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The use of decayed wood from some conifers and broadleaf trees for chemical pulping purposes

Användbarheten av rötskadad barr- och lövved för framställning av kemisk massa

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The use of decayed wood from some conifers and broadleaf trees for chemical pulping purposes*

The prevalence of rot fungi in the Swedish forests is not accurately known, nor have all the numerous species been identified, even if some extensive work has recently been done, especially by ERIKSSON (1958). Over the last few years information on the number of trees damaged in this way has been provided by the National Forest Survey, but as a rule an identification of the fungi cannot be carried out in the field, since the trees may often be severely attacked without formation of sporophores. In the Survey field work, however, increment cores of decayed wood are collected under sterile conditions and later placed on malt agar plates for identification of the outgrowing mycelia.

In the USA and Canada very well equipped laboratories are engaged in the identification or other evidences of internal decay fungi in culture, and the most important papers on this subject derive from these countries (*e.g.* LONG and HARSCH, 1918, FRITZ, 1923, CAMPBELL, 1938, DAVIDSON, CAMPBELL and BLAISDELL, 1938, DAVIDSON, CAMPBELL and VAUGHN, 1942, NOBLES, 1948, 1958 *a* and *b*). From the utilization standpoint, however, rot damage in trees has received less attention. In Sweden the quality of timber is very carefully maintained through official regulations — for instance with respect to rot damage — in connection with scaling of pulpwood of various types.

In an earlier investigation on rot damage in Swedish forests and its effect on the production of paper and rayon pulp (BJÖRKMAN, SAMUELSON, RINGSTRÖM, BERGEK and MALM, 1949) attention was centered on the damage to spruce (*Picea abies*) caused by the root-rot fungus *Fomes annosus* (F.) Cooke and its effect on the production of chemical pulp. The findings of this investigation, to which reference will be made in the following, formed the basis for regulations applied in scaling of rot-damaged wood. The economic importance of the damage due to this fungus in Sweden has been dealt with by PETRINI (1945) and ARVIDSON (1954), and the yearly loss in value caused by the fungus has been estimated at about 60 million Sw. crowns (RATTSJÖ and RENNERFELT,

* *Pinus silvestris* L., *Picea abies* Karst., *Betula verrucosa* Ehrh., *Betula pubescens* Ehrh., *Populus tremula* L. and *Alnus glutinosa* (L.) Gaertn.

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1955). Earlier Scandinavian investigations by JOHANSSON, 1933, 1935, 1942, WEGELIUS, 1938, BJÖRKMAN, 1946, 1953, 1958, PERILÄ and SEPPÄLÄ, 1952, and JENSEN, 1953, can be mentioned here.

American papers dealing more or less with this subject include SCHEFFER, 1936, HEPTING and CHAPMAN, 1938, HOLZER, 1941, ZASADA, 1947, HYTTINEN and SCHAFER, 1948, MARTIN, 1949, CLAUSEN, REES and KAUFERT, 1949, CREAMER, 1950, GLENNIE and SCHWARTZ, 1950, BROWN and McGOVERN, 1950, SHEMA, 1955, SHERIDAN, 1958, ZABEL, 1959, ZABEL and ST. GEORGE, 1960, COWLING, 1960, 1961, and SCHAFER, 1947, 1961.

Since the scaling regulations, promulgated on 25th September, 1948 (Kungl. Skogsstyrelsen, The National Board of Private Forestry, Circular 2A, 1948) governing the use of rot-damaged wood were almost exclusively concerned with damage due to *Fomes annosus,* which occurs primarily in southern and central Sweden (RENNERFELT, 1946), it was suggested by the Swedish Forest Industry that a similar investigation should be carried out on other fungi causing rot damage in conifers chiefly in northern Sweden.

Accordingly, a special committee, "The Rot-Damage Committee", was set up in 1949 by the Coordination Committee of the Forest Industries with the following objectives: 1) to determine the rot types and their frequency in the northern part of the country (Norrland, Dalecarlia, northern Värmland) by surveying the occurrence of rot damage, and 2) to assess the detrimental effect of the various types of rot on the pulp produced; this would be done by means of test cooks at various research laboratories.*

The investigation was conducted in the form of a random sample survey of the prevalence and types of rot damage, and test cooks of representative samples of decayed and corresponding sound pine and spruce wood. In the spring of 1952 The National Board of Private Forestry requested that a corresponding survey of the types and extent of rots in deciduous trees should be carried out, and this was undertaken in April—June of 1952 and 1953.

The results of the investigations of conifers were available in January, 1952, and of that on broadleaf trees in March, 1954. The data were used as a basis for scaling regulations, which subsequently remained unmodified for more than a decade. The results were not published, however. As new methods have been evolved and require-

* The Committee was composed of the following: J. L. EKMAN (Chairman), T. AROSENIUS, R. AXLING, A. G. BENTON, N. BERGSJÖ, E. BJÖRKMAN, G. DJURBERG, G. HALLMANS, E. MALM, M. NORDQUIST, S. PEHRSSON, K. PER-JÖNSSON, S. RASCH, E. RINGSTRÖM, E. RONGE, and H. SCHRÖDER.

ments relating to the products have been altered, publication of the results became highly desirable. For these reasons an outline of the investigations is presented below. Chapters I, II and IV are written by E. Björkman, Chapter III A by S.-O. Regestad, Chapter III B by E. Malm, Chapter III C by E. Ringström, Chapter III D by L.-H. Forssblad and Chapter III E by S. Rydholm.

I. Survey of rot fungi and decay types in *Pinus silvestris* and *Picea abies* in northern Sweden

The survey of the types of rots and their prevalence included pulp wood and fuel wood and was performed chiefly during the early winter, when the timber was transported to the temporary storage places along rivers or forest roads and could be considered on the whole to represent an average of the forests in the respective cutting areas. These studies were performed over three years (1949—1951) and covered a total of 5½ million logs distributed at storage places from the river Kalix älv in the north to the rivers Dalälven and Klarälven in the south.*

At these surveys an attempt was made to bring together the same or similar rots on the stems, as is necessary in practice; at the same time a large number of known and unknown types were collected. Some 1,500 pure cultures of rot fungi from these stored bolts were prepared at the Department of Forest Botany. At least 50 of these were found to belong to different species, the identification of most of which presented considerable difficulty. From utilization standpoints, however, the species as such is less important than the type of rot caused by the fungus. For practical application — with which the investigation is primarily concerned — it is therefore more valuable to assign as many rot fungi as possible to a few groups with respect to their effect on the pulp than to class the rots according to the species of fungi that cause them. To perform such a grouping it is necessary to know what types are prevalent.

Simultaneously with the survey, samples of various common and well defined types of rot were collected for test cooks.

The prevalence of rot in pine and spruce in the various provinces and regions in northern Sweden and Dalecarlia, based on the results of the National Forest Survey, is dealt with in the chapter "The rot frequency in Swedish conifer forests" in the paper by Björkman *et al.*, 1949 (pp. 8—12).

Table 1 shows the prevalence of rot damage and the most important

* These investigations were partly performed as examination field work at the Department of Forest Botany by N. Birgerson, B. Brynte, A. Grönkvist, P. Hargeby, S. Lundberg, Å. Oscarsson, F. Rydbo, G. Tovander, and G. Åkerblom.

Table 1. The frequency of heartrot in pine *(Pinus silvestris)* and spruce *(Picea abies)* in different parts of middle and northern Sweden.

Kind of pulp wood	Rot caused by	Upper parts of the provinces of Dalarna and Värmland 60°—62° Lat. N	South Norrland 61°—63° Lat. N	Middle Norrland 63°—65° Lat. N		Upper Norrland 65°—69° Lat. N	Total and means
				inland	coastland		
		Number of investigated storage places					
Pine and spruce		43	36	52	31	45	207
		Approx. number of pulp wood logs at the storage places					
Pine and spruce		1.360.000	1.400.000	1.290.000	960.000	540.000	5.550.000
		Approx. frequency of pulp wood logs damaged by heartrot, per cent of all logs at each place					
Pine and spruce		7.9	8.2	15.2	13.6	17.1	12.4
		Approx. frequency of heartrot caused by different fungi, per cent of all damage (occurrence, not volume)					
Pine	*Fomes pini*	70.5	80.6	67.0	73.2	63.1	70.9
	Coniophora fusispora	8.5	6.4	11.6	6.8	11.2	8.9
	Armillaria mellea	4.2	2.0	4.4	2.4	3.1	3.2
	Unknown	16.8	11.0	17.0	17.6	22.6	17.0
Spruce	*Stereum sanguinolentum*	26.2	22.9	15.2	10.1	16.6	18.0
	Corticium galactinum and similar fungi	8.1	5.3	12.0	4.1	9.0	7.8
	Armillaria mellea	25.1	22.5	22.7	26.4	24.7	24.3
	Fomes pini abietis	10.2	8.6	12.2	4.1	14.5	9.9
	Fomes annosus	6.1	19.4	2.5	40.3	2.1	14.1
	Coniophora olivacea a.o.spp.	8.8	7.4	10.9	5.7	12.2	9.0
	Merulius sp.	7.5	4.7	9.0	5.1	10.5	7.4
	Fomes pinicola, F. roseus, Polyporus borealis and unknown fungi causing destructive (brown) rot	7.9	9.2	15.5	4.2	10.4	9.5

fungi causing it, as disclosed by the survey performed at the storage places in 1949—1951. As Table 1 shows, *Fomes annosus* rot was not particularly common in northern Sweden (14.1 per cent of all rots recorded). Common rot fungi in spruce were *Armillaria mellea* (Wahl. ex Fr.) Quél., *Fomes pinicola* (Schw. ex Fr.) Cooke, *Polyporus borealis* Fr., *F. roseus* (Alb. & Schw. ex Fr.) Cooke, *Coniophora* spp. and *Merulius* spp. (Plate I), mostly causing butt rot and together constituting 50.2 per cent. Very common were also top rots due chiefly to *Stereum* *sanguinolentum* Alb. & Schw. ex Fr. (Plate I). In pine, *Fomes pini* (Thore ex Fr.) Karst. and fungi of the butt rot type as *Coniophora fusispora* (Cooke & Ellis) Cooke (Plate I) and *Armillaria mellea* (Plate I) were fairly general.

Certain rot fungi consume practically only the holocellulose, and in advanced stages of the decomposition of the wood the residue then consists almost entirely of lignin. These rots, characterized by cubical splitting of the wood, are known as *brown* or *destructive rots*. The opposite type of rot, that due to fungi decomposing only lignin, apparently does not exist in nature but is closely approached by the *white rots*, the residue of which is a white compound containing a high percentage of cellulose (FALCK and HAAG, 1927, CAMPBELL, 1952, LYR, 1961). The white rots occur chiefly in broadleaf trees. The corrosive rots, including the so-called white-pocket rot, lie between destructive and white rots, the cellulose and lignin being attacked by the fungus to approximately the same extent. This group is often included among the white rots. Many other forms of classification have been proposed, for instance those by GÄUMANN (1951) and MEIER (1955); *cf.* also BJÖRKMAN *et al.*, 1949, and HENNINGSSON, 1962. The term brown rot is chemically well defined but is not useful for descriptive purposes, as also many white rots are brown in early stages of their development. The term destructive rot is therefore preferred in the present investigation.

However, it has been found that from a technical and economic point of view, the stage of development of a rot damage may be of the greatest interest. A standard for the various degrees of the composition of the decayed wood is provided by the *volume weight*. In the investigation of 1949 the following examples of wood weight expressed in kg dry substance per m³ fresh wood — established by calculations with a mercury xylometer — was tabulated for various stages of rot in 5 different spruce trunks having a regular and typically formed *Fomes annosus*-rot:

sound wood	425.3
aniline wood	421.0
firm light rot	369.6
firm dark rot	321.4
soft dark rot	246.8

These types are distinguished for practical purposes and can be called *visual decay types*. A rot is considered to be *firm*, if pressure with, for example, the blunt backside of a pencil will make no impression

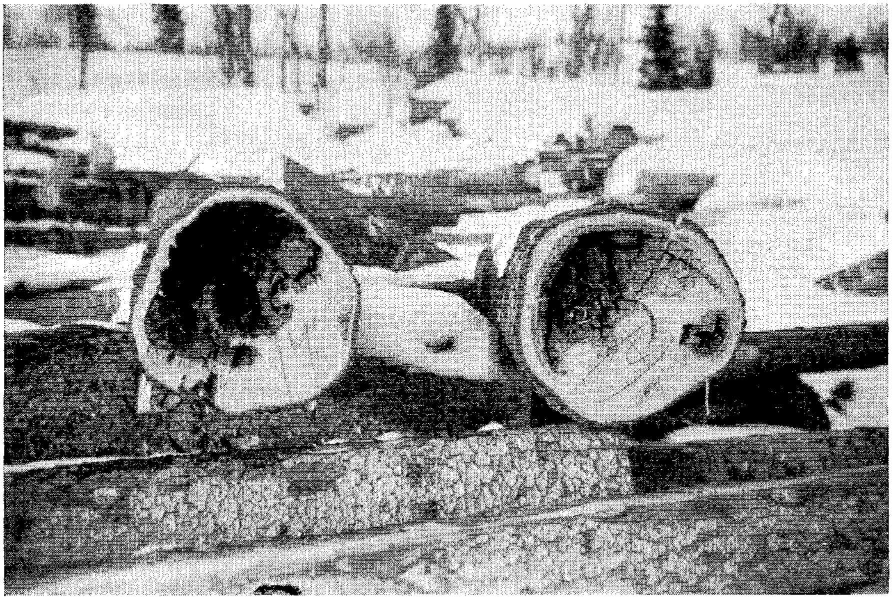

Fig. 1. Soft dark rot of the destructive (brown) rot type, caused by *Coniophora olivacea* in *Picea abies*. Butt rot up to about 50 cm from the ground. The province of Norrbotten.

in the wood or the same impression as in corresponding sound wood. A rot is said to be *soft,* if the decayed wood when pressed in the same way gives a deeper impression than the sound wood. As to the terms *dark* and *light,* a distinction can be made according to a certain colour-scale (*cf.* BJÖRKMAN *et al.,* 1949, Plates I and II). As these types have been found to give a good measure of the decomposition of the wood and the importance of the decay for pulping purposes, they are used for the classification of rot-damage in both conifers and broadleaf trees in the present investigation, with the exception of "aniline wood", which is included in a broader group called stained wood. The term soft rot — always combined with 'dark' or 'light' — should not be confused with the superficial "soft rot" described by SAVORY (1954) and others, this type of rot having no interest in the present connection.

A considerable number of the cultured fungi are of the destructive rot type, among them *Polyporus borealis, Polyporus schweinitzii* Fr., *Fomes pinicola, Fomes roseus, Coniophora olivacea* (Fr.) Karst. (Fig. 1, Plate I) and other *Coniophora* spp. and *Merulius* spp. in spruce. In pine *Coniophora fusispora* causes a typical dark destructive rot at the base of the trees and very often occurs in association with wetwood

(LAGERBERG, 1935, 1944). Also in spruce fungi of these types are found chiefly at the base of the trees often combined with wetwood. For the most part they can therefore be classified topographically as stump rot or wetwood fungi (*cf.* TIKKA, 1934, ROBAK, 1936, 1942, DAY and PEACE, 1936, PEACE, 1938, JØRSTAD and JUUL, 1939, DAY, 1948, BAVENDAMM, 1951, RISHBETH, 1950—1951, 1959, HARMSEN, 1954 WAGENER and DAVIDSON, 1954, NORDIN, 1954, LOWE, 1957, 1958, JØRGENSEN, 1956, KÄÄRIK and RENNERFELT, 1957, YDE-ANDERSEN, 1958, ERIKSSON, 1958, MOLIN and RENNERFELT, 1959, WALLIS, 1961, TSOUMIS, 1961).

Typical corrosive rots are caused by *Fomes pini* in both pine and spruce (*Fomes pini* var. *abietis* (Karst.) Overh.) trunks by infection through dead branches (*cf.* RENNERFELT and NACHT, 1955, JØRGENSEN, 1961), and by *Stereum sanguinolentum* causing top rot in spruce (*cf.* LAGERBERG, 1919, DAVIDSON and ETHERIDGE, 1963). Besides these very common fungi of this type other species have also been found sporadically, *e.g. Polyporus tomentosus* var. *circinatus* (Fr.) Sartory and Maire, and *Fomes nigrolimitatus* (Rom.) Egeland producing a very pronounced "white pocket rot".

Pure white rots in pine and spruce are relatively rare but are caused for example by *Armillaria mellea* and *Corticium galactinum* (Fr.) Burt. (*cf.* WHITE, 1951, and Plate I). The most important white rot fungus in this connection seems to be *Armillaria*, which, however, also consumes the cellulose to a great extent and always produces a dark discolouration of the wood (Plate I). The *Armillaria*-rot usually occurs as a butt rot, often in combination with wetwood.

II. Survey of rot fungi and decay types in *Betula verrucosa*, *B. pubescens* and *Populus tremula* in various parts of Sweden

To examine the prevalence of decay in growing birch and aspen in various parts of the country extensive observations of the occurrence of various types of wood-rotting fungi were performed in association with surveys in 1952—1953. These were undertaken in different seasons, often in connection with cutting operations in southern and northern Sweden, and, as in the case of the conifer pulp wood, estimates were made of the proportion of trees damaged by rot and the prevalence of the various types of rot.

A compilation of the National Forest Survey data was performed even if the type of rot could not be recorded (Table 2). The figures for the Forest Survey are in close agreement with the random sampling studies in various parts of the country, though often slightly lower than these. In the Forest Survey data, which are relied on in the following unless otherwise stated, waste timber has been included as decayed wood, as is probably appropriate since it is almost invariably affected by rot.

It is seen from Table 2 that the smaller dimensions of birch (10—25 cm diameter) have considerably less frequency of rot-damaged wood than the larger, but in the case of aspen there is little if any difference in this respect. Thus, young aspen is considerably more affected than young birch (Fig. 2). This may be due at least in part to the fact that the root suckers, which were also included in the observation material, are often damaged by rot at quite an early stage. Table 2 also shows that birch is much more commonly affected in the north than in the south of Sweden. In the inland areas of upper Norrland in particular birch is very often badly attacked. In this respect, too, aspen does not display such marked differences. On the whole, decay in aspen is about as common in southern Sweden as in Norrland.

If account is taken of *the total occurrence of rot-damaged wood* (including waste timber), irrespective of diameter class, the proportion of affected trees was 18.8 per cent for birch and 35.2 per cent for aspen (Table 3). The corresponding figures for conifers are not available

Table 2. The frequency of rot-damaged trees of birch *(Betula verrucosa* and *B. pubescens)* and aspen *(Populus tremula)*, expressed as the means for the diameter classes: 10—25 cm, above 25 cm; and in total; in different parts of Sweden according to the results of the National Forest Survey. The frequency is expressed in per cent of all trees.

Counties	Mean Lat. N	Survey	Birch			Aspen		
			10—25 cm	above 25 cm	total	10—25 cm	above 25 cm	total
Malmöhus a. Kristianstads	56°	1945	8.2	20.2	8.9	—	—	—
Kalmar a. Blekinge	57°	1945, 47, 48	10.5	20.9	11.1	22.6	32.6	23.8
Jönköpings a. Kronobergs	57°	1946—47	6.9	20.0	7.5	16.5	25.6	17.6
Hallands a. Göteborgs o. Bohus	58°	1946—49	4.7	13.1	5.2	40.9	52.2	41.3
Älvsborgs, Skaraborgs a. Örebro	58° 30′	1949—51	7.3	19.2	7.9	38.4	35.5	38.2
Östergötlands a. Södermanlands	58° 30′	1950—52	13.0	29.1	14.4	43.2	38.2	42.7
Stockholms, Uppsala a. Västmanlands	60°	1950—52	6.6	25.9	7.3	45.1	67.0	46.3
Värmlands	60°	1950	10.7	25.3	11.2	37.2	45.7	38.1
Kopparbergs (except Särna-Idre)	61°	1943	19.2	43.3	20.2	23.5	25.5	25.6
Gävleborgs	61° 30′	1942	20.1	46.1	21.4	41.7	66.4	49.1
Västernorrlands	63°	1938	10.0	38.6	11.4	19.7	43.4	24.3
Jämtlands	63°	1940	32.2	68.8	38.1	41.3	69.4	57.6
Västerbotten a. Norrbotten, coastal area	64°—66°	1939—41	23.2	51.4	25.1	30.3	36.2	33.1
Västerbotten, inland area	65°	1939	25.5	68.9	29.9	49.4	36.8	55.0
Mean			*18.2*	*37.1*	*18.8*	*34.1*	*46.5*	*35.2*

for the whole country but for Norrland and Dalecarlia they have earlier been estimated to be 0.9 per cent for pine and 5.7 per cent for spruce (Björkman *et al.*, 1949, Fig. 2).

As regards the distribution of rot, there was a greater degree of uniformity in the case of the broadleaf trees than the conifers. The most important type, that caused by *Fomes igniarius* (L. ex Fr.) Kickx, the "false tinder fungus", proved to be fairly uniformly distributed throughout the country, occurring in 39—56 per cent of all birch with rot damage (Table 3). In a large number of stems the rot was due to *Poria obliqua* (Pers. ex Fr.) Karst. (Fig. 3), the decay of which closely resembles that of *Fomes igniarius*. The latter occurred in 90 per cent of the aspen damaged by rot, with little difference between the south and north of the country.

A short survey will be given of the most common types of rot, and the fungi causing them encountered in the survey.

As mentioned above, the most common type of rot damage in birch was found to be due to *Fomes igniarius* (Plate II). This fungus, which frequently forms characteristic hoof-shaped fruiting bodies, occurs in

Table. 3. The frequency of heartrot in birch *(Betula verrucosa* and *B. pubescens)* and aspen *(Populus tremula)* in different parts of Sweden. Per cent of sample tests from 1,220,000 pulp wood logs.

Kind of pulp wood	Rot caused by	South Sweden 56°—59° Lat. N	Middle Sweden 59°—61° Lat. N	South and Middle Norrland 61°—65° Lat. N	Upper Norrland 65°—69° Lat. N	Mean
		Approx. frequency of rot damage caused by different rot fungi, per cent of all damage				
Birch	*Fomes igniarius*	56	44	45	39	46.0
	Poria obliqua	8	25	24	29	21.5
	Fomes fomentarius	21	14	12	8	13.8
	Polyporus betulinus	3	2	2	2	2.2
	Pholiota and *Pleurotus* spp.	3	2	1	1	1.8
	Armillaria mellea	4	7	6	7	6.0
	Diaporthe aristata	0	0	9	12	5.2
	Unknown	5	6	1	2	3.5
Aspen	*Fomes igniarius*	93	92	94	93	93.0
	Armillaria mellea	5	6	5	6	5.5
	Fomes applanatus and unknown fungi of similar type	2	2	1	1	1.5

a large number of races in numerous kinds of broadleaf trees (*cf.* VERRALL, 1937). The rates of growth of the mycelia of these races vary with temperature, and the enzyme effect and "activity" of the fungus seem to differ considerably from one race to another. The fungus produces a typical white rot with characteristic dark zone lines. The rot is dark at first and becomes lighter with time, the dark lines increasing in prominence (Plate II). At first the rot is firm but becomes softer later on. Unless there is other damage there is no tendency for the stem to become hollow.

Poria obliqua, as mentioned above, produces a rot very similar to the *Fomes igniarius*-rot. The fruiting bodies consist of clinker-like masses (Fig. 3).

Fomes fomentarius (L. ex Fr.) Kickx, the "tinder fungus", seems to be the most common to attack birch after *Fomes igniarius* and *Poria obliqua*. The conk is particularly common and often bears a close similarity to that of *Fomes igniarius*. It is, moreover, the most common rot fungus in beech (*Fagus silvatica* L.) and for this reason is often known as the "beech conk fungus" in southern Sweden. The rot is a typical white rot of the same kind as the *Fomes igniarius*-rot, but instead of the dark zone lines there are characteristic dark clusters of mycelia, visible as dark streaks in the wood, often several centimeters long and a few millimeters wide.

Fig. 2. Hardwoods (*Betula verrucosa* and *Populus tremula*) with typical stem and butt rots of the white rot type, mainly caused by *Fomes igniarius*. The province of Ångermanland.

The infection by *Fomes igniarius, Poria obliqua* and *Fomes fomentarius* occurs through spores, which germinate on exposed wood especially in branch wounds.

Polyporus betulinus Bull. ex Fr., the "birch conk fungus" is also a fairly common decay fungus in birch, its only host tree. Unlike the sporophores of *Fomes igniarius* and *Fomes fomentarius* the conks are soft and annual. They appear on dead branches and trunks. The decay is a typical destructive rot of a light brown colour, a type that is rare in broadleaf trees. The fungus attacks the cellulose and the wood breaks down until, in the advanced stage, it disintegrates into a fine powder (*cf.* Björkman, 1953, Table 7).

Armillaria mellea, the "honey fungus" is more common in broadleaf trees than in conifers; thus the fruiting bodies very often occur on dead roots and stumps. It is often possible to recognize the fungus through its characteristic flattened rhizomorphs between the wood and the bark. *Armillaria* can, however, as in conifers, appear also as a trunk rot in the central part of the tree usually causing a butt rot (Fig. 4). As mentioned before, *Armillaria mellea* causes a white rot but appears to attack chiefly the cellulose, at least in the earlier stages.

Fig. 3. Black deformation in the bark of *Betula verrucosa*, caused by *Poria obliqua*. The province of Ångermanland.

Pholiota destruens (Fr.) Bres. and *Pleurotus ulmarius* Fr. and other species of the same genera, like *Armillaria*, seem often to enter through the roots so that typical butt rots occur. The infection or invasion may also appear in the upper part of the trunk, for instance by *Pleurotus ostreatus* Jacq., "the oyster mushroom". If the moisture conditions permit, these fungi continue to grow after the tree has been cut.

An extremely common form of damage to the birch trunks in Norrland is the so-called birch canker which is produced by the Ascomycete *Diaporthe aristata* (Fr.) Karst. (Fig. 5, Plate II). This fungus grows on the lower parts of the trunk (not above 2 meters) and has been encountered chiefly in untended stands. The fungus produces a pronounced canker at the base of the stem, where the bark splits and is often pressed into fissures in the wood. The cambium is killed and the parts between the sites of attack therefore grow so that the tree appears finally to be standing on stilts. A marked black stain of the

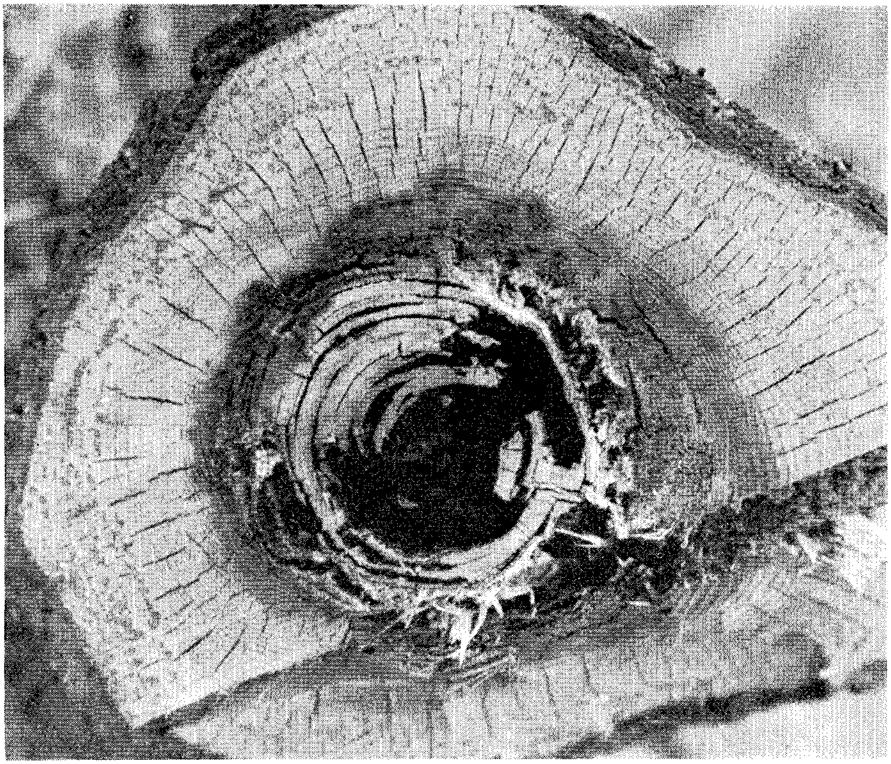

Fig. 4. Soft dark rot of the white rot type, caused by *Armillaria mellea*, in *Betula verrucosa*. Butt rot. The province of Västerbotten.

wood is typical of *Diaporthe*-damaged stems even when no perithecia are formed. The attack is often accompanied by a typical rot, which is probably due to the fungus but its nature is still rather obscure (*cf.* HORNER, 1956).

Other forms of abnormalities are various types of discolouration of wood due to changes in the heartwood of the growing tree. A greyish green stain is particularly common in birch and aspen, and in the former it often begins as a violet tone (Plate II). This stain occurs when air is able to penetrate to the central wood — for instance through branch stubs. In time these discoloured parts of the trunk are infected by wood-rotting fungi. Then, first a firm dark rot and later a more or less soft light rot occur (Plate II). It is difficult to decide where the border lies between stain alone and incipient rot. Another form of discolouration of wood is the so-called red heartwood of birch, probably of the same type as the more familiar red heartwood of beech (BUCHWALD, 1939, ZYCHA, 1948, RENNERFELT and THUNELL,

Fig. 5. Canker, caused by *Diaporthe aristata*, at the base of a stem of *Betula pubescens*. Black staining from the bark and soft rot. Province of Västerbotten. *Cf.* Plate II.

1950) and ash (Bosshard, 1953). It is light brown at first but darkens with age (Fig. 6, Plate II). Red heartwood — in the present investigation also called "firm red wood" — is not caused by decay fungi, although they may appear secondarily and produce severe damage. In birch it seems usually to be *Fomes igniarius,* and in beech *Fomes fomentarius* that are found. No accurate assessment of the prevalence of red heartwood has been performed. Very extensive red heartwood, which may involve practically the whole central part of the trunk, seems, however, to occur chiefly in old birch with thick bark in southern and central Sweden.

In dried twigs a typical branch rot sometimes forms; it finally occurs as a soft dark rot. In other cases the twig wound is healed over, and no rot will then be formed.

Rot fungi in aspen. — The predominant rot in aspen is, as mentioned above, due to *Fomes igniarius,* which is extremely common in this tree throughout Sweden (*cf.* its high frequency in America, reported by Schmitz and Jackson, 1927, Hirt, 1949, Riley, 1952, Davidson, Hinds and Hawksworth, 1959, and also in Russia and Siberia, reported by Ankudinov, 1939). The fungus occurs in the same way as in birch

Fig. 6. Firm red wood (red heartwood), caused by air reaching the heartwood through cracks in the stem, in *Betula verrucosa*. Beginning of rot, caused by *Fomes igniarius*, in the central parts. Province of Dalsland. *Cf.* Plate II.

and the kind of decay is also the same. The infection usually takes place through dry twigs on the trunk but also through root suckers from old stumps; opinions are divided on this, however. EKLUND and WENNMARK (1925) found that root rot in aspen is usually caused by *Armillaria mellea*. In the survey of rot in broadleaf trees this fungus was often encountered in aspen, where it had the same appearance as in birch. Moreover, other fungi were also encountered, *e.g. Fomes applanatus* (Pers. ex. Wallr.) Gill. (Fig. 7), *Collybia velutipes* Curt. ex F., and *Fomes pinicola* in a few cases. These other rots were preferably formed in the lower parts of the trunk as typical butt rots. A number of unidentified rot fungi were also found in aspen.

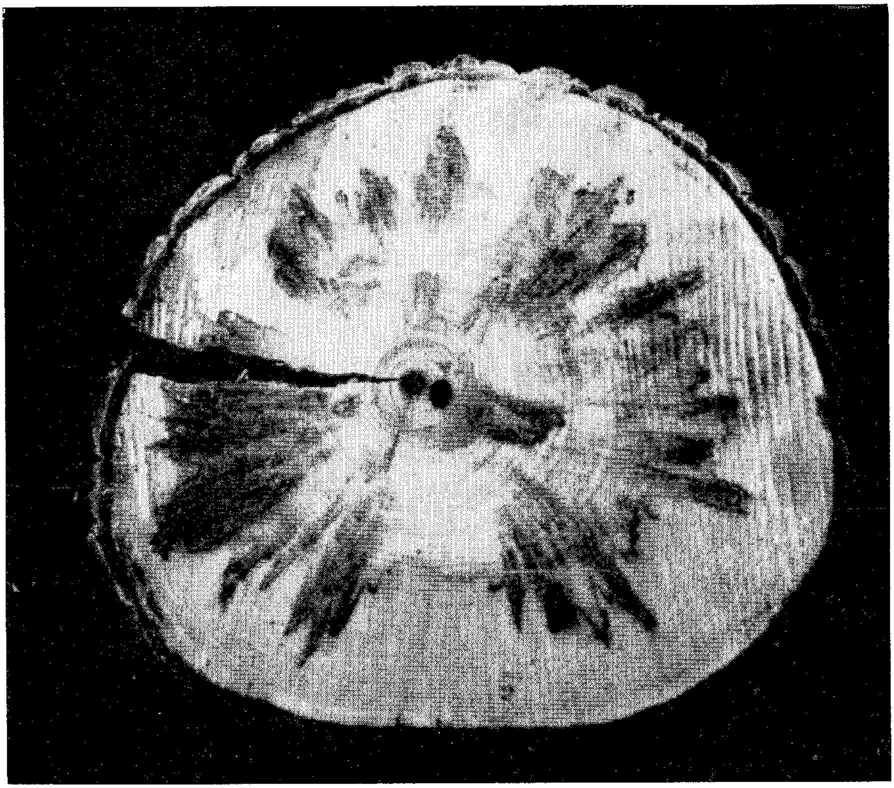

Fig. 7. Firm dark rot of the white rot type, caused by *Fomes applanatus;* in *Populus tremula.* Butt rot. Province of Småland.

III. Test cooks of pine, spruce, birch, aspen and alder wood from trees attacked by various rot fungi

To enable a direct comparison to be made, the samples of decayed and sound wood for the test cooks were taken largely from the same stems. In cases when this was impossible it ensured that the sound control wood was of about the same increment type as the decayed wood. The sound wood was mixed with 10, 20 and 50 per cent of the decayed wood. In some cases only a 10 per cent mixture was examined of conifer wood and a 20 per cent mixture of hardwood, this being the maximum proportion of decayed wood present in the wood received at the pulp mills. On the average the proportion of rots in the Swedish forests does not exceed a few parts per thousand of the cut timber volume and it is unlikely to reach one per cent. It was ensured that the chips for the test cooks consisted only of absolutely homogeneous decayed wood with no knots, compression wood etc. The chips measured about 25 × 15 × 5 mm.

Different types of pulp were prepared on a laboratory scale at the research laboratories of a number of Swedish forest industry companies: rayon pulp from spruce wood at Mo och Domsjö AB., Örnsköldsvik, sulphite pulp from spruce wood at The Swedish Cellulose AB., Sundsvall, sulphate pulp from spruce and pine wood at Uddeholm AB., Skoghall, sulphite pulp from birch, aspen and alder wood at Mo och Domsjö AB. and bleached greaseproof pulp from birch wood at Billerud AB., Säffle. Largely the same types of chips were used (often from the same tree) at the different laboratories so as to obtain the highest possible degree of uniformity. As the yield and quality of pulp may to a great extent depend on the stage of development of the rot, the test cooks must be considered as random sample studies as regards the respective type of rot in a relatively intermediate stage of development. Cooks of decayed wood of apparently similar types, however, may sometimes yield quite different values, since it is usually difficult to judge by inspection the stage of development of the rot. The results may therefore be ascribed their greatest importance if they either disclose the harmlessness of the rot or reveal a marked reduction in yield and impairment of the pulp prepared from it.

Owing to the difficulty of always finding enough uniform rot wood, and to the inevitable practical limitation of the number of test cooks, the results in several cases did not permit of broad-based conclusions and were of limited value for statistical analyses. Reliance was therefore placed largely on the clear indications provided by the test cooks of mixed sound and rot wood of various kinds.

Table 4. Wood analysis of spruce *(Picea abies)* chips for test cooking of rayon pulp.

Visual decay type	Rot fungus	Volume weight kg dry substance per m³ raw wood (Tappi 18-m)		Lignin content per cent (CCA 5)		Extractives content per cent (CCA 2)		Autoclaves litre	Remarks
		Sound wood	Decayed wood	Sound wood	Decayed wood	Sound wood	Decayed wood		
Firm-light	*Stereum sanguinolentum*	375	355	30.6	29.8	2.94	1.52	1.5	*cf.* Plate I
Firm-dark	*Fomes pini*	413	286	28.8	24.5	2.30	2.04	1.5	*cf.* Tab. 9 a.13
Soft-light	*Merulius* sp.	401	294	30.2	46.1	2.46	10.03	1.5	*cf.* Tab. 9, Plate I
Soft-dark	*Coniophora olivacea*	456	341	28.0	38.5	1.90	4.70	1.5	*cf.* Fig. 1, Tab. 9 a.13
Soft-dark	*Armillaria mellea*	400	169	29.9	25.6	4.02	2.07	1.5	*cf.* Tab. 9, Plate I
Firm-light	*Stereum sanguinolentum*	417	377	27.9	28.2	3.54	2.03	10.0	*cf.* Tab. 13
Firm-dark	*Armillaria mellea*	413	459	30.1	32.4	2.51	2.61	10.0	*cf.* Tab. 13

A. Production of rayon pulp from decayed spruce wood. Mo och Domsjö AB. Research Laboratory

Wood material

For each decay type the chip samples were composed of sound and rot-damaged wood from the same trunk. The analytical data for the samples are given in Table 4.

Method

Most of the cooks were performed in 1.5 litre stainless steel rotating autoclaves, heated in a polyglycol bath. Series of chip samples containing 0, 20 and 100 per cent of the various decay types were cooked to 4 viscosities. In two cases (Table 4) 10-litre rotating autoclaves were used. These were provided with 3 separate compartments to enable chip mixtures containing 0, 10 and 20 per cent of rot-damaged wood to be cooked simultaneously. Unlike the 1.5 litre-autoclaves, the 10-litre cooks were made with gas relief at 5 kp/cm². Other conditions were as shown in Table 5.

After cooking, the pulps were washed, dried and analyzed. Those

Table 5. Cooking conditions for production of rayon pulp from rot-damaged spruce *(Picea abies)* wood.

	1.5 litre autoclaves	10 litre autoclaves
Composition of cooking liquor: CaO g/l	9.0	9.0
total SO_2 g/l	50.5	70.5
Cooking liquor/oven-dry wood l/kg	4.5/1	5.5/1
Chemical added, per cent of oven-dry wood, CaO	3.9	3.9
total SO_2	22.0	30.8
Maximum temperature °C	148.0	148.5
Maximum pressure kp/cm²	5.0	5.0
Temperature schedule:	20°—105° C	3 hours
	at 105° C	5 „
	105°—148° C	3 „
	at 148° C to required viscosity	

from the 1.5 litre cooks were bleached by the following sequence: chlorination, neutralization, chlorination, hot alkali extraction, hypochlorite, and chlorine dioxide.

Results

The results of the most important analyses for the 1.5-litre cooks are given in Table 6; only values interpolated for a viscosity of 40 cp have been included. The results of the 10-litre cooks and subsequent bleaching are given in Table 7. In this case, the rot attack was at a considerably earlier stage than those in the decayed wood used in the 1.5-litre autoclaves. The effect of the decay on the yield of pulp, wood consumption and alpha-cellulose content is presented graphically in Figs. 8 and 9. The effect of different rots on the sulphite cooking of spruce wood is shown in Table 8.

The effect of each type of rot will be commented on separately, on the basis of the results of the test cooks. The comparison has been made consistently for 10—15 per cent of decayed wood by volume — a limit that is far above the average level under practical conditions.

Soft dark rot, formed by *Armillaria mellea* in the fully developed stage (Table 4), caused a considerable drop in yield and increase in wood consumption by about 15 per cent. The percentage of alpha-cellulose in the pulp was unaffected, but the overall yield was greatly reduced. An increase in the consumption of bleaching agent was noted, while Östrand's p-number was higher than for the corresponding sound wood. The brightness of the unbleached pulp dropped also (Plate II), but by bleaching (in the 10-litre cooks) it could be brought up to the level for pulp prepared from sound wood.

Table 6. Pulp yield, wood consumption, and analytical data for unbleached rayon pulp from mixtures of various kinds and quantities of decayed wood of spruce *(Picea abies)* and corresponding sound wood at the same trunk height. 1.5 litre autoclaves. All values interpolated to 40 cp viscosity.

Visual decay type	Rot fungus	Volume of decay per cent	Pulp yield per cent		Wood consumption in f³ of raw wood per ton of 90 % pulp		Alpha-cellulose per cent		Alpha-cellulose yield per cent		p-number according to Östrand		Brightness (Hunter blue) per cent	
			Absolute	Rel. sound wood	Absolute	Rel. sound wood	Absolute	Rel. sound wood	Absolute	Rel. sound wood	Absolute	Rel. sound wood	Absolute	Rel. sound wood
Firm-light	*Stereum sanguinolentum*	0	43.3	100	196	100	85.1	100	36.9	100	6.6	100	63	100
		20	43.4	100	197	100	86.9	102	37.7	102	8.1	123	63	100
		100	44.3	102	202	103	84.7	100	37.5	102	12.0	182	55	88
Firm-dark	*Fomes pini abietis*	0	43.9	100	175	100	86.5	100	37.9	100	7.0	100	65	100
		20	46.5	106	176	100	83.9	97	39.0	103	7.5	107	64	98
		100	55.5	126	200	114	76.5	88	42.4	112	~25.0	360	~50	77
Soft-light	*Merulius* sp.	0	43.3	100	183	100	84.8	100	36.7	100	8.0	100	68	100
		20	38.0	88	220	120	83.1	98	31.6	86	8.8	110	63	93
Soft-dark	*Coniophora olivacea*	0	44.8	100	155	100	85.1	100	38.1	100	5.8	100	72	100
		20	43.9	98	167	108	78.5	92	34.4	91	6.8	117	66	92
Soft-dark	*Armillaria mellea*	0	44.1	100	180	100	85.4	100	37.7	100	10.7	100	68	100
		20	39.7	90	226	126	84.8	99	33.7	89	12.1	113	51	75
		100	25—30	~60	620—750	400	76—80	89—94	~22.0	60	~38.0	350	~20	29

Table 7. Pulp yield, wood consumption, analytical data for unbleached and bleached rayon pulp from mixtures of two various kinds and different quantities of decayed wood of spruce *(Picea abies)* and corresponding sound wood at the same trunk height. 10 litre autoclaves.

Visual decay type and pulp type	Rot fungus and viscosity cp	Volume of decay per cent	Pulp yield per cent		Wood consumption in f^3 of raw wood per ton of 90 % pulp		Alpha-cellulose per cent		Alpha-cellulose yield per cent		p-number according to Östrand		Brightness (Hunter blue) per cent	
			Absolute	Rel. sound wood	Absolute	Rel. sound wood	Absolute	Rel. sound wood	Absolute	Rel. sound wood	Absolute	Rel. sound wood	Absolute	Rel. sound wood
Firm-light	*Stereum sanguinolentum*													
Unbleached	29.8	0	43.9	100	174	100	—	—	—	—	7.7	100	—	—
pulp	31.8	10	43.5	99	177	102	—	—	—	—	6.8	88	—	—
	34.4	20	44.0	100	177	102	—	—	—	—	6.8	88	—	—
Bleached	26.7	0	40.4	100	189	100	90.7	100	36.6	100	—	—	90.3	100
pulp	29.2	10	39.9	99	193	102	90.6	100	36.1	99	—	—	90.7	100
	27.4	20	40.2	100	193	102	91.0	100	36.6	100	—	—	90.8	101
Firm-dark	*Armillaria mellea*													
Unbleached	32.5	0	45.9	100	168	100	—	—	—	—	9.6	100	—	—
pulp	33.6	10	45.0	98	169	100	—	—	—	—	13.5	141	—	—
	33.7	20	44.7	98	169	100	—	—	—	—	17.4	181	—	—
Bleached	25.0	0	41.5	100	186	100	90.6	100	37.6	100	—	—	91.0	100
pulp	27.7	10	40.8	98	186	100	90.8	100	37.0	98	—	—	91.0	100
	32.4	20	40.4	97	186	100	91.1	101	36.8	98	—	—	90.1	99

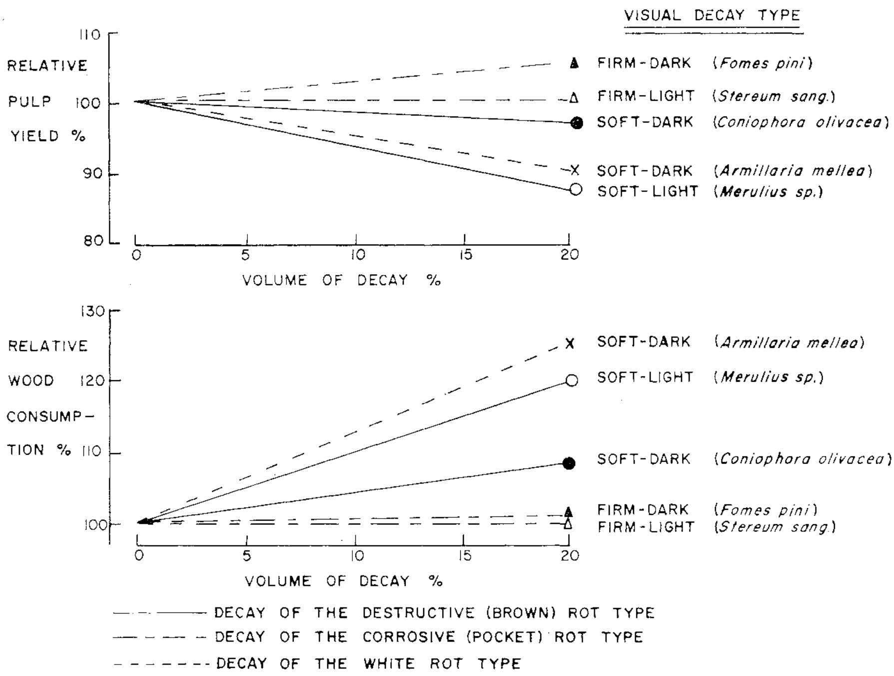

Fig. 8. Relative pulp yield (weight basis) and relative wood consumption (volume basis) in production of unbleached rayon pulp from mixtures of various kinds and quantities of decayed wood and corresponding sound wood at the same trunk height of *Picea abies*. Viscosity 40 cp. Mo och Domsjö AB. Research Lab.

Rot wood at an earlier stage of decay development, studied in the 10-litre cooks, gave a considerably better result. Both unbleached and bleached yields dropped slightly but by no means as much as for the more advanced stages of decay (in the 1.5 litre-autoclaves). The consumption of wood was also the same as for sound wood, but Östrand's permanganate number increased greatly. The values for the bleached pulp, however, were the same as for pulp prepared from the corresponding sound wood.

Soft dark rot, due to *Coniophora olivacea,* mixed with the corresponding sound wood, gave a considerably darker pulp than the sound wood. The yield, calculated as a percentage by weight, was slightly lower, as the decayed wood had to the same extent disappeared during the cook (*cf.* the high lignin content, Table 4). The wood consumption increased as did the permanganate number (by about 10 per cent). The yield of

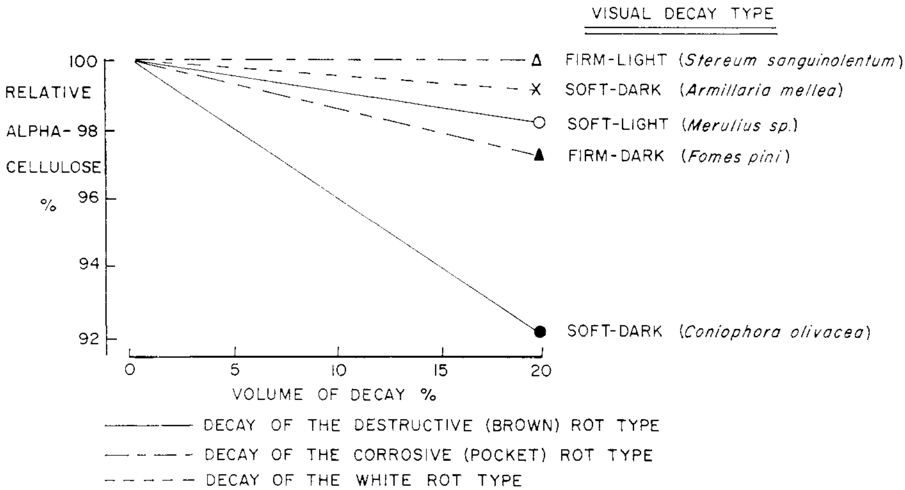

Fig. 9. Relative alpha-cellulose content in production of unbleached rayon pulp from mixtures of various kinds and quantities of decayed wood in corresponding sound wood at the same trunk height of *Picea abies*. Viscosity 40 cp. Mo och Domsjö AB. Research Lab.

alpha-cellulose dropped almost as much as for the mixture with *Armillaria*-rot, and the brightness also diminished greatly.

Soft light rot, due to a *Merulius* species, greatly reduced the yield and raised the consumption of wood (10—15 per cent) and the permanganate number. The yield of alpha-cellulose was the lowest obtained for all the types of decay examined. The brightness was also lower.

In practice there seems to be no difference between the soft dark and the soft light rot, both being of the destructive rot type with a greatly reduced cellulose and increased lignin content of the wood (Table 4).

Firm dark rot, due to *Fomes pini,* gave rise to an at first sight inexplicable increase in pulp yield, while the wood consumption was practically the same as for the corresponding sound wood. However, when it is born in mind that the yield is calculated on the basis of the percentage weight and that the fungus in this rot (white pocket rot) consumes also the lignin (Table 4), the explanation is self-evident. For the same reason, the alpha-cellulose yield was greater than for the corresponding sound wood, in spite of the drop in alpha-cellulose content. The permanganate number was slightly higher but the colour of the pulp was hardly affected by the presence of this rot (Plate II).

Firm light rot, due to *Stereum sanguinolentum* at a relatively early stage of development, gave about the same yield of pulp in per cent by

Table 8. Change (increase +, reduction —) of pulp yield, wood consumption, alpha- cellulose yield, requirement of chemicals (Östrands p-number) and brightness for unbleached rayon pulp from admixtures of 20 per cent volume of decayed wood with corresponding sound wood at the same trunk height of spruce *(Picea abies)* compared with pulp from 100 per cent of sound wood. Viscosity 40 cp.

Visual decay type	Rot fungus	Pulp yield per cent	Wood consumption in f^3 of raw wood per ton of 90 % pulp	Alpha-cellulose yield per cent	p-number according to Östrand	Brightness
Firm-light	*Stereum sanguinolentum*	0	0	+ 2	+23	No influence
Firm-dark	*Fomes pini*	+ 6	0	+ 3	+ 7	,, ,,
Soft-light	*Merulius* sp.	—12	+20	—14	+10	Impaired
Soft-dark	*Coniophora olivacea*	— 2	+ 8	— 9	+17	,,
Soft-dark	*Armillaria mellea*	—10	—26	—11	+13	Highly ,,

weight as the corresponding sound wood; the wood consumption was also the same. This may be due to the fact that the rot fungus had still not attacked the wood severely. The alpha-cellulose content and yield were unaffected by the rot. On the other hand the permanganate number was remarkably high, indicating a greater consumption of bleaching agent. The brightness, however, was unaffected by this type of rot up to 20 per cent mixture (*cf.* Table II).

The mixture of 20 per cent of wood affected by this type of rot in a still earlier stage of development, examined in the 10-litre autoclaves, resulted in no changes in any respect.

B. Production of sulphite pulp from decayed spruce wood. The Swedish Cellulose AB. Research Laboratory

Wood material

The test material consisted of knot- and bark-free chips from various types of rot-damaged wood. Admixtures of 10, 20 and 50 per cent by volume of decayed wood to the corresponding sound were used (Table 9). Except in the case of firm light rot the material was the same as that used for making rayon pulp (Table 4). The firm light rot had been caused by the same fungus but at a slightly later stage of development.

Table 9. Volume weight — expressed in kg dry substance per m³ raw wood — of spruce chips attacked by various rot fungi mixed with chips of corresponding sound wood for test cooking of sulphite pulp.

Visual decay type	Rot fungus	Kg dry substance per m³ raw wood — Volume of rot per cent				Remarks
		0	10	20	50	
Firm-dark	*Stereum sanguinolentum*	410	404	399	382	*cf.* Plate I
Firm-dark	*Fomes pini*	413	400	387	349	*cf.* Tab. 4 a. 13, Plate I
Soft-light	*Merulius* sp.	401	390	379	347	*cf.* Tab. 4 a. 13, Plate I
Soft-dark	*Coniophora olivacea*	456	444	433	399	*cf.* Tab. 4 a. 13, Plate I
Soft-dark	*Armillaria mellea*	400	376	353	284	*cf.* Tab. 4, Plate I

Method

The cooking was performed in 400 ml autoclaves under the following conditions.

Cooking schedule:

50°—100° C 6 hours
100°—110° C 2 »
110°—128° C 3 »
At 128° C For a varied period

Wood-to-liquor ratio 1: 4.0

Mill cooking liquor: total SO_2 6.2 percent
bound SO_2 1.3 »

After cooking the pulps were defiberized for 2 minutes. The screening was performed in the Wennberg laboratory screen with a slit width of 0.2 mm. The water was recirculated to avoid any loss of fibres, and thus the screened pulp contained all the fines. This procedure was used in order to obtain exact yield figures. It differs from that in the mills where the loss of fibers on the filter is appreciable. In many cases fiber fractionation is practiced (Schibbye screening) and the fiber loss may exceed 3 per cent.

Results

If the results of the test cooks — carried out at chlorine numbers varied between appr. 2 and 10 for each decay type — are interpolated to a chlorine number of 5 or 6, the pulp yield and quality values are obtained as illustrated in Table 10 and Figs. 10—11.

Table 10. Pulp yield, wood consumption and brightness in production of unbleached non-fibre-sorted sulphite pulp from mixtures of various kinds and quantities of decayed wood of spruce and corresponding sound wood at the same height in the trunks. The chlorine number — interpolated from Östrand's p-number — as near 5 as possible. *Cf.* Figs. 10 and 11.

Visual decay type	Rot fungus	Volume of rot per cent	Chlorine number	Viscosity cp	Pressure time hr	Pulp yield per cent		Wood consumption		Brightness per cent G.E.
						screened pulp	screen rejects	m^3 of raw wood per ton of 90 % pulp	f^3 per ton of 90 % pulp	
Firm-dark	*Stereum sanguinolentum*	0	4.9	202	3.40	50.0	0	4.40	155	69.5
		10	4.9	175	3.45	49.5	0	5.51	160	57.6
		20	4.3	146	4.30	48.5	0	4.66	165	59.9
		50	5.2	142	4.30	48.0	0	4.91	174	48.7
Firm-dark	*Fomes pini*	0	4.5	188	3.25	53.1	0	4.10	145	65.1
		10	4.9	193	3.20	53.3	0	4.23	150	61.6
		20	4.3	160	3.40	52.3	0	4.45	157	65.0
		50	5.0	108	3.40	52.5	0	4.91	173	61.1
Soft-light	*Merulius* sp.	0	5.0	140	3.30	50.0	0	4.50	159	66.5
		10	4.6	—	3.40	48.0	0	4.80	170	63.9
		20	5.5	162	3.10	45.8	0	5.19	183	61.6
		50	5.7	—	2.45	36.4	0	7.81	276	57.8
Soft-dark	*Coniophora olivacea*	0	4.6	160	3.40	50.0	0	3.95	139	68.9
		10	5.5	—	3.20	47.3	0	4.29	152	64.6
		20	5.7	127	3.15	45.6	0	4.56	161	63.0
		50	5.4	125	3.00	36.0	0	6.27	221	52.0
Soft-dark	*Armillaria mellea*	0	5.9	190	3.45	49.0	0	4.60	163	64.5
		10	5.8	164	3.45	48.6	0	4.92	174	57.6
		20	6.3	146	3.40	49.0	0	5.20	184	48.5
		50	6.3	121	4.20	47.5	0	6.66	235	37.5

In a test series the various types of pulps were mixed in such proportions as to provide a pulp with chlorine number 6. These pulps were used for beating according to Lampén and dirt count. The results are given in Table 11.

From Tables 10—12 and Figs. 10—11 the following conclusions may be drawn. The comparison was made consistently with a 10 per cent mixture by volume of decayed wood, this being a reliable upper margin for the rot mixture in practice.

Soft dark rot, caused by *Armillaria mellea* in the fully developed stage (Plate I) resulted in a considerable reduction in the pulp yield and an 8 per cent increase in wood consumption. The screen reject count increased by quite a large amount and the colour of the unbleached pulp deteriorated considerably. On the other hand, the addition of 10 per cent of this rot did not appreciably reduce the strength of the pulp.

Soft dark rot, due to *Coniophora olivacea,* caused a considerable drop in yield and so great an increase in wood consumption that it is prob-

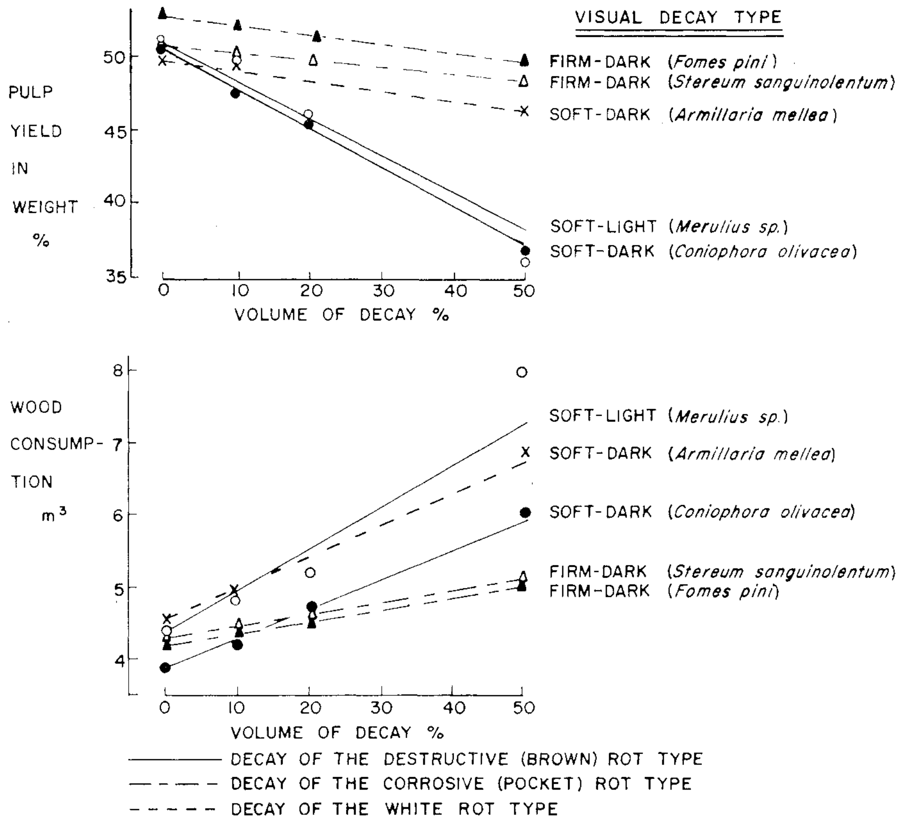

Fig. 10. Pulp yield (weight per cent of corresponding sound wood) and wood consumption (m^3 of raw wood per ton of 90 % pulp) in production of unbleached sulphite paper pulp from mixtures of various kinds and quantities of decayed wood in corresponding sound wood at the same trunk height of *Picea abies*. Chlorine number 6. The Swedish Cellulose AB. Research Lab.

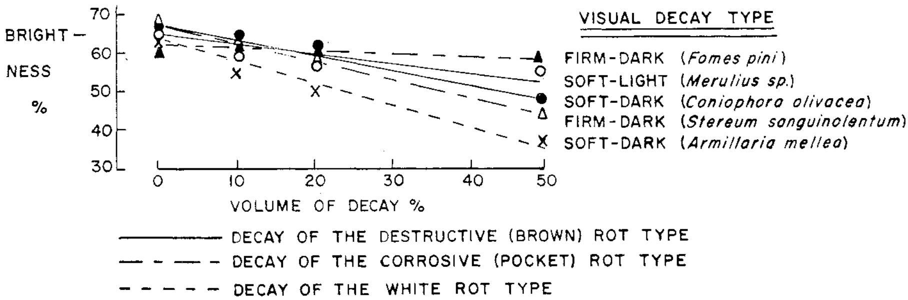

Fig. 11. Brightness (per cent G.E.) in production of unbleached sulphite paper pulp from mixtures of various kinds and quantities of decayed wood in corresponding sound wood at the same trunk height of *Picea abies*. Chlorine number 6. The Swedish Cellulose AB. Research Lab.

Table 11. Dirt count and strength tests conducted at a chlorine number of about 6 of unbleached sulphite paper pulp made from mixtures of various kinds and amounts of decayed spruce wood *(Picea abies)* and the corresponding sound wood at the same trunk height.

Visual decay type	Rot fungus	Volume of rot per cent	Dirt		Strength tests				
			Screen rejects number per 100 g pulp	Specks number per 100 g pulp	Beating number	Breaking length (according to Schopper) km	Tear factor (according to Brecht-Imset) gcm/cm	Bursting strength (Mullen-test) per cent	Double fold number
Firm-dark	*Stereum sanguinolentum*	0	14000	—	17000	12.6	74	90	5900
		20	18000	—	15000	12.4	67	87	5250
		50	18000	—	13250	12.5	70	81	3800
Firm-dark	*Fomes pini*	0	4000	—	14000	11.9	77	78	3800
		10	10000	—	15000	11.9	63	82	4150
		20	12000	—	12500	11.4	64	87	4250
		50	18000	—	11500	10.7	58	69	3300
Soft-light	*Merulius* sp.	0	6000	—	14000	13.3	78	98	5500
		10	8000	—	13000	12.5	74	83	3900
		20	13000	—	10000	13.1	60	89	3800
		50	24000	—	10000	11.5	59	75	2450
Soft-dark	*Coniophora olivacea*	0	4000	500	15500	12.0	73	87	5600
		10	5000	550	15000	13.0	70	92	5500
		20	7500	550	15000	11.9	70	83	4600
		50	13000	600	11750	11.1	66	83	3300
Soft-dark	*Armillaria mellea*	0	7000	—	16000	12.9	71	93	5750
		10	16000	—	16000	12.1	70	92	5350
		20	19000	—	14500	12.5	70	82	4000
		50	25000	—	11000	11.1	65	86	2900

able that most of the decayed wood was dissolved during the cook. The brightness and screen reject count were therefore not affected as much as would be expected, nor was the strength of the pulp.

Soft light rot, due to a species of *Merulius,* mixed with the corresponding sound wood, gave a considerably lower pulp yield than the corresponding sound wood, and the wood consumption was about 7 per cent higher. The screen reject count increased considerably, although not as much as expected. Since the soft light rot, like the dark type, was a typical destructive (brown) rot, the effect may reasonably be ascribed to the consumption of a considerable portion of the decayed wood in the cook. As a consequence there was little change in colour or strength of the pulp.

Firm dark rot, due to *Fomes pini,* caused a reduction of about 5 per cent in the yield and about the same increase in wood consumption. The screen reject count was increased by a fairly large amount, whereas neither colour nor strength was affected appreciably.

Firm dark rot, due to *Stereum sanguinolentum* in a typical top rot

Table 12. Change (increase +, reduction —) of pulp yield, wood consumption, brightness, impurities and strength in production of unbleached sulphite paper pulp from admixtures of 10 per cent by volume of decayed spruce wood *(Picea abies)* to corresponding sound wood at the same trunk height. Chlorine number 6. *Cf.* Tables 10 and 11, Figs. 10 and 11.

Visual decay type	Rot fungus	Pulp yield per cent	Wood consumption in f^3 of raw wood per ton of 90 % pulp	Brightness per cent G.E.	Specks number per 100 g pulp	Screen rejects number per 100 g pulp	Beating number	Breaking length km	Tear factor gcm/cm	Bursting strength per cent	Double fold number
Firm-dark	*Stereum sanguinolentum*	—2.9	+3.0	—4.0	—	+2000	+1000	—0.1	—2	—2	—400
Firm-dark	*Fomes pini*	—4.8	+5.0	—0.5	—	+5500	+ 600	—0.2	—6	±0	+200
Soft-light	*Merulius* sp.	—6.5	+6.8	—2.0	—	+3500	+1000	—0.4	—4	—5	—700
Soft-dark	*Coniophora olivacea*	—8.3	+9.1	—2.0	+50	+1000	+ 500	+0.5	—1	+3	—300
Soft-dark	*Armillaria mellea*	—7.3	+7.7	—6.0	—	+7500	+ 500	—0.3	—1	—3	—650

in the intermediate stage of development (Plate I), resulted in a reduction in the pulp yield and an increase in wood consumption of about 3 per cent. The brightness was considerably lower but the strength practically unchanged.

C. Production of sulphate pulp from decayed pine and spruce wood. Uddeholm AB. Research Laboratory

Wood material

For the preparation of the sulphate pulp, chips of the same type as in the test cooks of rayon and sulphite pulps were used (Tables 4 and 9). The types of rot and the proportions of rot-damaged wood are given in Table 13, with the data on the volume weight, lignin, and pentosan content of the material.

Method

In the test cooks the same procedure was used as in the earlier examination of decayed wood with *Fomes annosus* (Björkman *et al.*, 1949, pp 39—49).

Table 13. Wood analysis of spruce *(Picea abies)* and pine *(Pinus silvestris)* chips for test cooking of sulphate pulp.

Visual decay type	Wood	Rot fungus	Volume weight kg dry substance per m³ raw wood (Tappi 18-m)		Lignin content (CCA 5) per cent		Pentosan content per cent		Remarks
			Sound wood	Decayed wood	Sound wood	Decayed wood	Sound wood	Decayed wood	
Firm-light	spruce	*Stereum sanguinolentum*	417	377	28.4	29.1	5.23	5.28	*cf.* Tab. 4
Firm-dark	spruce	*Fomes pini*	413	286	28.8	24.5	—	—	*cf.* Tab. 4 a.9
Firm-dark	pine	*Fomes pini*	417	331	—	—	—	—	*cf.* Plate I
Firm-dark	spruce	*Armillaria mellea*	413	459	29.2	34.8	4.77	4.58	*cf.* Tab. 4
Soft-light	spruce	*Merulius* sp.	401	294	30.2	46.1	—	—	*cf.* Tab. 4 a.9, Plate I
Soft-dark	spruce	*Coniophora olivacea*	456	341	28.0	38.5	—	—	*cf.* Tab. 4 a.9, Fig. 1
Soft-dark	pine	*Coniophora fusispora*	448	318	26.8	68.7	4.26	2.03	*cf.* Plate I

Results

The results of the test cooks are given in Table 14 and Fig. 12. Fig. 12 shows, as for the test cooks of *Fomes annosus* wood, a linear relationship between the proportion of decayed wood and the yield. The severity of the rot attack is represented by the slope of the lines. The 45° line in the diagram indicates complete dissolution of the rot wood. The soft light and the soft dark rots closely approach this line for both pine and spruce. The light type seems to be as harmful as the dark one. Both dark and, especially, light firm rot and *Armillaria* rot, which in this case was in an early stage of development, were practically harmless, at least in the 10 per cent mixture (*cf.* Table 4, 10-litre autoclaves).

Bleaching tests. — After the cooking, the pulps containing 20 per cent decayed wood of different types were bleached and compared with pulps prepared from the corresponding sound wood. In all cases 100 g of unbleached pulp was used with a chlorine number as near 5 as possible.

Pre-bleaching:

1st stage, hypochlorite (per cent Cl = chlorine number)

2nd stage, chlorine water, 3 per cent Cl

3rd stage, alkali extraction, 2.5 per cent NaOH

Table. 14. Pulp yield of sulphate pulp made of mixtures of various kinds and quantities of decayed wood of spruce *(Picea abies)* and pine *(Pinus silvestris)* and corresponding sound wood at the same trunk height, and requirement of alkali (g NaOH per kg wood) at constant time of cooking, and reduction of pulp yield in comparison with the yield of corresponding sound wood.

Visual decay type	Wood	Rot fungus	Volume of decay per cent	Pulp yield		Active alkali g NaOH per kg wood	Reduction of pulp yield per cent, rel. sound wood
				per cent	kg per m^3 wood		
Firm-light	spruce	*Stereum sanguinolentum*	0	47.7	199	204	± 0
			10	47.6	197	205	— 2
			20	47.2	193	205	— 3
			50	46.6	185	207	— 7
Firm-dark	spruce	*Fomes pini*	0	48.1	201	202	± 0
			10	48.0	196	201	— 2
			20	47.9	192	201	— 4
			50	47.5	178	199	—11
Firm-dark	pine	*Fomes pini*	0	46.2	191	207	± 0
			10	46.0	184	209	— 3
			20	45.9	178	210	— 7
			50	44.7	156	220	—18
Firm-dark	spruce	*Armillaria mellea*	0	47.5	196	203	± 0
			10	46.7	195	203	— 1
			20	46.1	195	208	— 1
			50	43.8	191	210	— 3
Soft-light	spruce	*Merulius* sp.	0	45.2	181	211	± 0
			10	43.8	171	213	— 5
			20	41.0	156	221	—14
			50	32.2	112	251	—33
Soft-dark	spruce	*Coniophora olivacea*	0	48.1	219	201	± 0
			10	45.2	201	209	— 8
			20	43.3	187	213	—15
			50	34.1	136	244	—38
Soft-dark	pine	*Coniophora fusispora*	0	48.3	216	203	± 0
			10	45.2	197	209	— 9
			20	41.8	178	218	—18
			50	29.8	114	253	—47

Final bleaching:

The pulp was divided into 3 equal parts, which were bleached as follows:

A. 1.5 per cent chlorine as hypochlorite, 0.5 per cent NaOH, 3.5 hours at 40° C

B. 2.5 per cent chlorine as hypochlorite, 1.0 per cent NaOH, 5 hours at 45° C

C. 1. As A

2. 0.5 per cent NaOH, 1 hour at 60° C

3. 1.0 per cent Cl-$NaClO_2$ (chlorite), 4 hours at 60° C

All pulps were washed, treated with 1 per cent sulphur dioxide for 30 minutes at 20° C, washed again and formed into sheets. For all the

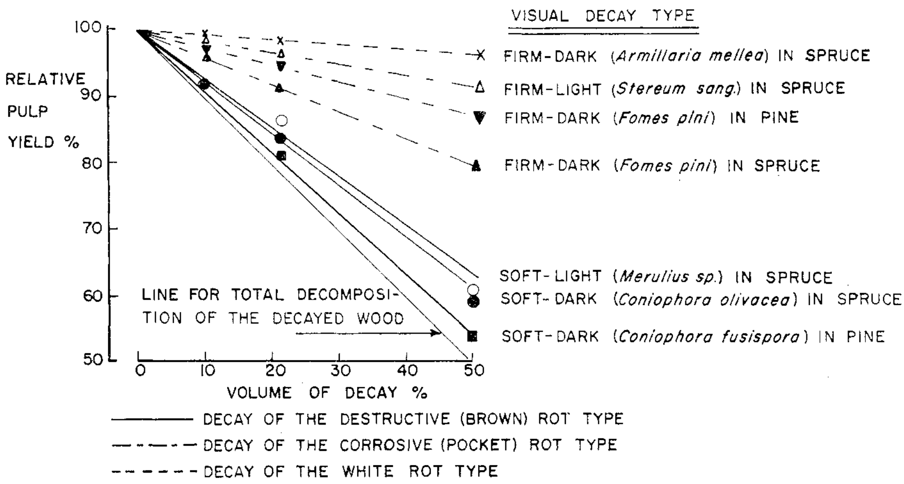

Fig. 12. Relative pulp yield (weight per cent of corresponding sound wood) in production of unbleached sulphate paper pulp from mixtures of various kinds and quantities of decayed wood in corresponding sound wood at the same trunk height of *Picea abies* and *Pinus silvestris*, respectively. Uddeholm AB. Research Lab.

stages of treatment and washing in the final bleaching, distilled water was used. The results of the comparison are given in Table 15.

For the 20 per cent mixtures used for the bleaching tests no statistically significant effect was found with respect to either viscosity or brightness. Even when bleachings A and B are combined there is no significant difference between the rot-damaged and sound woods.

Strength tests. — For this purpose pulps with a chlorine number as near 5 as possible were chosen from the cooking series. In some cases new cooks had to be performed specially for the strength tests. The test was carried out according to Swedish Standard Method CCA 17 by beating in a Lampén mill to between 40° and 50° SR. Table 16 gives the breaking length, the tear factor and the bursting strength for different types of rot and proportions of rot in corresponding sound wood.

To examine the reproducibility of the method, an additional series of cooks (10 autoclaves for each series) with absolutely sound spruce wood was carried out under the same conditions as the test cooks, and the samples were subjected to all the tests used as a basis of assessment. The means and range of variation were calculated, the latter as the standard deviation. In addition the confidence limits were determined for the 90 per cent probability of being able to distinguish between two separate samples. This requirement was satisfied if the

Table 15. Viscosity and brightness of bleached sulphate pulp of spruce *(Picea abies)* and pine *(Pinus silvestris)* wood at different types of final bleaching. Admixtures of 20 per cent volume of decayed wood to corresponding sound wood. Chlorine number 5.

Visual decay type	Wood	Rot fungus	Final bleaching					
			A		B		C	
			Viscosity cp	Brightness per cent G.E.	Viscosity cp	Brightness per cent G.E.	Viscosity cp	Brightness per cent G.E.
Firm-light	spruce	*Stereum sanguinolentum*	19.1	84.6	12.3	86.2	20.4	90.4
Firm-dark	spruce	*Fomes pini*	16.5	85.6	10.1	87.6	17.3	90.0
Firm-dark	pine	*Fomes pini*	18.4	84.8	10.6	87.5	20.1	90.2
Firm-dark	spruce	*Armillaria mellea*	18.6	85.0	12.1	87.8	21.7	90.9
Soft-light	spruce	*Merulius* sp.	16.5	84.0	10.3	86.5	18.9	89.5
Soft-dark	spruce	*Coniophora olivacea*	18.5	84.0	10.2	86.8	19.1	89.3
Soft-dark	pine	*Coniophora fusispora*	18.4	84.8	10.6	87.5	20.1	90.2

values varied by $\pm$ 2.6 σ. Within these limits the probability was in fact greater than that given above, since the tests were usually included in a series in which the only difference was a greater proportion of decayed wood, or, conversely if the probability was kept constant the limits could be made narrower.

As Table 17 shows, it was only in exceptional cases that the inclusion of decayed wood resulted in a statistically significant reduction in strength at the 90 per cent level of confidence. As pointed out above, the limits may be narrower in this case since for each type of rot the experimental material consisted of 4 samples containing different proportions of decayed wood. The earlier impression provided by the findings for *Fomes annosus* rot (BJÖRKMAN *et al.*, 1949) was thus confirmed, namely that the strength is hardly affected by the inclusion of small amounts of decayed wood. This might appear strange in view of the fact that the cellulose from such wood was more or less decomposed, as was evident from, for instance, the viscosity and fibre length (*cf. Fomes annosus, loc. cit.*). As mentioned above, however, the explanation probably lies in the fact that in some cases the yield of cellulose from the decayed wood was extremely low. In the case of soft dark rot, which for the 50 per cent mixture gave only 53 per cent of the yield of sound wood, the amount of cellulose derived from the decayed wood was only about 5 per cent. As regards the fibre loss in

Table 16. Strength tests after beating in a Lampén mill to a beating degree of 40°—50° SR of sulphate pulp from spruce *(Picea abies)* and pine *(Pinus silvestris)* wood with admixtures of decayed wood (0 per cent and 10 per cent together, and 20 per cent and 50 per cent together, respectively).

Visual decay type	Wood	Rot fungus	Volume of rot per cent	Breaking length (according to Schopper) km	Tear factor (according to Brecht-Imset gcm/cm	Bursting strength (Mullen-test) per cent
Firm-light	spruce	*Stereum sanguinolentum*	0—10	13.1	299	277
			20—50	12.5	267	244
Firm-dark	spruce	*Fomes pini*	0—10	11.8	264	232
			20—50	11.4	250	210
Firm-dark	pine	*Fomes pini*	0—10	12.2	278	248
			20—50	12.2	272	238
Firm-dark	spruce	*Armillaria mellea*	0—10	12.2	306	252
			20—50	12.2	269	239
Soft-light	spruce	*Merulius* sp.	0—10	13.2	236	262
			20—50	12.2	211	258
Soft-dark	spruce	*Coniophora olivacea*	0—10	12.6	290	250
			20—50	12.3	270	238
Soft-dark	pine	*Coniophora fusispora*	0—10	11.6	335	232
			20—50	11.3	318	224

sheet formation, the amount in the paper produced of the pulp was probably still lower. It is consequently not so strange that no statistically significant effect on the strength was noted even in this case, in spite of the extremely severe attack by this fungus. The risk of a lower quality of the paper is probably greater for a rot of the type that gives a higher pulp yield and where the fungus has only begun its destructive activity on the cellulose with a reduction in the degree of polymerization (viscosity) as a consequence. In both cases the reduction in volume yield and the increase in the consumption of chemicals in the cooking remain the most serious effect of including decayed wood.

A more reliable assessment of the effect of a large proportion of decayed wood may be obtained from the experimental findings by combining the two highest proportions 20 and 50 per cent, considering this as the mean of a duplicate sample and comparing it with the corresponding mean for 0 and 10 per cent samples. The confidence limits in this duplication of the number of specimens can then be narrowed to 1.8 times the σ-value in Table 17 against 2.6 for the comparison of single specimens. The results of such a calculation are shown in Table 16. It is seen that even with the narrowed confidence limits there was a statistically significant reduction in the strength in only 3 cases, namely in breaking length for soft light rot, and in bursting strength (Mullen) for firm dark rot and for firm light rot.

Table 17. Means, standard deviations, and confidence limits of strength tests of experimental cooks of sulphate pulp of sound wood of spruce *(Picea abies)*. Number of cooks 10. Chlorine number 5. Beating, 40°—50° SR. Viscosity and brightness determined on bleached pulp.

Analysis	Mean	Standard deviation		Confidence limit $2.6 \times \sigma$ in per cent of mean
		in the same unit as mean	in per cent of mean	
Pulp yield	47.67	0.12	0.25	0.65
Chlorine number	4.37	0.07	1.60	4.2
Viscosity	17.87	0.31	3.95	10.3
Brightness	84.68	1.37	1.62	4.2
Breaking length	11.5	0.28	2.5	6.5
Tear factor	319.7	15.2	4.8	12.5
Bursting strength	243.0	6.7	2.8	7.3

The latter two are types of decayed wood that provide a relatively high yield, that is to say, they may be expected to be included in the paper to an appreciable extent. It should be observed, however, that in all the cases examined both bursting strength (Mullen) and tear factor were lower for the higher proportion of decayed wood; this is convincing proof that the rot-damaged wood usually reduces the strength of paper.

D. Production of sulphite pulp from decayed or stained birch *(Betula verrucosa)*, aspen *(Populus tremula)* and alder *(Alnus glutinosa)* wood. Mo och Domsjö AB. Research Laboratory

Wood material

Chips of eight samples of birch, aspen and alder wood were mixed with the corresponding sound wood in the proportions 20 and 50 per cent per volume. Data for the test material are given in Table 18. The soft light rot in aspen and the soft dark rot, caused by *Armillaria mellea,* in birch were in a far advanced stage. The wood affected by *Diaporthe aristata* consisted of approximately equal parts of dark stained wood and soft rot associated with this dark coloured wood. The "firm red" wood consisted of a fairly dark variant of the so-called red heartwood of birch, in which there was no rot. *Cf.* Plate II.

Method

The sulphite cooks were performed in rotating electrically heated 10-litre autoclaves. These were provided with small containers divided

Table 18. Wood analysis of birch *(Betula verrucosa)*, aspen *(Populus tremula)*, and alder *(Alnus glutinosa)* chips for test cooking of sulphite pulp.

Visual decay or stain type	Wood	Rot fungus	Volume weight kg dry substance per m³ raw wood (Tappi 18-m)		Lignin content per cent (CCA 5)		Pentosan content per cent (CCA 24)		Extractives content per cent DMC — ethanol per cent		Remarks
			Sound wound	Decayed or stained wood	Sound wood	Decayed or stained wood	Sound wood	Decayed or stained wood	Sound wood	Decayed or stained wood	
Firm-dark	Birch	*Fomes igniarius*	524	508	19.8	21.8	23.7	24.7	2.53	3.30	*cf.* Plate II
Firm-dark	Aspen	*Fomes igniarius*	367	334	17.0	19.7	19.4	21.4	3.53	1.45	
Soft-dark (advanced)	Birch	*Armillaria mellea*	539	194	20.0	58.6	24.0	7.5	0.36	4.15	*cf.* Fig. 3
Soft-dark	Birch	*Diaporthe aristata*	—	461	—	23.4	—	24.1	—	4.62	*cf.* Fig. 4, Plate II
Soft-dark	Alder	*Polyporus radiatus*	—	358	—	29.1	—	20.4	—	5.60	
Soft-light	Birch	*Fomes igniarius*	463	205	20.1	27.2	25.3	18.8	2.18	2.98	*cf.* Plate II
Soft-light (very advanced)	Aspen	*Fomes igniarius*	399	160	17.1	21.5	18.8	19.3	3.39	2.76	
Firm-red (red heartwood) (stain)	Birch	—	523	539	19.6	20.9	27.0	23.0	1.90	6.35	*cf.* Fig. 5 Plate II

into three compartments, which enabled three chip mixtures containing 0, 20 and 50 per cent of attacked wood to be cooked simultaneously under identical conditions as regards cooking time, quantity of chemicals added, temperature and pressure.

The cooks were made with liquors containing 1.2 per cent of calcium oxide and 6.0 per cent of sulphur dioxide. The quantities of chemicals added, based on the dry weight of the wood, were 4.2 per cent of calcium oxide and 21.0 percent of sulphur dioxide. The wood-to-liquor ratio was 1: 4.5. The maximum cooking temperature was 135° C and the pressure 5.5 kp/cm². In the cases in which the wood was rot-free the birch and alder pulps were cooked to a chlorine number in the range 3.5—5.5; for the aspen pulps the corresponding range was 2.5—3.0.

The samples of washed and screened pulps were dried, and subjected to beating in the Lampén mill. Sheets were made according to Swedish Standard Methods, and finally subjected to strength tests in the unbleached state.

Bleaching tests were performed with all the birch and aspen pulps to determine the chemical consumption and brightness. The bleaching process was performed by the following sequence: chlorination, alkali extraction, hypochlorite treatment, chlorine dioxide treatment, sulphur dioxide washing.

Results

Tables 19—21 give the results of the most important analyses with respect to yield, consumption of chemicals, brightness and strength. Figs. 13—15 show the effect of rot damage on pulp yield, wood consumption and degree of cooking (Roe's chlorine number).

An increase in chlorine number reflects a greater consumption of chemicals in the bleaching of the pulp, as is illustrated by the corresponding values of the chlorine number, chlorine consumption and brightness given in Tables 19 and 21. In the latter table the test results are given in a greatly abridged form.

From Tables 19—21 and Figs. 13 and 14 the following tendencies can be seen despite the limited test material. The comparison was made consistently for the 20 per cent mixture of decayed or stained wood — a reliable upper margin for such a mixture that can occur in broad-leafed trees and which may be comparable with approximately a 10 per cent margin for conifers (*cf.* Table 12 and Fig. 9).

Soft light rot in birch, caused by *Fomes igniarius,* in a fairly

Table 19. Pulp yield, wood consumption, requirement of chemicals, and brightness in production of unbleached and bleached sulphite pulp from mixtures of various kinds and quantities of decayed or stained wood of birch *(Betula verrucosa)*, aspen *(Populus tremula)* and alder *(Alnus glutinosa)* and corresponding sound wood at the same trunk height.

Visual decay or stain type	Wood	Rot fungus	Volume of decay or stain per cent	Unbleached pulp: Pulp yield per cent of absolute dry wood, Absolute	Unbleached pulp: Pulp yield per cent of absolute dry wood, Rel. sound wood	Unbleached pulp: Wood consumption in f^3 of raw wood per ton of 90 % pulp, Absolute	Unbleached pulp: Wood consumption, Rel. sound wood	Unbleached pulp: Chlorine number, Absolute	Unbleached pulp: Chlorine number, Rel. sound wood	Bleached pulp: Pulp yield per cent of unbleached pulp, Absolute	Bleached pulp: Wood consumption in f^3 of raw wood per ton of 90 % pulp, Absolute	Bleached pulp: Wood consumption, Rel. sound wood	Bleached pulp: Consumption of active chlorine per cent of unbleached pulp, Absolute	Bleached pulp: Consumption of active chlorine, Rel. sound wood	Brightness per cent G.E.
Firm-dark	Birch	*Fomes igniarius*	0	49.9	100	122	100	3.5	100	91.5	134	100	6.57	100	86.5
			20	49.4	99	124	102	3.7	106	93.2	133	99	6.12	93	86.7
			50	48.5	97	128	105	5.6	160	91.8	139	104	9.23	140	86.7
Firm-dark	Aspen	*Fomes igniarius*	0	53.6	100	162	100	2.6	100	94.5	—	—	—	—	92.6
			20	53.5	100	165	102	2.9	111	95.3	—	—	—	—	92.3
			50	53.8	100	169	104	3.8	146	90.6	—	—	—	—	92.1
Soft-dark	Birch	*Armillaria mellea*	0	44.4	100	135	100	5.4	100	95.9	146	100	9.13	100	85.2
			20	47.2	105	149	110	8.5	157	94.5	158	109	13.87	152	84.2
			50	49.8	112	189	140	>12	—	—	—	—	—	—	—
Soft-dark	Birch	*Diaporthe aristata*	0	50.3	100	122	100	5.2	100	91.9	133	100	9.25	100	90.7
			20	49.2	98	136	112	6.8	131	91.5	149	112	11.32	123	89.5
			50	50.4	100	145	119	9.3	179	86.2	168	127	14.92	161	86.7
Soft-dark	Alder	*Polyporus radiatus*	0	41.0	100	205	100	5.4	100	—	—	—	—	—	—
			20	42.3	103	227	111	6.7	124	—	—	—	—	—	—
			50	40.6	101	243	119	8.8	163	—	—	—	—	—	—
Soft-light	Birch	*Fomes igniarius*	0	42.9	100	160	100	3.5	100	95.1	168	100	6.52	100	85.7
			20	46.3	108	165	103	3.8	108	93.5	176	105	6.43	99	86.9
			50	50.1	116	187	114	5.6	160	92.2	203	121	10.00	153	88.5
Soft-light	Aspen	*Fomes igniarius*	0	54.4	100	146	100	2.6	100	94.2	155	100	5.31	100	92.5
			20	52.7	97	172	117	3.1	119	94.2	182	117	—	—	92.6
			50	51.0	94	223	152	3.8	146	91.4	244	156	—	—	92.7
Firm-red (red heart-wood) (stain)	Birch	—	0	48.7	100	126	100	4.0	100	92.5	—	—	7.10	100	86.3
			20	47.4	97	128	102	5.0	125	93.3	—	—	8.48	119	85.0
			50	47.0	96	128	102	7.3	183	92.0	—	—	10.94	154	86.0

Table 20. Strength tests after beating of sulphite pulps of birch *(Betula verrucosa)* and aspen *(Populus tremula)* wood with admixtures of decayed or stained wood to corresponding sound wood.

Visual decay or stain type	Wood	Rot fungus	Volume of decay or stain per cent	Degree of beating °SR	Beating number of revolutions	Breaking length (according to Schopper) km	Tear factor (according to Elmendorf)	Burst factor (Mullen-test)
Firm-dark	Birch	*Fomes igniarius*	0	38.5	10.000	7.2	73	45
			20	43.5	10.000	7.1	61	43
			50	43.0	10.000	7.0	50	42
Firm-dark	Aspen	*Fomes igniarius*	0	45.0	11.500	7.2	128	47
			20	46.5	11.100	7.5	112	49
			50	47.5	10.000	7.9	106	51
Soft-dark	Birch	*Armillaria mellea*	0	50.0	10.000	7.7	76	49
			20	41.0	5.000	7.2	67	46
			50	47.0	5.000	7.0	61	37
Soft-dark	Birch	*Diaporthe aristata*	0	47.5	10.000	8.2	72	56
			20	35.0	7.200	8.2	72	58
			50	39.0	7.000	8.1	65	57
Soft-light	Birch	*Fomes igniarius*	0	44.0	17.500	9.0	107	66
			20	48.5	16.000	9.3	95	68
			50	59.0	16.000	9.6	77	69
Soft-light	Aspen	*Fomes igniarius*	0	46.0	12.000	7.3	115	48
			20	47.0	9.000	7.2	110	46
			50	51.5	7.000	7.5	109	44
Firm-red (stain)	Birch	—	0	42.0	12.000	7.9	99	54
			20	45.5	14.000	8.1	87	50
			50	49.5	12.000	8.1	78	53

advanced stage gave a higher pulp yield but also a higher consumption of wood than the sound wood from the same tree. The chlorine consumption increased with the proportion of decayed wood. As the strength test on the pulps had to be performed at different degrees of beating — evidently because the beating properties were depending on the percentage of decayed wood present — no clear effect on the strength could be demonstrated.

As to *soft light rot in aspen,* caused by *Fomes igniarius,* in an advanced stage (Table 18), for a given cooking time the yield was lower and the wood consumption much greater than for the sound wood from the same tree. The decaying process was evidently so far advanced that the cellulose had already been extensively consumed by the fungus. Moreover, this rot, like the same type in birch, increased considerably the degree of cooking (chlorine number) and consumption of bleaching agents. It had little effect on the strength of the pulp but facilitated the beating. The brightness of the bleached pulp was not affected.

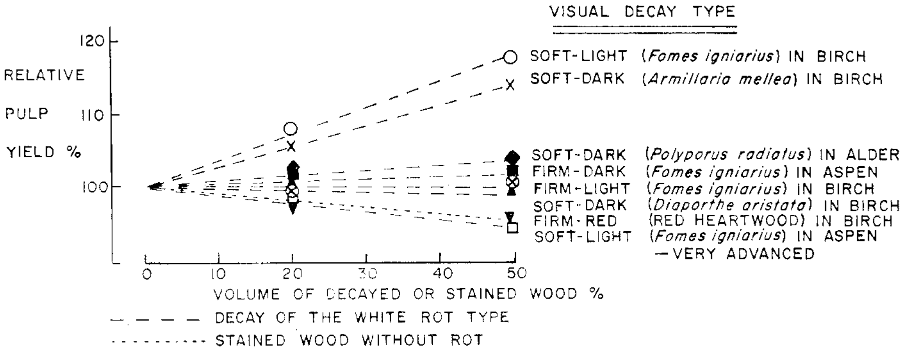

Fig. 13. Relative pulp yield (weight basis) in production of bleached sulphite paper pulp from mixtures of various kinds and quantities of decayed or stained wood in corresponding sound wood at the same trunk height of *Betula verrucosa*, *Populus tremula* and *Alnus glutinosa*, respectively. Mo och Domsjö AB. Research Lab.

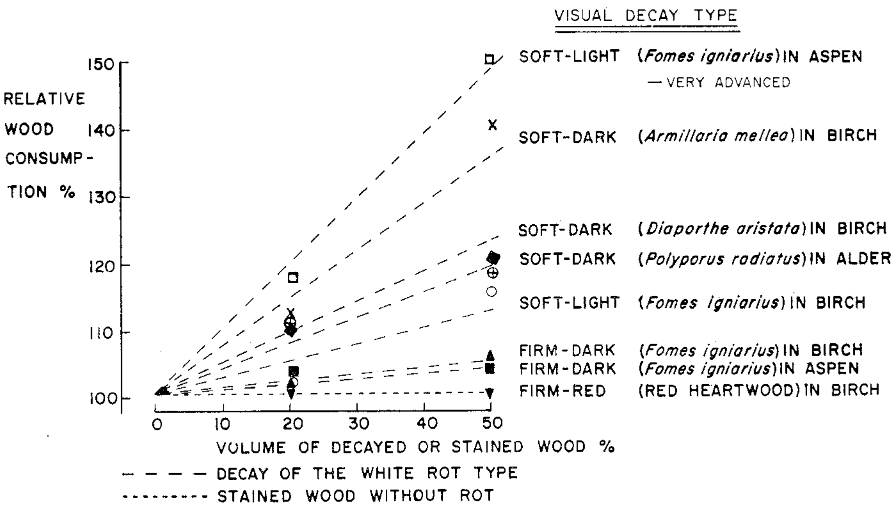

Fig. 14. Relative wood consumption (volume basis) in production of bleached sulphite paper pulp from mixtures of various kinds and quantities of decayed or stained wood in corresponding sound wood at the same trunk height of *Betula verrucosa*, *Populus tremula* and *Alnus glutinosa*, respectively. Mo och Domsjö AB. Research Lab.

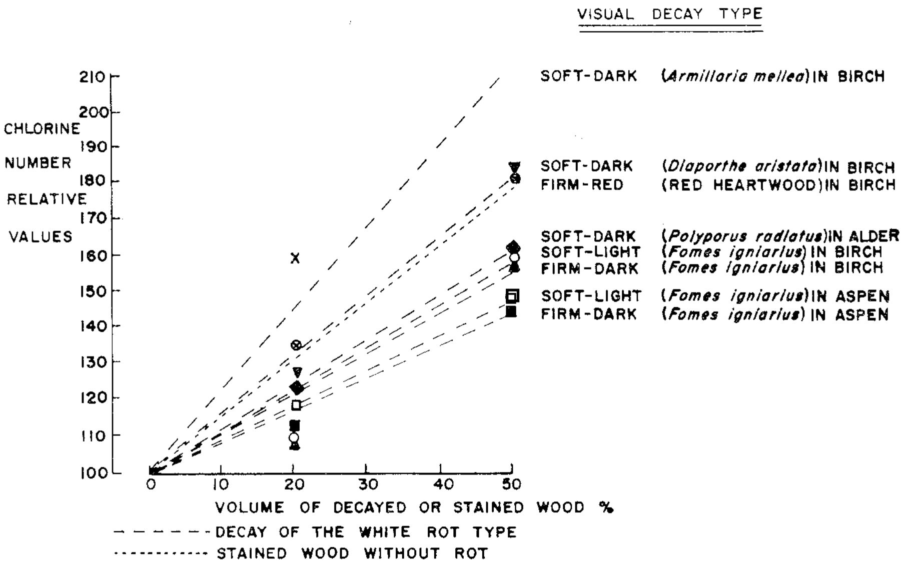

Fig. 15. Relative change in the chlorine number (degree of cooking, consumption of bleaching reagent) at constant time of cooking in production of bleached sulphite paper pulp from mixtures of various kinds and quantities of decayed or stained wood in corresponding sound wood at the same trunk height of *Betula verrucosa, Populus tremula* and *Alnus glutinosa,* respectively. Mo och Domsjö AB. Research Lab.

Soft dark rot in birch, caused by *Armillaria mellea,* increased considerably the consumption of wood over that required by the corresponding sound wood. The presence of such rot caused a much higher consumption of chlorine in the bleaching of the pulp. It was not established whether the brightness of the bleached pulp was affected. On the other hand, there was a marked reduction in the strength when *Armillaria* rot was added.

Soft dark rot in birch, caused by *Diaporthe aristata,* gave the same yield as the corresponding sound wood but the consumption of wood was greatly increased. The inclusion of *Diaporthe*-damaged wood resulted in a higher chlorine number and a considerable increase in the consumption of bleaching chemicals. The pulp was not so bright as when sound wood was used. Apart from a tendency for a slight impairment of the tear factor, the strength was unaffected.

Soft dark rot in alder was examined in a few samples attacked by *Polyporus radiatus* and proved to cause a great increase in wood and chemical consumption.

Table 21. Change (increase +, reduction —) of pulp yield, wood consumption, chlorine number (consumption of chemicals), and bleaching properties in production of unbleached sulphite pulp from mixtures of 20 per cent decayed or stained wood of birch *(Betula verrucosa)*, aspen *(Populus tremula)* and alder *(Alnus glutinosa)* and corresponding sound wood at the same trunk height. Time of cooking constant.

Visual decay or stain type	Wood	Rot fungus	Pulp yield per cent	Wood consumption in f³ of raw wood per ton of 90 % pulp	Chlorine number	Brightness per cent G.E. after bleaching
Firm-dark	Birch	*Fomes igniarius*	—0.5	+ 2	+0.2	+0.2
Firm-dark	Aspen	*Fomes igniarius*	—0.1	+ 3	+0.3	—0.3
Soft-dark	Birch	*Armillaria mellea*	+2.8	+14	+3.1	—1.0
Soft-dark	Birch	*Diaporthe aristata*	—1.1	+14	+1.6	—1.2
Soft-dark	Alder	*Polyporus radiatus*	+1.3	+22	+1.3	—
Soft-light	Birch	*Fomes igniarius*	+3.4	+ 5	+0.3	+1.2
Soft-light	Aspen	*Fomes igniarius*	—1.7	+26	+0.5	+0.1
Firm-red (stain)	Birch	—	—1.3	+ 2	+1.0	—1.3

Firm dark rot in both birch and aspen, produced by *Fomes igniarius,* in an earlier stage of development than in the soft light rot (Plate II) gave a pulp that differed little from the pulp made from the corresponding sound wood, as regards pulp yield, wood consumption and brightness of the bleached pulp. On the other hand, the inclusion of decayed wood resulted in an increase in the degree of cooking and the consumption of chemicals in the bleaching of sulphite pulp. The presence of firm dark rot diminished the strength (tear factor) of the pulp to some extent.

Firm red wood in the so-called red heartwood in birch, devoid of rot (Plate II), gave a pulp which, as regards wood consumption and brightness after bleaching, was similar to the pulp made from sound wood. There was a tendency for a lowering of the strength (tear factor) and a considerable increase in the chlorine number, and hence in the quantity of chlorine required for bleaching.

E. Production of greaseproof pulp from decayed or stained birch *(Betula verrucosa)* wood. Billerud AB. Research Laboratory

Wood material

For a direct comparison of the production of greaseproof with the production of "ordinary" sulphite pulp in the Mo och Domsjö test cooks (Chapter D), with respect to pulp yield, bleaching and strength, chips of the same type were used and in the same proportions (Table 18). As a consequence the available chip material was rather limited, especially the control wood from the same trunk, and a thorough statistical analysis was also not possible. Since the cooks were performed with much greater proportions of decayed wood than would occur in practice, the effects were, however, so greatly accentuated that even with the relatively wide dispersion in the limited experimental material certain trends were clearly apparent.

Methods

Cooking. — Cooking liquor: 6.0/1.3 per cent. Wood-to-liquor 1: 4.0. Cooking schedule: Evacuation 10 minutes, addition of liquor, 20°—125° C for 6 hours, 125° C for 5 hours. Quantity of wood in small digesters 100 g, and for 10-litre digesters with three-section baskets of wire net 400 g per section. Treatment of pulp: For the small-scale cooks, washing, conditioning for 2 days and determination of dry weight. For the larger cooks, washing, screening separately for each section, granulation, conditioning for 2 days and determination of dry weight. For all cooks pulp yield was calculated and for the larger cooks the percentage screen rejects as well. Chlorine number was determined for all pulps. Because of a fairly wide variation in the degree of cooking all pulp yields were corrected to chlorine number 5, and a conversion factor of 1.25 per cent per chlorine number was used for this purpose. The results are presented in Table 22 and Fig. 16.

Bleaching. — Twelve pulps from small cooks were bleached. Chlorination was performed with a chlorine charge (active chlorine per ton of pulp) of 15 times the chlorine number, which after 1 hour of chlorination gave a mean residual chlorine of 15 per cent. The consistency of the pulp was 3 per cent and the temperature 20° C. The alkali treatment was standardized at 3 per cent consistency, 0.15 g/l of sodium hydroxide and 20° for 2 hours. The hypochlorite added was standardized at 10 kg active chlorine per ton pulp, at excess alkali of 40 per cent, at a consistency of 6 per cent, temperature 35° C, and a bleaching time to 0 per cent residual chlorine. The brightness determination then gave the effect of rot-damaged wood for a standardized hypochlorite charge. For the large cooks it was possible to determine the effect of rot damage on the hypochlorite consumption at a given brightness. In larger experiments on the same pulps this charge of hypochlorite was added, and the bleached pulps were then subjected to beating and strength tests. The bleaching results are given in Table 22.

Table 22. Pulp yield and chemical consumption in the production of greaseproof pulp (for bleaching to 77 per cent G. E.) from mixtures of various kinds and quantities of decayed or stained birch wood *(Betula verrucosa)* and corresponding sound wood at the same height of the trunks. Chlorine number 5.

Visual decay or stain type	Fungus	Volume of deteriorat-ed wood	Pulp yield per cent	Brightness per cent G.E.	Consumption of hypo-chlorite kg active chlorine per ton of pulp
Firm-dark	*Fomes igniarius*	0	55.4	77.4	10
		10	54.9	77.3	10
		50	54.0	67.3	15
		100	50.2	—	25
Soft-dark	*Armillaria mellea*	0	46.7	80.4	9
		10	45.3	69.9	14
		20	41.6	59.5	—
Soft-dark	*Diaporthe aristata*	0	49.0	75.4	11
		10	47.7	73.1	12
		50	41.5	—	—
		100	—	43.3	—
Soft-light	*Fomes igniarius*	0	52.5	83.5	9
		10	53.9	79.4	9
		20	51.6	65.9	17
		50	47.7	—	25
		100	40.7	—	~
Firm-red	—	0	48.6	79.6	9
(red heart-		10	50.3	75.3	11
wood)		20	50.3	—	—
(stain)		50	49.1	—	—
		100	46.2	49.0	~

Beating and strength tests. — The pulps were placed in a Wennberg hollander beater in the wet state; 450 g of pulp (0.0 basis) and a total volume of 22.5 l (pulp + water) were used. Samples of the pulp were taken before beating and after beating to about 35°, 55° and 75° SR. Sheets, 60 g per m², were formed in accordance with CCA 17 except for pressing and drying. The pressing was performed only once and with a pressure of 5 kp/cm² for 5 minutes. The sheets were dried between blotting paper at 60° C for 1 hour and tested as specified in CCA 17. For each degree of beating 16 determinations of breaking length and Mullen factor, 5 determinations of tear factor and 9 determinations of double folding strength were made. The means of these values were graphed as a function of the degree of beating, and from the curves so obtained the values for the respective quantities were read off at 45° and 70° SR. The results are not reported here in detail but the effect of the two most important types of rot (in equal parts) on the strength for two degrees of beating are illustrated in Fig. 18.

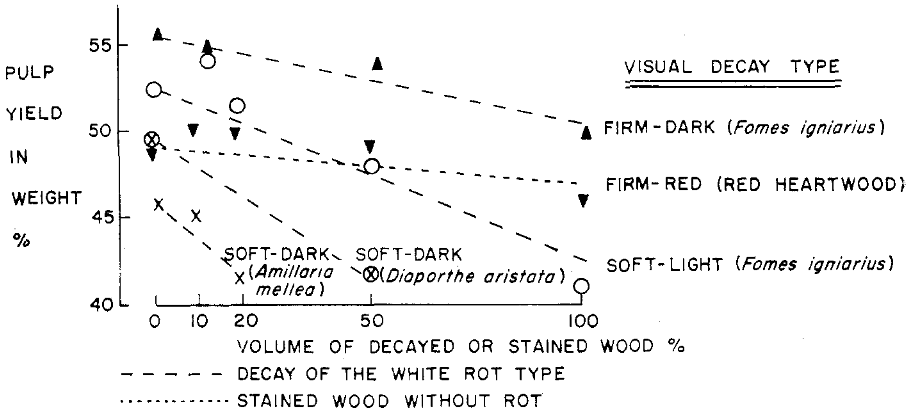

Fig. 16. Pulp yield (weight per cent of corresponding sound wood) in production of bleached greaseproof from mixtures of various kinds and quantities of decayed or stained wood in corresponding sound wood at the same trunk height of *Betula verrucosa*. Billerud AB. Research Lab.

Results

Cooking. — The degree of cooking varied but showed no clear correlation with the rot volume (means for 0, 10, 20, 50 and 100 per cent: 6.2, 5.9, 6.5, 6.6 and 8.4 respectively in chlorine number). The pulp yield decreased with the proportion of rot-damaged wood, the magnitude of the decrease depending on the type of rot (Fig. 16). Thus, the lowest yields were obtained in the case of soft dark rots and the highest for the firm dark rot. The screen reject content was consistently lower for 50 and 100 per cent decayed wood than for the corresponding sound wood. This could compensate for the losses in pulp yield in cookings to higher chlorine numbers, 8—10, but for normal greaseproof pulp cooks to chlorine numbers 5—6 the screen reject content was insignificant even for the sound wood. In general, the presence of 10 per cent decayed wood had no significant effect on the results of the cooking.

Bleaching. — The general picture was the same here. The bleaching was greatly affected by the presence of 100 per cent decayed wood of all types, and the effect was noticeable at 20 per cent and in some cases even for the 10 per cent mixtures. The most serious influence was again noted for the soft dark rots, and the relative order of effect of the various rots was approximately the same as in the case of the pulp yield (Fig. 17).

Beating and strength tests. — The results of the strength tests showed that 10 per cent decayed wood (the most common types of

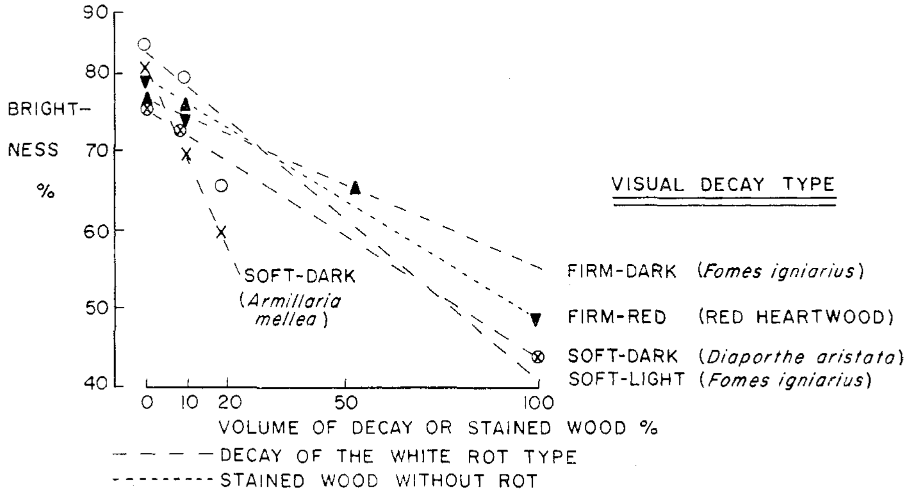

Fig. 17. Brightness (per cent G.E.) in production of bleached greaseproof from mixtures of various kinds and quantities of decayed or stained wood in corresponding sound wood at the same trunk height of *Betula verrucosa*. Billerud AB. Research Lab.

rot, soft light rot and firm dark rot) did not affect the strength values apart from the tear factor, which was reduced by about 10 per cent. Higher proportions of rot-damaged wood resulted in a consistently marked deterioration in strength (Fig. 18); soft light rot gave the greatest reduction. It was, however, not possible to decide how much of the deterioration in strength at these higher proportions of decayed wood was due to the rot and how much to increased oxidation during the hypochlorite bleaching, which in the case of pulps with a high percentage of decayed wood must be made rather drastic to give the required brightness. That the fibres in the pulps containing 100 per cent decayed wood were much weaker than those from sound wood was evident from the fact that they could not be beaten above 65—70° SR, since the beater then began to vibrate owing to the contact between the knives. The times required to reach a given degree of beating were also greatly reduced as the proportion of decayed wood was increased.

In summary, the yield, brightness and paper strength of bleached birch sulphite pulp for greaseproof are all decreased by the four types of decay investigated, but to an extent which makes a 10 per cent addition hardly detectable in the results. It may, however, be significant that the so-called sound wood indicates great variability in pulp character from various sound samples, with the lowest yield for "sound wood" from the trunk which had soft dark rot.

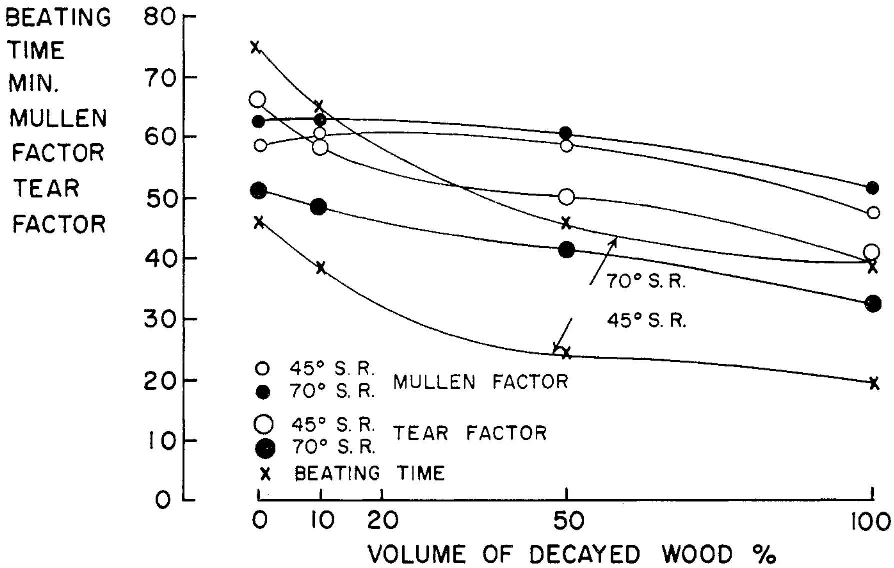

Fig. 18. Strength tests and beating time in production of bleached greaseproof from mixtures of decayed wood of *Betula verrucosa* (1:1 of soft light and firm dark rot, caused by *Fomes igniarius*) of various quantities in corresponding sound wood at the same trunk height of *Betula verrucosa*. Billerud AB. Research Lab.

F. Supplementary studies

Other rots and stages of rot development were examined in less detail.

Of those decay columns continuing through one or two logs a characteristic type was chosen for test cooks. This rot was designated "pencil-rot" owing to its appearance in streaks narrow as a pencil, often several metres in the axial direction of the trunk. The rot was found to be due to *Corticium galactinum* (Fr.) Burt. (*cf.* WHITE, 1951), which forms a typical white rot (Plate I). Since it was difficult to obtain large enough samples of this rot from any one tree, the results of the test cooks were rather unreliable, and they have therefore not been included. This type of rot is, however, not of major economic significance.

Decayed beech wood (*Fagus silvatica* L.) attacked by *Fomes fomentarius* was examined by test cooks at the Brusafors-Hällefors Company's Laboratory at Silverdalen. The available material was, however, too limited to permit reliable conclusions. Nevertheless, some difficulty in cooking was noted when high proportions of this decayed wood were used.

Finally, mechanical pulp was prepared on half-practical scale at the Central Laboratory of the Cellulose Industry in Stockholm. The material consisted of various stages of *Fomes annosus* rot in a spruce trunk (*cf.* Björkman *et al.*, 1949). Since, however, these studies do not fall within the scope of this paper on chemical pulp, it will suffice to summarize the findings. By including 10 per cent of wood affected by soft dark or firm dark rot — a proportion that might only very seldom be present in sorting and production of rot-damaged wood of this kind — the loss of strength probably will not exceed 1 per cent. For the same mixture the brightness was reduced by 2—3 G.E. units. For smaller amounts of decayed wood the decrease in quality is proportionally smaller. If the most advanced stages of rot are avoided, the loss of quality for moderate mixtures, below for instance 5 per cent, will be barely measurable. No tests were performed for heartrots other than that due to *Fomes annosus*, which is the most important, at least in southern and central Sweden.

IV. Discussion of the results

There are various ways in which decay fungi can enter the trunk of conifers and broadleaf trees: 1) through the roots, as in the typical root rots due to such fungi as *Fomes annosus, Fomes pinicola, Polyporus borealis, Polyporus schweinitzii,* and *Armillaria mellea,* 2) through branch stubs—fungi such as *Fomes pini, Fomes igniarius,* and *Fomes fomentarius,* and 3) through broken stem tops — fungi such as *Stereum sanguinolentum.* The fungi grow at different rates in the trunk and produce rots in different stages of development. For practical purposes these decays, caused by several different fungi, may be grouped into soft dark, soft light, firm dark and firm light rots. These have proved to be easy to identify in practice during scaling of pulp wood.

Studies of the importance of various types of rot fungi in the production of chemical pulp can give widely divergent results, depending on the type of rot caused by a particular fungus — destructive (brown), corrosive (white pocket) and white rots — and depending on the stage of the rot. Moreover, a rot often begins as a discolouration of the wood, for instance the aniline wood in connection with attacks by *Fomes annosus* (*cf.* BJÖRKMAN *et al.,* 1949, Plate I). Staining may also have some other cause, for instance the penetration of air to the heartwood, especially red heartwood in beech or birch (Plate II). Such dark discolouration or rot — even in cases where dark rot precedes a light one, as often happens in broadleaf trees — may greatly increase the consumption of chemicals in bleaching and a corresponding rise in costs. In more advanced stages the decayed wood often becomes rather soft, indicating that the fibres have been heavily attacked or perhaps distroyed, as in the case of destructive rot, due to fungus genera such as *Coniophora, Merulius,* and *Fomes.*

In some cases a darkening in firm wood, sometimes in the form of canker formations, may be directly associated even with more or less soft rot, as may occur in damage by *Armillaria mellea* or by *Poria obliqua* and *Diaporthe aristata* in birch. Such types are difficult to classify as soft and firm rots but have been included in the visual decay types in the present investigation for the sake of uniformity.

The various visual decay types are formed by quite different fungi presumably with different enzyme compositions. The soft dark rot caused by *Fomes annosus* (BJÖRKMAN *et al.,* 1949, Fig. 1) is thus for instance a typical corrosive (white pocket) rot, whereas the soft dark rots examined in the present studies are destructive (brown) rots. The *Fomes pini* rot in pine and spruce, which has been taken as representative of firm dark rot (Tables 4 and 8), is at first light red (*cf.* the names "red heart" and "red ring rot"). On the other hand the typical top rot in spruce caused by *Stereum sanguinolentum,* which has been taken as representative of firm light rot (Tables 4 and 13), changes to a firm dark rot (Table 9). These types, however, produce the same kind of breakdown, namely corrosive rot.

As regards broadleaf trees, rots of the white rot type are the most common, although they do not warrant this colour designation until a fairly late stage has been reached. This is the case for the broadleaf tree rot caused by *Fomes igniarius* dealt with in the present investigation. Soft dark rot — including surrounding wood — can, however, also occur, produced by for instance the fungi *Armillaria mellea* and *Diaporthe aristata.*

An extremely large number of test cooks at many different stages of development would therefore be needed to obtain definite results. By selecting representative samples of the respective types of rot in a typical stage of development for the test cooks, it was nevertheless possible to detect certain trends. It was also possible to combine similar types for use in practice, and the essential object of the present studies could therefore be achieved, namely to establish whether a proportion of various types of decayed wood might be mixed with sound wood without impairing the quality of the chemical pulp.

It might be questioned whether a detailed registration of heartwood damage is justified in scaling of the pulp wood, which instead may be assessed, for instance, by weighing, as is now being introduced by certain industries, especially for deliveries from their own forests. If, however, it is desired to exploit the forest to the full, while at the same time ensuring that there shall be no impairment of quality through inclusion of rot-damaged wood such a determination seems to be justified. Some damage may then be considered as "deduction defects" while other damage may be referred to as "tolerance defects", for which no volume deductions may be necessary (*cf.*Kungl. Skogsstyrelsen, Board of Private Forestry, Circular V: 9 and V: 11, 1963; *cf.* also for example DENMAN, and GLENN, 1960).

There follows a summary of the conclusions reached as to the extent to which different visual decay types may be used for producing various kinds of pulp, and an attempt is made to grade roughly the various types of rot with respect to their deleterious effect on the pulp.

Wood of conifers

Soft dark rot and *soft light rot.* — From the test cooks it would seem that *Armillaria*-rot, which in earlier stage of development belongs to the firm dark rot (*cf.* Fig. 10), in the fully developed stage causes a marked reduction in pulp yield and an increase in wood consumption in the production of rayon pulp and unbleached sulphite pulp (Figs. 8 and 10). For the production of sulphate pulp this type of rot caused hardly any reduction, even in large proportions (Fig. 12). However, this latter conclusion is drawn on the basis of an *Armillaria*-rot in a fairly early stage of development. As regards the strength of the sulphite and sulphate pulps, this rot gave only slightly poorer values than the corresponding sound wood. The brightness was much reduced (Fig. 11, Plate II); the level could, however, always be brought up to that for pulp prepared from sound wood though with a much greater consumption of chemicals. In the production of bleached sulphite pulp there was quite a marked increase in the content of screen rejects (Table 11), but for sulphate pulp there was no appreciable deterioration on including wood affected by *Armillaria* (Table 15). Owing to the serious effect of *Armillaria*-rot it should not be present in wood intended for sulphite pulp of high quality, though it may otherwise be included if the decayed wood in question is subjected to a 100 per cent deduction of volume.

Even for quite a high proportion of other typical soft dark rots the reduction in pulp yield, calculated as percentage by weight, was large and considerably greater if the losses were expressed as percentage increase in wood consumption. This may be ascribed to the fact that the decayed wood, which consists largely of lignin, is dissolved in the cooking. The brightness was only slightly reduced by the inclusion of rot-damaged wood. The strength was not appreciably reduced for bleached sulphite and sulphate pulp.

Soft dark and soft light rots of the destructive (brown) rot type may thus be included in the pulp production, but in view of the loss of wood a 100 per cent volume deduction is recommended.

Firm dark rot. — This rot, represented in the test cooks by *Fomes pini*-rot and a *Stereum sanguinolentum*-rot (top-rot in spruce) in a fairly advanced stage of development (Figs. 10—11, Plate I) — both of the corrosive (pocket white) rot type — caused a reduction of 3—5 per cent in weight yield of sulphite pulp and a corresponding increase in wood consumption with mixtures of 10 per cent by volume of decayed wood to corresponding sound wood; for the production of rayon pulp, however, an increase in the weight yield was noted for the same mixtures of *Fomes pini*-wood. An examination of the decayed wood in the latter case, however, showed a lower lignin content than normal (Table 4), which indicates that the cellulose had still not been attacked to the same extent as the lignin. The higher values for the cellulose yield were thus obtained because they were calculated on wood with a lower lignin content. In the production of sulphate pulp from mixtures of sound spruce and pine wood with 10 per cent of *Fomes pini*-decayed wood the pulp yield was reduced by 2 and 3 per cent, respectively (Table 14). The inclusion of firm dark rot did not result in any appreciable reduction in strength of the pulps. Except in the case of sulphite pulp produced from mixtures of firm dark rot caused by *Stereum sanguinolentum* the brightness was also satisfactory.

From the test cooks it would seem that firm dark rot — at least in the most common type, corrosive rot — may be added to sound wood in the production of all pulps that are to be bleached. *Owing to the loss of cellulose in such wood, some deduction, as a suggestion 50 per cent, seems to be justified. For the sake of simplification a deduction of 100 per cent for the decayed volume may, however, be recommended.*

Firm light rot. — This rot type was represented in the material by a less advanced stage in an attack of *Stereum sanguinolentum* (top-rot in spruce). In the production of rayon pulp and sulphate pulp no appreciable loss of yield was recorded even for the 20 per cent mixture, and there was no impairment of strength or brightness.

This experience confirmed earlier results of test cooks involving firm light rot caused by *Fomes annosus* (Björkman *et al.*, 1949) and shows *that such decayed wood may be permitted in conifers without risk and with no deduction,* as has been recommended in 1948 and since applied in the case of spruce damaged by *Fomes annosus*. Through the "tolerance" of this defect some compensation for the too great deduction in respect of firm dark rot is obtained.

Wood of broadleaf trees

Owing to the numerous types of rot damage in broadleaf trees and their different stages of development there is some difficulty in grouping them in the same way as the rot damages affecting conifers. With some simplification, however, this proved to be possible. In addition, there is a very common occurrence of stained wood which, at least initially, usually appears independently of fungi. One example of such discolouration is the grey-green stain in birch and aspen which is due to the penetration of air into the wood; other examples are the characteristic violet colour usually seen as the pre-stage of rot in birch (Plate II), and red heartwood, here called 'firm red wood', in birch due to penetration of air to the centre of the wood.

Soft dark rot and *soft light rot.* — For the sake of uniformity two types of damage have been included in this group which also could be distinguished as specific types, caused by *Armillaria mellea* and by *Diaporthe aristata* and other fungi combined with canker or abnormal sporophore formation.

It is evident from the results of the test cooks that the inclusion of as little as 10 per cent of wood affected by *Armillaria mellea* greatly increases the wood consumption in sulphite cooking and the production of bleached greaseproof, and reduces considerably the strength and brightness. In bleaching there is an increase in the consumption of chemicals. While such rot should thus not be present in first-class broadleaf tree wood intended for the production of unbleached sulphite pulp, there is no reason why a certain amount of such wood should not be permissible in the production of bleached pulp. A 100 per cent deduction for rot wood would be justified however.

Birch affected by *Diaporthe aristata* would seem to demand a greater amount of wood, even for the low proportion of decayed wood (Figs. 13, 14, 16); and the consumption of chemicals increased strongly in bleaching when admixtures of 20 per cent *Diaporthe*-wood to corresponding sound wood were used. Such wood should therefore not be added to sound wood in the production of unbleached sulphite pulp, but is on the other hand permissible for bleached sulphite pulp and greaseproof to a certain extent. A 100 per cent volume deduction for the *Diaporthe* wood would, however, appear to be justified.

Soft dark or soft light rot, usually due to *Fomes igniarius, Fomes fomentarius* or *Poria obliqua,* give a marked increase in wood consumption for the 20 per cent mixture and also impair the strength of the pulp. A greater consumption of bleaching chemicals was recorded for high proportions of decayed wood. The effect was the same for bleached greaseproof except that the strength was not appreciably affected. The test cooks would thus indicate that, as in the case of the rot damage in conifers, *the soft rot may be assessed uniformly, irrespective of the wide variation in colour presented by severely attacked hardwoods, and thus be accepted for pulp production with a 100 per cent volume deduction.*

Firm dark rot. — The presence of such decayed wood in broadleaf trees — often an early stage of, for instance, *Fomes igniarius*-rot — does not result in a higher wood consumption even when as much as

20 per cent is included. There was, however, some loss of strength and an increase in the bleaching chlorine required. In the production of greaseproof the strength values in particular were affected.

In view of its limited effect on the pulp, however, it would seem that *a deduction of not more than 50 per cent is justified for firm dark rot. For practical use, however, it seems desirable to follow the assessment for coniferous wood and apply a 100 per cent volume deduction.*

Firm light rot occurs in broadleaf trees usually as a transition stage to soft light rot, but in quite small amounts. *No deduction seems to be justified for firm light rot.*

Discoloured wood without rot. — The discolouration often encountered in broadleaf tree wood and occurring primarily through damage to the trunk — for instance the greyish green discolouration in birch and aspen or the violet staining in birch — is sometimes difficult to distinguish from true rot, for it is often accompanied by typical rot damage. The same is the case with red heartwood in the central parts of birch trunks. *Cf.* Plate II.

Test cooks showed that such discoloured wood that had not been damaged by rot did not affect the wood consumption or the brightness of the pulp (sulphite pulp, greaseproof) although the tear factor was possibly impaired slightly in the production of sulphite pulp. In bleaching, however, the chemical consumption rose rather steeply with the intensity of discolouration. Since all grades of staining and transition to pure rot wood are found, at least dark discolouration should be assessed as rot-damaged wood, and in view of the greater consumption of chemicals in bleaching some volume deduction is indicated.

Summary

1. The frequency and appearance of rot of various types in standing trees of Scots pine *(Pinus silvestris)*, Norway spruce *(Picea abies)*, birch *(Betula verrucosa* and *B. pubescens)*, aspen *(Populus tremula)* and alder *(Alnus glutinosa)*—so-called heartrots—have been examined in various parts of Sweden (Tables 1—3).

2. Rot due to a number of rot fungi has been studied with respect to the effect on the production of chemical pulp (Figs. 1—7, Plates I and II).

3. The studies were concerned chiefly with the production of rayon pulp (Tables 4—8, Figs. 8—9), and sulphite pulp (Tables 9—12, Figs. 10—11) from spruce, sulphate pulp (Tables 13—17, Fig. 12) from pine and spruce, sulphite pulp (Tables 18—21, Figs. 13—15) from birch, aspen and alder, and finally bleached greaseproof (Table 22, Figs. 16—18) from birch. The main purpose of the investigation was to obtain an impression of the quantities of various types of decayed wood that may be mixed with sound wood without affecting the quality of the pulp.

4. Since the stage of development of rot damage may be assumed to determine to a large extent its value for pulping purposes but since it is impracticable to study closely all stages of development, a characteristic stage of the respective rot was chosen—usually an intermediate stage. The investigation was centered on common rot fungi and the rots caused by them. As regards coniferous wood it was chiefly the types of rot occurring in northern Sweden that were examined, as a supplement to the earlier investigation on *Fomes annosus* (BJÖRKMAN *et al.*, 1949), the most common rot in southern and central Sweden.

5. The rot damage was assigned to 4 main visual decay types: soft dark rot, soft light rot, firm dark rot and firm light rot. Included in the soft dark rot was also *Armillaria mellea*-rot, which could have been distinguished as a separate type by virtue of its characteristic appearance (Fig. 4, Plate I). For the same reason the damage caused by *Diaporthe aristata* to birch could have been regarded as a separate type (Fig. 5, Plate II). Stained or discoloured wood of various kinds was not included in the decay types, in which no rot damage could be detected (Plate II; *cf.* also the so-called aniline wood, described in greater detail in the earlier paper of 1949).

6. The same visual decay types were distinguished for both coniferous and broadleaf tree wood.

7. Since the significance of rot damage increases with the amount of decayed wood, such wood was included with the corresponding sound wood in various proportions, namely 10, 20 and 50 per cent of the various types of decay; in some cases the effect of pure rot wood ("100 per cent") was examined. On the basis of practical experience and random sample studies a proportion of 10 per cent decayed wood for coniferous wood and 20 per cent for hardwood was found to be the upper limit of what can occur in practice. General conclusions have therefore been drawn substantially on the basis of the results of the test cooks for these proportions.

8. The investigation was performed chiefly at a time when new instructions for scaling of pulp wood were being developed. The present findings constitute the main basis for these new regulations so far as rot damage is concerned.

9. If a detailed assessment of pulp wood is required as a guarantee against impairment of the pulp quality, it is appropriate to distinguish between "deduction defects" for such wood that may be included but which justifies some volume deduction, and so-called "tolerance defects" for rot-damaged wood that have proved not to impair the pulp produced and therefore do not justify any deduction.

10. The unbleached sulphite pulp is the most prone to impairment of quality, being stained by quite small amounts of dark rot, produced by for example *Armillaria* or *Diaporthe.* If bleaching is performed, as is normally the case, the discolouration disappears, but at the cost of an increase in the consumption of chemicals. Account must then be taken of this in the assessment of such damage, and a deduction is thus justified.

11. Soft dark and soft light rot proved to result in a great increase in wood consumption and impairment of the quality of the pulp. When bleaching of the pulp takes place, such rot may, however, be admitted. A volume deduction of 100 per cent for the damaged volume of such decay is suggested.

12. Firm dark rot, apart from its impairment of quality, also gave a lower yield than the corresponding sound wood. A certain proportion might therefore be included in pulp wood provided that some deduction is allowed for. A deduction of 100 per cent for the volume of decayed wood seems to be unnecessarily high but might be justified by the need for the maximum simplification of the assessment in practice.

13. Firm light rot did not cause an appreciable impairment of the pulp, whatever proportion was included. Although there was undoubtedly some initial breakdown and loss of strength, this type of decayed wood may conveniently be included without deduction and thus counted as a "tolerance defect". Some compensation for the too great deduction for firm dark rot is thereby obtained. This system, which is recommended on the basis of the earlier study on *Fomes annosus*-rot in spruce, has also been applied in the instructions for scaling of pulp wood since 1948 with no impairment of the quality of the pulp. In broadleaf trees this type of rot rarely develops. Such rot damage often begins as a darkening of the wood, with gradual progress to the final stage of soft light rot.

14. A discolouration need not be due primarily to an attack of rot and may, for the lighter forms at least, be assessed as a "tolerance defect". It is, however, often difficult to distinguish it from incipient rot, which often accompanies staining (Plate II). To be on the safe side therefore, a dark stain is best assessed as firm dark rot. Bleaching of such discoloured wood invariably requires a greater quantity of chemicals than does sound wood.

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Sammanfattning

Användbarheten av rötskadad barr- och lövved för framställning av kemisk massa

Förekomsten av röta av olika slag i stående träd av tall (*Pinus silvestris*), gran (*Picea abies*), björk (*Betula verrucosa*) och asp (*Populus tremula*) — s. k. skogsröta eller kärnvedröta — har undersökts i olika delar av Sverige (tab. 1—3).

Röta förorsakad av ett antal olika rötsvampar har undersökts med avseende på sin betydelse för framställning av kemisk massa (fig. 1—7, plansch I och II).

Undersökningarna har huvudsakligen avsett framställning av silkemassa (tab. 4—8, fig. 8—9) och blekt sulfitmassa (tab. 9—12, fig. 10—11) av gran, kraftsulfatmassa (tab. 13—17, fig. 10) av tall och gran och blekt sulfitmassa (tab. 18—21, fig. 11—15) av björk och asp samt slutligen blekt greaseproof (tab. 22, fig. 16—18) av björk. Avsikten har framför allt varit att få en föreställning om hur stora kvantiteter av olika rötskadad ved som kan inblandas i motsvarande frisk ved utan att den färdiga produktens kvalitet blir lidande.

Då en rötskadas utvecklingsstadium i hög grad kan antagas bestämma dess användbarhet vid massaframställning men a l l a förekommande stadier icke rimligtvis kan noggrant undersökas, har i allmänhet e t t karakteristiskt stadium för resp. rötsvamp utvalts, i regel en intermediär utveckling av rötan. Företrädesvis har mycket allmänna rötsvampar och av dem framkallad röta blivit föremål för undersökning. Beträffande barrveden har företrädesvis röttyper förekommande i norra Sverige undersökts som en komplettering till den tidigare undersökningen över *Fomes annosus* (BJÖRKMAN m. fl., 1949), som är den vanligaste rötan i södra och mellersta Sverige.

Rötskadorna har indelats i fyra för blotta ögat urskiljbara tekniska klasser, avsedda för praktisk användning t. ex. vid virkesmätning: mörk lösröta, ljus lösröta, mörk faströta och ljus faströta. Den rötskada, som förorsakas av *Armillaria mellea* har räknats till mörk lösröta trots att den på grund av sin specifika karaktär mycket väl kunde ha urskilts som en särskild typ (fig. 4. plansch I). Av samma anledning skulle den av *Diaporthe aristata* framkallade skadan hos björk ha kunnat hållas isär som en särskild typ (fig. 5, plansch II). »Missfärgad ved» av olika slag, i vilken utbildade rötskador ännu ej uppträtt (plansch II) har ej inräknats i röttyperna; detsamma gäller den s. k. anilinveden, huvudsakligen förekommande i samband med *Fomes annosus*-röta och närmare beskriven och avbildad i den tidigare avhandlingen 1949.

Samma röttyper och beteckningar har i grova drag befunnits användbara för barrträd och lövträd.

Då en rötskadas betydelse ökar med dess omfattning, har en inblandning i motsvarande frisk ved i form av flisblandningar företagits av olika röttyper till 10, 20 och 50 %, och dessutom har i några fall ren rötved (»100 % röta») undersökts. Med ledning av praktisk erfarenhet och företagna stickprovsundersökningar har för barrträd 10 % och för lövträd 20 % rötainblandning befunnits vara en övre gräns för vad som någonsin kan förekomma i praktisk skala. Med ledning av provkokningsresultaten för dessa inblandningsgrader har därför vissa generella slutsatser i stora drag dragits.

Undersökningen utfördes i huvudsak vid en tidpunkt då utarbetande av nya mätningsbestämmelser för massaved var aktuellt. De här framlagda resultaten utgör det grundmaterial, på vilket de nya bestämmelserna beträffande rötskador grundar sig.

Vill man upprätthålla en detaljbedömning av massaveden vid inmätning som en garanti mot kvalitetsförsämring, kan man lämpligen urskilja *avdragsfel* för sådan ved, som kan medtagas men bör föranleda visst avdrag, och s. k. *toleransfel* för sådana vedskador, som visat sig ofarliga vid framställning av massa och därför icke behöver föranleda något avdrag.

Mest ömtålig för kvalitetsnedsättning är oblekt sulfitmassa, som missfärgas även genom relativt små kvantiteter mörka skadetyper, framkallade av t. ex. *Armillaria* eller *Diaporthe*. Om dessa skador blekas, vilket numera är det vanligaste, försvinner all missfärgning men ökar kemikalieåtgången. Stor hänsyn måste tagas härtill vid bedömningen av en sådan skada, som sålunda bör föranleda visst avdrag.

Lösröta — såväl mörk som ljus — har visat sig medföra kraftigt ökad vedförbrukning samt sämre kvalitetsegenskaper hos den framställda massan. Den kan dock alltid blekas och därför medtagas i viss kvantitet, om den samtidigt åsättes ett visst avdrag, förslagsvis 100 % för den skadade volymen.

Mörk faströta har utom genom sin kvalitetsnedsättande effekt även visat sig ge något lägre utbyte än motsvarande frisk ved. Den torde därför kunna medtagas till viss kvantitet i massaved, om den åsättes ett visst avdrag. Ett 100 %-igt avdrag för den rötade volymen är härvid utan tvivel oberättigat högt men kan ändå motiveras med hänsyn till önskvärdheten av största möjliga enkelhet vid den praktiska bedömningen.

Ljus faströta har knappast visat sig medföra nämnvärt försämrande effekt på den framställda massan varken vid 10 % eller högre inblandning i motsvarande frisk ved. Även om otvivelaktigt en viss nedbrytning av cellulosan redan tagit sin början och styrkevärdena börjat påverkas, torde denna röttyp lämpligen kunna medtagas utan avdrag i full utsträckning och sålunda räknas som toleransfel. En viss kompensation för det alltför kraftiga avdraget för mörk faströta erhålles också härigenom. Detta system, som kan rekommenderas på grundval av den tidigare undersökningen rörande *Fomes annosus*-röta i gran, har även tillämpats vid inmätning av massaved sedan 1949 utan någon värdenedsättande effekt på den framställda massan. Hos lövträd förekommer mera sällan denna röttyp väl utbildad. En rötskada börjar här ofta med en mörkfärgning av veden, som så småningom övergår i slutstadiet ljus lösröta.

En missfärgning behöver ingalunda primärt förorsakas av ett rötangrepp och kan åtminstone i de ljusare formerna bedömas som ett toleransfel. Den är emellertid ofta svår att skilja från en begynnande rötskada, som ofta utvecklas i samband med missfärgning (jfr plansch II). Av säkerhetsskäl bör därför i varje fall mörk missfärgning lämpligen bedömas som en rötskada av typ mörk faströta. För blekning av sådan missfärgad ved stiger alltid kemikalieförbrukningen.

Plate I.

Upper row, left: Soft light rot of the destructive (brown) rot type, caused by a *Merulius* species, in *Picea abies.* Butt rot. The province of Västerbotten.

Upper row, right: Soft dark rot of the destructive (brown) rot type, caused by *Coniophora fusispora,* in *Pinus silvestris.* Butt rot. The province of Västerbotten.

Middle row, left: Firm dark rot of the corrosive (pocket) rot type, caused by *Fomes pini,* in *Pinus silvestris.* In the outer parts of the heartwood dark rings of sound wood with a high concentration of pinosylvin and no rot. Trunk rot. The province of Uppland.

Middle row, right: Firm dark rot of the corrosive (pocket) rot type, caused by *Stereum sanguinolentum,* in *Picea abies.* Top rot with decayed wood in the centre, lower in the trunk streaks of rot in the inner part of the sapwood and outer part of the heartwood. The province of Västerbotten.

Lower row, left: Soft light rot of the white rot type, caused by *Corticium galactinum,* in *Picea abies.* Trunk rot in long narrow streaks. The province of Västerbotten.

Lower row, right: Soft dark rot of the white rot type, caused by *Armillaria mellea,* in *Picea abies.* Butt rot. The province of Jämtland.

Plate II.

Upper row, left: Purple stained wood with incipient rot of the white rot type (below), caused by *Fomes igniarius,* in *Betula verrucosa.* Branch and trunk rot. The province of Ångermanland.

Upper row, right: Firm dark rot of the white rot type, caused by *Fomes igniarius,* in *Betula verrucosa.* Trunk rot. The province of Ångermanland.

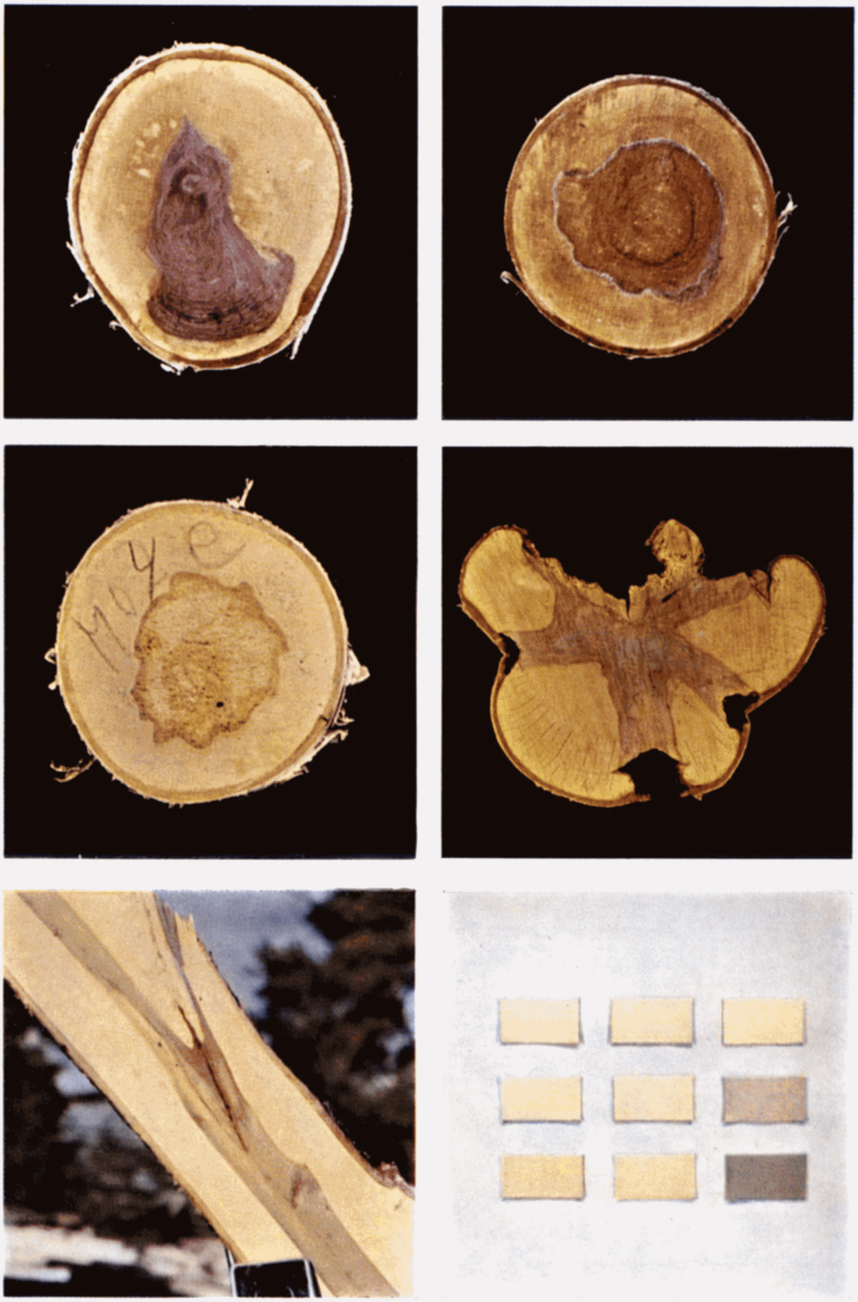
Middle row, left: Soft light rot of the white rot type, caused by *Fomes igniarius,* in *Betula verrucosa.* Trunk rot. The province of Ångermanland.

Middle row, right: Soft dark rot of the white rot type, caused by *Diaporthe aristata* (black staining from the bark included), in *Betula verrucosa.* Butt rot. The province of Västerbotten. *Cf.* Fig. 5.

Lower row, left: Firm red wood (red heartwood), caused by air reaching the heartwood through cracks in the stem, in *Betula verrucosa.* No rot. The province of Dalsland. *Cf.* Fig. 6.

Lower row, right: Sulphite pulp produced of birch wood attacked by (from left to right) *Fomes igniarius, Fomes fomentarius* and *Armillaria mellea,* causing decayed wood of the white rot type. Each vertical row from above: sound wood, mixture of 10 % decayed wood and sound wood and mixture of 20 % decayed wood and corresponding sound wood.

I



II