results of fires which have occurred throughout the centuries. In general the tropical hardwood forests consist of large and straight trees, often in swampy locations with a thick undergrowth of jungle. Exploitation, therefore, presents difficulties although with modern methods and equipment these can be reduced; the effect on the economics of the process is nevertheless often only too evident. In this connection, reference may be made to the woods of the Amapa region of Brazil near the mouth of the Amazon, and here there are considerable and rich natural stands of wood such as imbauba and caripe which are of the tropical rain forest type. This has been the subject of a detailed study made under the auspices of the Food and Agriculture Organization (UNO) and is referred to further below.

E. Species Survey of Tropical Hardwood Forests

It is apparent that a complete survey of a hardwood forest is an extremely important feature of any investigation on the possible utilisation of the woods it contains. This is because of the tremendous variation which exists in the species and in the properties of the species present. Unfortunately this itself often involves difficulties owing to the large number of species concerned and their irregular distribution. The usual, and indeed only course, is to adopt a method of sampling which gives as representative a sample as possible of all the trees present and yet covers as wide an area as possible in the sampling process. This very often entails a considerable amount of work under rather difficult field conditions because each individual tree in the selected pulping area must be measured and otherwise evaluated; for example samples taken for pulp tests.

Moreover, forest surveys for pulping purposes differ from the ordinary type of botanical survey, because the pulp maker is interested only in trees of a suitable shape and size, and in weight of wood as distinct from volume. The conventional surveys are usually, (and correctly) made on a volume basis, and corrections must then be applied if the results are to be interpreted on a weight basis because, as already pointed out, the moisture contents and the specific gravity of the trees involved can vary over wide ranges.

One of the best methods of carrying out such surveys is known as the stratified random strip method. It is based on that developed by Griffith in 1952 at the Empire Forestry Research Station, Kenya. Thus in one example of a particular survey with which the writer was concerned the area selected for sampling was 12 x 9.6 kilometres and this, it was hoped, was typical of a total forest area of 83,000 hectares. The rectangle chosen was divided into six strips of 12 x 1.6 kilometres each and each strip was further divided into 80 strips each of 12 km. x 20 metres. Two of each of the 80 strips were then selected at random, thus giving 12 unit sample strips for examination. It should be mentioned that a good deal of terrain concerned was in hilly country, and this made more difficult the selection of the strips and the ultimate sampling of them.

In each case the tree was classified according to: (a) species, (b) number present, (c) actual volume, (d) percentage volume, (e) volume per hectare, (f) diameter. The diameters were divided into 13 categories.

Of the area sampled, 3 per cent was 'blank' (i.e., roads, rocky ground, plantations, rivers, etc.); and 14 per cent was bush secondary forest. It was found that only 9 of the most abundant species comprised more than 3 per cent of the total volume of the sample. Of these one only exceeded 7 per cent of the total. The total volume of these 9 species taken together comprised nearly 36 per cent of the whole sample. In addition to these 9 species there were found approximately 110 named and measured species; and there were also about 100 various unnamed species which together comprised 6.9 per cent by volume of the whole (see Table of results). The difficulties of dealing with this large number of different species in a well mixed tropical forest of this kind are obviously considerable.

Series I

Individual volumes exceeding 3%:

Species	Volume
Bundji	7.21 per cent
Fita	3.38
Ghila	4.93
Kumunu	3.17
Kumunu-Kumunu	3.06
Lianu	3.04
Penzi	4.52
Tombo	3.47
Tombo Simika	3.03
Total Volume	35.81

Series II

Individual volumes between 2 and 3%:

Kikubi Lomba	2.69 per cent
Koma	2.75
Kumunu Babongo	2.28
Muvava	2.33
Safukala	2.07
Total Volume	12.12

Series III

Individual volumes between 1 and 2%

Species	Volume
Banga	1.48 per cent
Bumbulu	1.08
Fundugulu	1.19
Kasu Kumbi	1.02
Kila Kumbi	1.34
Kisoko	1.22
Kuma Kuma	1.82
Libula	1.53
Limeme	1.52
Menga Menga	1.24
Singa Libayi	1.24
Singa N'Dola	1.41
Tchitola	1.42
Vanza	1.66
Total Volume	19.18

Series IV

Individual volumes between 0.5 and 1%

22 Species, total volume 14.69 per cent

Series V

Individual volumes below 0.5%

43 Species, total volume 11.25 per cent

In all, 93 samples of wood were examined, but as a result of the study of the botanical survey it was decided to select only 23 of the wood species collected, and to blend them together in the proportions by volume in which (according to the survey) they occured in the forest in question. The logs received were debarked by hand, and 3 to 8% of the total sample was removed in this way. The debarked wood was chipped, and the chips were well mixed to make a composite sample and these were used for the laboratory experiments. It was felt that this should correspond approximately with the type of blend which would be obtained by clear cutting. The results of this experimental work are referred to elsewhere in this Paper in connection with the investigation, which took place in the lower Congo area.

F. Pulping Methods

As will be realised, the selection of the optimum pulping conditions for mixed tropical hardwoods could be difficult. On the one hand there is the possibility that the forest contains a high proportion of trees which can best be processed by one particular pulping method. If these trees can be extracted economically on their own without the other trees (which seems unlikely in many cases) then the pulping conditions could be specified and used and a constant quality of pulp obtained. However, these ideal conditions seldom arise. It is more often necessary to cater for a mixture, in which case the pulping conditions have to be so adjusted so as to resolve the most resistant of the constituents of the mixture. This inevitably means that the least resistant members of the mixture are overprocessed - which results in turn in a higher consumption of chemicals and in a final pulp of lower strength. The other alternative to this dilemma is to cook the mixture in a manner best suited to the majority of the constituents present, and to eliminate the minor under-digested species by screening; or to use the resulting lower grade of pulp in lower grades of paper, or in board. If the resistant species are not too abundant, simple screening may be quite adequate for their removal.

The barking of tropical trees is very often readily carried out by hand and, since labour is usually cheap and employment is short in the countries in which these forests occur, then this method has often much to recommend it. However, it is possible to treat the tree chemically either before of after cutting, and this method is now being investigated to facilitate the removal of the bark. On the other hand some tropical species can be digested successfully after mechanical barking, or even without barking if sufficient screening facilities are available. Much will depend on the particular type of paper to be made.

Work carried out to date indicates with a fair measure of certainty the following conclusions:

1. An alkaline process is more suitable than the sulphite process for the production of pulp. In many, indeed most cases, the alkaline process is assisted by the use of a mild kraft liquor. However, whether this should be used or not is more often determined by the possibility of obtaining sulphur or iron pyrites from within easy reach of the mill concerned. If sulphur is not obtainable at a reasonable price, then a straight alkaline process must be used.
2. Both the soda and soda-sulphur (sulphate or kraft) processes are suitable for the production of bleached or unbleached pulps.
3. The soda-sulphur process especially, is suitable for bleached pulp. In general this process appears to be the most promising for mixed tropical hardwoods. It is very adaptable to a wide range of species, and it is flexible in that it can produce a greater range of pulps from a given mixture of woods. Also it tends to give stronger pulp than do the other processes, and with the more sophisticated types of bleaching processes (such as those using chlorine dioxide) it is possible to retain the strength and yet obtain a reasonably high degree of brightness and cleanliness. Finally such a process can very often digest many types of bark, especially the light coloured barks which occur on some tropical trees. It often, indeed usually, dissolves the other non-cellulosic constituents of wood, such as gums, resins and other extractives.
4. Consideration has also to be given to semi-chemical processes which have been found useful in certain cases and, if followed by multi-stage bleaching, can even be used to obtain a bleached pulp of reasonably good colour. The possibilities of semi-chemical sulphite pulp also have to

be borne in mind in this connection.

5. It seems unlikely from present experience that high grade groundwood pulp or even chemi-groundwood pulps can be made successfully from mixed tropical hardwoods. However, certain individual species exist which give passable results. Experience with substitutes for coniferous woods for the manufacture of groundwood for newsprint have never been very successful. It seems unlikely that the tropical hardwoods are an exception to this experience, especially when it is remembered that ease of running on the paper machine in the case of newsprint is just as important a factor as the properties and paper making qualities of the pulp itself.

6. In this connection the use of mixed tropical hardwoods for making corrugating medium needs to be borne in mind, but economic objections can arise with such a product, which has so low a selling price as compared with most papers made from wood pulps.

G. Investigational Approach to the Forests

The sum total of the above statements may be summarised in the following recommendations for the method of approach to the investigation of a particular forest as a source of material for pulping.

1. In the first place a survey should be made of all the species in the forest under study, i.e., the type of forest study given as an example above in which the proportions by weight of the trees present are estimated.

2. A preliminary sorting test should be carried out so as to separate those species which cannot be pulped under reasonably drastic conditions, leaving those which can.

3. Then fuller pulping tests should be carried out individually on the remainder of the species which are probably more amenable. In this way the preferential pulping procedure can be selected.

4. The next stage should be the collection of species comprising 75/80% of the total volume of wood available; this must be distinguished from the total number of trees available. Due regard should be paid first to their availability, and secondly to the ease with which they can be pulped.

5. If a forest is clear-cut this might mean a sorting process which eliminates say, the 20% of the whole forest which is very resistant to pulping as shown by the preliminary experiments: or, of course, which is more valuable for other purposes such as sawn timber for furniture and plywood, etc. Then the remaining 80% should be investigated in order to ascertain their pulping characteristics. This operation falls into two headings: (a) the best chemical process for pulping purposes; (b) the types of paper in which the mixed pulp is best used.

The above procedure has been used by the writer successfully in a number of tropical hardwood forest studies, and it has been found that reasonably reliable and consistent results may be obtained so far as pulping experiments and the properties of the paper are concerned. However, the procedure recommended is only an instrument used to ascertain the feasibility of the study. In actual fact none of these studies has come to fruition, the reason being largely economic, as indicated elsewhere in this report.

H. Uses for Tropical Hardwood Pulps

If one studies the literature of the subject one finds a large number of opinions on this subject, mostly optimistic. Thus in one of the studies referred to in this paper the following conclusions were reached: (1) Unbleached pulps may be used for up to 100% of the furnish in second-grade wrappings. (2) The addition to these of relatively small amounts of coniferous pulps would enable papers approaching first-grade wrappings to be made. (3) Bleached pulps could be used in high proportions (and in some cases exclusively), for the manufacture of writings and printings. (4) Rayon pulps could also be produced from the bleached grades, although the above study did not envisage the manufacture of these. (5) The manufacture of groundwood pulps seems to be an unlikely possibility, and is excluded. However, it may be possible to make pulps for newsprint by means of the cold caustic soda process, although the particular study cited does not take this possibility into account.

Unfortunately many of these opinions are misleading because they are based on the technical quality of the pulps rather than the economics of their production. It is well-known that it is possible to make good cellulose pulp from almost any growing plant, but this can seldom be done economically. In the writer's experience the actual uses of pulps made from tropical hardwoods are very much more limited. They may be summarised as follows for the various types of pulps which can be produced.

Rayon Pulps. - These have been produced on experimental scale, but it is doubtful whether tropical hardwoods can be regarded as a reliable source of this material on an economic basis; especially as there are tried alternatives.

With dissolving pulps there are, of course, exceptions to this generalisation. One such appears to be Anthocephlus cadamba, a tropical hardwood occurring in Asia and the Far East and particularly in the Philippines. It is of special interest because of its fast rate of growth. Work at the Tropical Products Institute in London has shown that, using a pre-hydrolysis kraft process, a promising dissolving grade can be obtained. however, there is no evidence that this has been done other than on the laboratory scale.

Bleached Pulps. - It would be unwise to assume that bleached pulps made from tropical hardwoods could compete with the temperate hardwood bleached pulps which have now reached a high standard of quality in the northern hemisphere.

However, it is more likely that by taking certain selected species, giving them individual attention and rigorously excluding the others, a competitive pulp might be produced. Even so, on balance there is likely to be an unfavourable comparison between temperate hardwoods and the tropical hardwoods, and much will depend on the price of the latter - which is equivalent to the price at which the wood can be purchased. Another factor which intervenes will be the market in which the pulp is to be sold. If there is a local paper market, then bleached tropical hardwoods from selected species might well serve a useful function if only to save foreign currency, although the quality of the paper is likely to be poorer for the change.

The types of papers in which the pulps can be used would probably be the general-purpose printings and possibly the poorer grades of writings. It is unlikely that they would be suitable for use in any large quantity in the higher grades of paper comparable with those produced in the northern hemisphere.

Wrappings. - If one considers unbleached wrappings then there is probably a fairly good scope for pulps made from tropical hardwoods where strength is not of importance. There is usually a good market for such pulps in the developing countries and the question of strength, cleanliness and general appearance is often a minor consideration. However, this is only a short term view; without doubt, in time the quality standards demanded in these countries will be equivalent to those which at present exist in the northern hemisphere. In this event it is unlikely that the tropical hardwoods will be economically of much use unless some new process is devised for improving them. In this connection it should be noted that methods for the final screening of pulp have improved considerably during the last few years, and some tropical hardwood pulps which produced unfavourable reports 10 years ago could probably be brought to a much higher degree of cleanliness by using the modern methods. However, here again the question of economics arises.

Perhaps a more promising outlet for the unbleached tropical hardwoods would be as additives to stronger coniferous pulps to produce wrappings which are fairly strong; for example, a coniferous kraft wrapping might have, say, one-third of its furnish replaced by a tropical hardwood, and the loss in strength may well not matter for the purposes for which it is used. If the tropical hardwood pulp is home-produced and very much cheaper this could be a viable proposition in the producing country. Here again, much depends on local markets and conditions.

Newsprint- Groundwood Pulp. - It has been claimed that such pulp has been made from tropical hardwoods, but there is no evidence that a paper in any way comparable with the newsprint and mechanical printings as known in the northern hemisphere has been made on an economic basis. In any case the selling price of such a pulp would be very low, and probably incommensurate with the cost of producing the pulp.

Semi-Chemical Pulps. - These probably offer the greatest possibilities, for instance in the manufacture of board or, possibly better still, in the manufacture of corrugating medium for carton manufacture. However, here again the quantity of pulp which would have to be produced in order to make the project viable would have to be considerable, and this would entail a large local carton consumption. In the developing countries where these forests occur, the consumptions of cartons are not great enough to make such a scheme viable; and it must be remembered that for every 100 tons of corrugating medium produced one must obtain, (from imports as a rule), some 200 tons of kraft liner paper - which cannot be produced from semi-chemical tropical hardwoods. Here again, therefore, there is the question of quality versus expedience. Nevertheless, corrugating medium does offer a possibility for this pulp, assuming that the economics can be satisfied.

So far as the production of board is concerned, the pulp should be suitable, particularly for the thinner substances - such as cardboard. With the thicker substances there is a tendency to obtain a rigid product, which tends to warp on drying and generally lacks the subtle character of true board made in laminates on a vat machine. Probably more investigations on these lines would yield a better product, but this has not been achieved as yet.

In developing countries tropical hardwoods can sometimes be blended with other local products, not necessarily woody, and a scheme of this nature was put forward in Malaya some time ago. This referred particularly to rubber wood and it was felt that the following blends of materials were worth examining:

1. Rubberwood and the tops and branches of timber trees, for the manufacture of hardboard.
2. Padi straw, (augmented with lalang) and bamboo, for bleached chemical pulp; and rubberwood (perhaps augmented by yemane) for mechanical pulp. These pulps to be blended for the manufacture of a range of writing and printing papers.
3. Pineapple leaves and lalang for bleached chemical pulp, and rubberwood for mechanical pulp; these pulps to be blended to make a range of writing ar printing papers and perhaps wrapping paper.
4. Padi straw (augmented with pineapple leaves) for strawboard, by lime cooking.

I. Examples of the use of Mixed Tropical Hardwood Forests

It is difficult to make a selection of examples which will be really informative, because so few have come to real fruition. A number of studies have, however, been made, and several within the present writer's experience are described in places in the Report. The difficulty is that, as stated repeatedly above, no two sets of conditions, no two regions and no two types of forests are alike; and each project must thus be considered on its own merits. In selecting examples, therefore, one is liable to take a case which is typical only of itself and one cannot, therefore, argue in general terms from it. The following examples, therefore, are selected firstly because the writer is familiar with them: and secondly because they illustrate a diversity of conditions and of regions.

One of the most comprehensive laboratory studies of tropical hardwoods is that carried out by K. Lauer of the University of Alabama. He was principally concerned with trees from the Amazon valley in Brazil and his results, therefore, are appropriate to the present paper. The species selected for the full scale tests were the paumulato, abiurana, breubranco, imbauba IT, imbauba IV and palmeiria assai, the last being the local palm tree. These species had lignin contents ranging from 24.8 to 28.3% and alpha-cellulose contents from 46.2 to 49.2%. In accordance with generally accepted views it was assumed that the alkaline process would be the most promising one.

Each species enumerated above was digested on its own, and the resulting pulps were analysed and evaluated for strength. The digestion time varied from 2 to 4 hours, and the temperature from 165° to 170°C; the total chemicals ranged from 18 to 24% with a sulphidity of 25 to 30%. The yields ranged from 42 to 59% the last-named being recorded for paumulato. As might be expected, the yields from the palm were low, i.e. around 40 to 46%, but the long fibre constituents gave the pulp high tearing and folding strength values. High alkaline consumption was necessary to achieve this; and this was in line with the high lignin content which necessitated a higher consumption of chemicals.

Perhaps the most important generalisation to be drawn from these tests is the fact that, unlike the conifers, the chemical composition of the pulps provides little or no indication as to their quality. The best that could be read into them was the fact that pulps with high breaking length contain greater amounts of pentosans. There is also some indication that the alpha-cellulose of the wood holocelluloses has a bearing on sheet properties; yet there was no correlation between pulp quality and the fibre length-to-width ratio. It therefore seems that different criteria of evaluation must be used when tropical hardwoods are being considered, as compared with those adopted for the conifers, and even for the temperate hardwoods. This is in line with experience with non-woody fibres, where it is even less easy to derive information based on criteria used in the evaluation of pulps from conifers.

Further experiments dealt with mixtures of certain of the above woods, and these were compared with those of industrially manufactured kraft pulps from mixtures of southern hardwoods and of hardwoods and pines. One mixture consisted of 13 selected species, which were present in proportions ranging from 4 to 11% of the whole. Comparison of the resulting strength tests showed that the breaking lengths of pulp from the mixtures of the tropical hardwoods are about equal to those of the industrial southern hardwoods; however, the bursting strength, tearing resistance and folding resistance are somewhat lower for the tropical pulps. This again is in line with general experience with tropical hardwoods elsewhere in the world.

Finally, tests were made to investigate the possibility of obtaining high yield pulps from tropical hardwood. For this purpose neutral sulphite and sulphate cooking methods were used with two species Lucuma dissepala and Secropia juranyana, and with a mixture of 8 different species. Yields ranging from 60 to 74.7% were obtained for the sulphate pulps and from 50 to 75% for the neutral sulphite semi-chemical (NSSC) pulps. There were also other indications of the definite advantage of alkaline pulping over the neutral sulphite semi-chemical process. With identical yields the physical pulp characteristics were higher for the alkaline pulps, even for the poorest of them. On the other hand all the high yield pulps from the alkaline (sulphate) digestions had a darker red brown colour than the light grey of the NSSC pulp. This difference was in evidence when bleaching tests were carried out. A higher consumption of chlorine and alkali was required for the alkaline pulps than for the NSSC pulps, but the brightness of the latter was the better.

To sum up, the alkaline process gave better pulp qualities for identical yields; and the NSSC process gave less chemical consumption and high yield and brightness for identical strength characteristics. In the unbleached state the pulps correspond with those obtained by similar processes from ash, maple or eucalyptus; but the bleached pulps were poorer, expecially in colour.

It is very interesting to compare the forests of the lower Congo in West Africa with those of Central Mocambique in East Africa. The former are about 300 miles and the latter 1,300 miles south of the Equator, and they are separated by the breadth of Africa - some 2,000 miles. Both are areas of extreme heat and humidity, with a well-defined rainy season, but, whereas the Congo forests are in hilly country, the Mocambique forests are in flat and, at times, swampy land only 500 feet above sea-level. In general, the Congo forests are dense, the trees are very tall, and straight, and unbranched, and the number of different species present is very large. In Mocambique on the other hand, the forests are very sparse. The trees are much shorter and much more stunted, and they are branched from or near the ground; moreover, they are interspersed with areas (very extensive in places) of scrub and swampy ground, with an abundance of elephant grass (Pennisetum purpureum Schum.). Bamboo and papyrus are also to be found in smaller quantities. Growth is very rapid, a tree 10 m. tall being obtained in 10 to 15 years. The most interesting difference as compared with the Congo forests is the relatively restricted range of species of trees encountered. In one quite large area for instance, some 80 to 90 per cent of the forests consist of two species only, namely, Missaca (Brachystegia spiciformis) and Mafumuti (Piptadenia buchananii).

The former predominates, comprising some 60 per cent of the whole. Also found, though more rarely, are Fever Tree, Acacia, Mangrove (*Rhizophora* species), Kasu, Baobab or Imbondeiro (*Adansonia digitata*), Megerenge (*Albizi* species), Chamfuda and Umbelo. Of these, the last two only are of importance for sawn timber, Chamfuda being specially suitable for railway sleepers. Of course, Acacia and Mangrove supply barks which yield valuable tanning agents.

It is perhaps also useful to consider here in rather more detail the study in Congo, Brazzaville and referred to above.

The forests cover the slopes of a number of relatively steep and short valleys which run in an approximately North-South direction towards the valley of the Boukoula River, along which runs the railway line between Brazzaville and Pointe Noire. The valleys are comparatively steep and narrow, but it should not be difficult to work along the bottoms of the valleys, felling the trees on either side and dragging them down to the bottom of the valley by gravity, working up the sides of the valleys all the while.

Areas of grassland occur at various places in the forest. Bordering on these the forests are of a secondary character, and the same applies to the borders of the roads and tracks for the making of which it has been necessary to clear the primary forests. Features of the secondary forests are palms, bamboo, and a relatively large proportion of small trees of little value for paper manufacture, as well as a good deal of thick undergrowth. It therefore appears that the nature of the secondary forest appearing when the primary forests are cut needs to be controlled carefully if raw material for pulping is to be ensured in perpetuity. It has however, been calculated on a conservative basis that existing supplies for a mill producing 40,000 tons of pulp per annum should be available for about 40 years and possibly for a second cycle of growth of 40 years following that. In the intervening period there should be ample time to plan for the control of the future growth of this forest, seeing that in 40 years it should be possible to ascertain which species are best suited both to the climate and for the manufacture of pulp.

In a report on the possibilities of local materials for paper in Malaya, consideration was given to a number of trees and other agricultural materials, but as the medium to light hardwoods are used for timber their market values are consequently well above the economic figures for pulp. There is indeed no problem concerning the disposal of these materials and it is axiomatic that pulp cannot compete with saw logs for wood. The tops and branches moreover are more likely to be valuable for fibreboard manufacture, and probably rubber wood can be used in this way as well. Rubber wood appears to be worth thorough examination to ascertain the best method of using it for paper pulp. Its fibre and chemical properties are similar to those of the eucalyptus species, which are widely used in Australia. On the other hand there is the interesting possibility of an integrated rubber and rubber wood products industry with regular and reliable replanting schemes to provide the rubber wood and from it, to produce mechanical or chemical pulp.

Similar remarks were made about oil palm stems but these appear to be less promising material. Pineapple leaves were also considered and to some extent these are analagous to sisal, which is well-known as a paper making material of value where economics are favourable.

While rubber wood and other local hardwoods appear to be unsuitable for wrappings (see above) the use of bamboo and the pineapple leaves might together produce a composite material having adequate strength for the lower grades of wrapping, where cleanliness and strength are not of the prime importance. So far as writing and printing papers are concerned in Malaya one is faced with bleaching problems; nevertheless there are some promising species, in particular Gmelina arborea, which has been found promising pulp material on the experimental scale not only in Malaya but also in Nigeria and elsewhere. The possibilities of using such woods for cardboard has already been discussed briefly above, and this too was under consideration in the study made in Malaya. The other alternative is fibreboard, but this falls outside the scope of this Paper.

By way of contrast is an example from the Latin American equatorial belt, experiments on the pulping of cetico wood (Cecropia Sp.) from the upper Amazonian regions of Peru. Newsprint pulp was the main objective, and good results were obtained from a mixture of cetico groundwood with 25 to 30% spruce chemical pulp. Satisfactory, though rather inferior results were obtained from a mixture of sulphate pulp with 35% of cetico groundwood pulp. The work favoured the establishment of a newsprint mill based on cetico as a raw material.

Broadleaved species predominate to the extent of 75% in the forests of the Far East which themselves comprise about 25% of the total area of the region (India, Pakistan, China, Japan, Burma, Indonesia, Thailand and the Philippines). The remainder of the forests are coniferous. However, only about 50% of these forests are at present readily accessible for exploitation. The number of species is very large and comprises many hardwoods, but relatively few have commercial use. The better known of these are teak (Burma and Malaya), oak, birch and aspen (China and Japan), and indigenous eucalyptus (Indonesia). From a pulp-making point of view, much less is known of the Far Eastern tropical hardwoods than of those of Central America and Africa.

There was not a single paper mill in Pakistan in 1947. Bamboos were available in large quantities and could be used for high quality paper, but were too expensive for newsprint. An investigation reported that Gewa (Excoecaria agallocha, Euphorbiaceae) could be used for manufacture of mechanical pulp and then cheap newsprint. It was found that 3.5 million cubic feet of Gewa wood of 6 in. minimum diameter could be obtained annually on a substantially sustained yield basis for manufacture of newsprint. A mill of 30,000 tons of paper annually was set up a Khulna in East Pakistan. Gewa wood dries up quickly and rots and becomes unsuitable for pulping. The extraction in rafts specially prepared and hauled by tugs from the forest to the mill site had to be organised. Special blocks of forest were set apart for supply of wood to the newsprint mill. After working for sometime, it was found that by reducing the minimum diameter of billets and intensifying utilization, the yield of Gewa wood could be increased to 5.7 million cubic feet per year. The capacity of the mill was therefore extended.

J. Conclusions

1. It is apparent that there are many uncertainties attached to the production of pulp for paper and board from tropical hardwoods.

2. The case of each forest must be examined separately and assessed on its own merits. It is unwise to generalize.

3. In spite of the above it seems highly probable that in most cases the tropical hardwood forests can make some useful contribution towards the problem of meeting any shortage in the world-wide supply of cellulose.

4. It is unlikely that the cellulose obtained from tropical hardwoods will be equal to that obtainable from the conifers in qualities such as colour, cleanliness and strength, or cost of production. This applies specially to the higher grades of pulp and paper (i.e., bleached grades), but much less to the lower grades, e.g., those used for boards. It is obvious, therefore, that the price at which the wood can be delivered to the pulp mill will be the deciding factor in determining the economic success or otherwise of a tropical hardwood pulp scheme. For many types of paper the addition to the tropical wood pulps of a long coniferous fibre pulp, even in relatively small proportions, will be essential.

5. For the above reasons it will usually be more logical to make (as far as possible) pulp for paper suitable for local consumption rather than to attempt

to compete with existing supplies of pulp from other parts of the world by exporting to the world markets.

6. Due regard must be paid to the utilization of those species of tree from the tropical forests which are of more value for specialized uses (e.g., sawn timber, veneer, furniture, etc.) than as pulp. Their segregation and utilization where possible will often help to carry the abnormal costs of developing tropical sites. Similar consideration can apply to the use of low grade wood as a fuel supplement.

7. Any survey should also take into account the long-term view, namely, what will happen when the primary stands have been cut, either as a result of the growth of secondary forests, or of a planned planting programme.

8. If the latter is decided upon the questions arise what trees can be grown on a permanent rotation, and can they be pulped in the same plant and by the same process as used for the trees of the virgin forest?

9. Finally, on the economic side it is important to balance the (as a rule) cheaper wages, pulp wood and fuel costs of a site in an undeveloped region, against the higher capital cost of erecting the mill and the higher chemical and transport costs. If in addition the site is so undeveloped as to involve opening up and 'settlement' costs, these may be so great as to scare away private capital. There is then usually a strong case for governmental assistance of some kind towards the initial costs of such colonization.

10. An important decision that has to be made when deciding how to deal with tropical hardwood forests is whether to clear-cut or whether to cut selectively. If the latter course is adopted it is necessary to remove the species which have the better pulping properties and to deal with them separately. This means that other species (which either are too valuable for pulp wood or are unsuitable for some other reason) have to be left standing in the forest. This is not always easily done; much depends on the proportion and spacing of such unwanted (or temporarily unwanted) trees. If the latter are few in

number then the problem is not very serious; but if the pulping species are few in number then there can obviously be difficulty in taking these trees out, especially if they are large or if the terrain is difficult such as hills or inaccessible or remote from roads. The pulping properties of the selected trees must be studied thoroughly and the relevant trees would have to be marked before they are felled; the felling must be organised in such a way that the wanted species can be taken out of the forest with the minimum of difficulty. Fortunately several species do offer promise in this respect. Among these may be mentioned Musanga, and Gmelina arborea, referred to above, which has been the subject of some promising investigations in places as far apart as Malaya, Peru, Nigeria and the Ivory Coast.

11. If the decision is to clear-cut then from a forestry point of view there are few direct problems. However, associated problems can arise. In the first instance there is the possibility of erosion even in humid countries, and in any case the consequence of upsetting the balance of nature in this way are always unknown in advance. It is extremely unlikely that the virgin forest will reproduce itself, and one may well find unexpected species taking over the forest. Musanga is a particularly ubiquitous tree so far as replacement is concerned; and belba in Central America similarly, takes over the land from virgin forests once these have been felled. In this event, one might find that a useful forest is replaced by something more useful; by something less useful; or even by something quite useless if re-afforestation is not controlled and shrubs of a stunted type such as Brachystegia, grow up in place of the original trees. Clear cutting, therefore, is always open to a certain amount of risk.

12. However, it can have its merits because it clears the ground and then the problems of re-afforestation arise. Re-afforestation is an expensive procedure even if the cost is spread over a number of years in advance, because it is essentially a long-term project. Many developing countries

are not prepared to plan far ahead, and such capital as they have for investment is required for immediate projects and must yield a return as soon as possible. Consequently recommendations for planting on a long-term basis so that in 7 years at the least, but perhaps even over 10, a forest will be obtained suitable for a paper industry, does not always appeal; indeed it seldom appeals. There seems little doubt, however, that this is the wisest thing to do, and if the tropical hardwood forest can be replaced by eucalyptus or preferably tropical conifers, then this is a very logical proposition and one that can hardly fail economically in the long run. The reason is, that if the conifers are not wanted for wood pulp production they are always a tree of value in other branches of the economy; and in any case, they grow rapidly and they produce, so to speak, a standard tree and, therefore, a standard wood. However, the reaction of exotic trees to their environment can be unexpected; and an example is Auraucaria angustifolia in Central Brazil; here promising stands of plantation Parana pine, several years old but apparently quite healthy, sickened just as they were coming to maturity and died off - and there was no apparent reason.

Reafforestation with these exotics, therefore, is prone to grave risks and here again the question of risking money on long-term projects which are not necessarily a dead certainty, would arise. It is, therefore, perhaps preferable to reafforest with a species which is known to grow in the conditions concerned, and this need not necessarily be wood. Bamboo for example, is an extremely good paper making fibre as has been shown in India for many years, and there is no doubt that reafforestation of certain clear-cut tropical hardwood forest land with bamboo would be a successful proposition. The writer has carried out studies on cultivated bamboo in Nepal, and it would appear that under those conditions at any rate it can be grown economically for pulp manufacture.

13. Whichever scheme is decided on careful preparation must be made because there must be no chance of the existing forest being used up before the new crop of exotic material is available. This should not be beyond the bounds of possibility, but it entails experimental work on the species concerned and, as pointed out above, this does not always go according to plan.

Finally one may fittingly conclude this paper with the dictum that the only thing that is really certain about the approach to the tropical hardwoods is its uncertainty. It is, therefore, extremely dangerous to generalise, and each particular case must be the subject of its own detailed and intensive feasibility study.

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