Interpretation of the results of paper analyses

1) Scope

WWF Deutschland ("WWF") commissioned the Johann Heinrich von Thünen Institute ("vTI") to perform a blind study with 15 paper samples (papers of defined composition manufactured on a laboratory scale) which were analysed by two laboratories (Integrated Paper Services ("IPS") and Technische Universität Darmstadt ("TUD") with an aim to determine the type of wood[1] contained therein. The results including the data of the individual samples from both laboratories, as well as the basic data of vTI's blind study are available. The customer asked vTI not to be informed about the composition of the samples until the laboratory results were published.

Dr. Helge Hedden's report interprets the results in response to the question regarding the extent to which tropical wood[2] can be detected in paper.

2) Evaluation

The results of the evaluation of the available laboratory data compared to the basic data are as follows[3]:

Fibre traces

Both laboratories identified wood fibres,[4] which the basic data did not list[5] (except samples[6] containing recycled paper). The principle isolated fibres identified in the samples were:

Poplar	TUD: B, G, K, M, Q	IPS: B, G, K, L, M
Maple	TUD: M	IPS: B, G, H, L, M
Birch[7]	TUD: C	IPS: H, F, P
Beech	TUD: -	IPS: P
BSP[8]	TUD: -	IPS: K, M
Straw	TUD: B, J	IPS: -
Amber[9]	TUD: B	IPS: -

[1] The term "wood" is here synonymous for wood species and genera.
[2] Tropical wood as used in this report are bintangor, durian, gerutu, kasai and red meranti.
[3] The laboratories noted considerable fibre damage in the samples. IPS pointed out that the freeness value was higher than usual on an industrial scale.
[4] The term "fibre" as used in this document is synonymous for all kinds of cells in the xylem.
[5] One possible explanation for this deviation could be contamination because none of the two laboratories works under the maximum cleanliness conditions.
[6] Unlike TUD, IPS also analysed the samples containing recycled paper (A, D, I) for individual woods. The fact that pinewood accounts for the largest percentage in the coniferous wood share results from the composition of the recycled paper. Safdari et al. (2011) also found in their analyses of recycled paper that pinewood is the coniferous wood found most frequently in their samples. The fibre traces found in samples A, D and I may originate from the recycled paper.
[7] Birch and beech were listed because they were not contained in the pertinent samples according to the basic data.
[8] BSP is the abbreviation for "bleached soda pulp".
[9] "1 fibre similar to amber"

Each of the two laboratories identified poplar fibre traces in five samples; four of the samples are identical. The remaining sample pair (Q/L) additionally featured an identical composition. Maple fibre traces were believed to be identified in five IPS samples and in one TUD sample.

Number of unknown woods

The laboratory results of the samples were evaluated with regard to the number of unknown wood (columns TUD and IPS).

Sample A	TUD: no data	IPS: at least 4	actual value: 4
Sample B	TUD: probably 2	IPS: at least 3	actual value: 4
Sample C	TUD: probably 1	IPS: at least[10] 1	actual value: 1
Sample D	TUD: no data	IPS: 0	actual value: 0
Sample E	TUD: probably 2	IPS: at least 3, probably 4	actual value: 4
Sample F	TUD: probably 3[11]	IPS: at least 4	actual value: 4
Sample G	TUD: 0	IPS: 0	actual value: 0
Sample H	TUD: probably 3	IPS: 1[12]	actual value: 1
Sample I	TUD: no data	IPS: 1[13]	actual value: 1
Sample J	TUD: probably 3[14]	IPS: at least 4	actual value: 5
Sample K	TUD: 0	IPS: 0	actual value: 0
Sample L	TUD: probably 1	IPS: at least 3	actual value: 5
Sample M	TUD: probably 3	IPS: 1[15]	actual value: 1
Sample P	TUD: probably 3	IPS: at least 3	actual value: 5
Sample Q	TUD: probably 3	IPS: at least 3	actual value: 5

The statements by the laboratories are uncertain, as demonstrated by the remarks: "probably" or "at least". The difference is interpreted in such a manner that "probably" means that the number of unknown woods stated is most likely to correspond to the value shown, but that upper or lower deviations are possible. "At least" is understood to mean that the number stated represents the lower limit of the unknown wood types assumed to be verified. At the same time, the potential presence of further wood in the samples is not ruled out.

Disregarding samples A, D and I (recycled paper), IPS's number of unknown wood types in eight to ten[16] of the remaining twelve samples is closer to the number of unknown woods than TUD's result.

Fibre detection

Another aspect of the evaluation of the laboratory results addressed the question as to whether existing wood types (other than tropical woods) were not detected and/or whether existing wood types were incorrectly labelled.

Oak:

TUD did not mention oak in any of the samples even though samples B, D, G, K, L and M did contain oak.

[10] "We could not be certain if any other types were present."
[11] "… and 1 unspecified vessel cell"
[12] "It could not be determined if any other types were present."
[13] "… we could not determine if any other types were present."
[14] "… and 1 unspecified vessel cell"
[15] "It could not be determined if any other types were present."
[16] Depending on the evaluation of samples P and Q.

IPS was unable to definitely identify oak in any of the samples because the available fibre fragments were not sufficient. With regard to samples B, L and M, an annotation was added stating that it was suspected that oak might be contained. With regard to sample D, the possibility was also considered that fibres contained in this sample might be of oak origin[17]. However, eucalyptus was identified, but this might also originate from the deinked-pulp share. Oak and eucalyptus were alternatively identified in samples G and K because the laboratory did not detect any clear indications of any one of the two woods. No oak was identified in sample Q even though it did contain oak.

IPS explains that the difficulty in detecting oak and in distinguishing it against eucalyptus is due to the high degree of destruction of the fibres in the samples. In the case of hardwood, the term "fibres" refers primarily to the vessel elements as vessel building blocks. Unlike the libriform fibres and fibre tracheids, which are relevant for paper manufacture, relatively clear and constant identification parameters exist here, such as vessel perforations, thickening, pitting and tylosis (Ilvessalo-Pfäffli 1995 S. 44, Isenberg 1967, p. 156). Oak vessel elements are generally rare and hard to find in pulp; furthermore, large early wood vessel elements exist as fragments only (Parham and Gray 1982, p. 162, 164).

Acacia and eucalyptus:

TUD identified acacia in sample E even though it did not contain any. Acacia and eucalyptus were identified in samples B and F even though they were not contained in these samples. The above-mentioned samples contained tropical woods either exclusively or in part. One reason for this finding may be the use of dyes.[18]

IPS identified acacia whenever this was contained. Eucalyptus was also identified as such.[19]

Note: Both laboratories found a high degree of vessel cell destruction in the blind study. IPS pointed out[20] that this degree of fibre destruction is exceptional and that identification was hindered by this. Isenberg (1967, p. 150) points out that morphological, chemical or mechanical influences hinder fibre or sometimes even prevent fibre identification. Parham and Gray (1982, p. 25) also refer to the problem of the diverse ways in which fibre material is treated and the resultant reduction in clear identification information. Safdari et al. (2011) refer to the importance of the vessel cells which are most helpful for identification purposes due to vessel perforations, thickening and mottling. Audenaert and Taylor (1976) describe the risk of destruction of vessel cells because these cells feature a large lumen and relatively thin cell walls.

Identification of tropical woods

The final analysis addresses the identification of tropical hardwoods.

TUD considered the existence of tropical wood in samples B, C, E, F, H, J, L, M, P and Q to be possible. This corresponds precisely to those samples which contained tropical woods (except samples A and I which contain recycled paper). Concrete information was not given. Since TUD found at least one unknown wood in the above-mentioned samples, the possibility of tropical wood is not ruled out. However, the existence of tropical wood is not confirmed either.

[17] The vessel elements of tropical genera (including eucalyptus as a plantation wood) can strongly resemble those from the early wood area of ring-porous wood (Ilvessalo-Pfäffli 1995 p. 44, 254).

[18] "During staining with Alexander, many spindle cells of hardwood pulp are stained red rather than violet as expected. These are probably the spindle cells of acacia."

[19] The oak/eucalyptus aspect is discussed under the "oak" heading.

[20] "Normally in commercial papermaking, hardwoods are not heavily refined and this level of vessel damage was not evident in any of the commercial samples that WWF has submitted for analysis […]."

IPS found at least one unknown wood species in each of the twelve samples (A, B, C, E, F, H, I, J, L, M, P and Q). This corresponds precisely to those samples which contained tropical woods (including samples A and I which contain recycled paper). In a first version of the result presentation, IPS did not equate the unknown woods with tropical woods either. Its written summary described the existence of tropical wood as possible. However, eleven samples (except sample B[21]) were always supplemented by a note stating that the anatomy found for some fibres resembles that of dipterocarpaceae. This reference to dipterocarpaceae is correct because each of the twelve tropical wood samples contained at least one dipterocarpacea (red meranti – shorea genus, gerutu – parashorea genus). Furthermore, it was noted that some of the characteristics found in samples A, C, H, M, P and Q suggest the presence of the shorea genus[22]. This is correct with the exception of sample A because red meranti was found in samples C, H, M, P and Q. In a revised presentation of results, IPS revised its statement regarding the terminology. The unknown woods of the above-mentioned samples were classified as "unknown tropical".[23]

Note: There is no characteristic feature which definitely classifies the tropical hardwoods as tropical. Combinations of characteristic features often suggest the existence of woods of tropical origin (drum/barrel-type to elongate vessel elements, vessel elements with large pitted areas, large parenchyma share, fibre structure – Ilvessalo-Pfäffli 1995, p. 59). The fact that the concrete genera of the tropical woods (exceptions: acacia and eucalyptus as plantation woods as well as shorea in some cases) could not be determined is due to the lack of knowledge. Although descriptions of individual genera are available (acacia, albizzia, anthocephalus, eucalyptus, gmelina, musanga, shorea, for instance, in Ilvessalo Pfäffli 1995, p. 244ff.), this knowledge does not suffice to determine all woods in papers containing mixed tropical hardwood (MTH). MTH can, for instance, contain around 100 different wood species.

3) Result interpretation

- Both laboratories correctly identified recycled paper in the blind study. Whilst TUD uses optical brighteners as the main characteristic to determine recycled paper, IPS identifies recycled paper on the basis of the diverse and characteristic fibre composition (coniferous wood/hardwood, bleached, unbleached, mechanically/chemically macerated).
- The fibres of wood not contained in the samples (such as poplar, maple) described by both laboratories in individual cases and/or in traces can be neglected. These results are probably due to the fact that all these samples contained European wood species whose appearance may occasionally resemble that of poplar or maple fibres. TUD mentions this situation in its written supplementary notes to the analysis results[24]. Safdari et al. (2011) make comparable statements in their comparison of the betula and alnus as well as populus and carpinus genera. Traces of fibre contamination of commercial pulp are not unusual in industrial applications (Parham and Gray 1982, p. 1).
- The quantitative ratios of the different wood types in the individual samples were determined by IPS only. Although the results currently do not permit exact statements, the ratios are determined by way of approximation so that a very general statement is possible.

[21] No such statement was made for sample B. Instead, it was mentioned that the large vessels in the sample were badly damaged.

[22] Vessel elements of the shorea genus are large and thick-walled and have pits of strongly varying size and shape. Furthermore, vasicentric tracheides are found (Ilvessalo-Pfäffli 1995, p. 176, 260).

[23] Note: IPS reports MTH (mixed tropical hardwood) in analyses of industrially produced papers. This was not possible in the case of the test sheets manufactured on a laboratory scale because the characteristic feature (large number of different species) of industrially produced papers was not given in the samples analysed.

[24] "Each tree species has very diverse vessel cells, […]. An additional problem are similarities with other genera."

- TUD does not definitely confirm the existence of tropical woods. Instead, it classifies such wood species as "unknown". TUD did, however, classify the existence of tropical woods as "possible". IPS confirms the existence of tropical woods with the words "unknown tropical" and assumed the tropical family of dipterocarpaceae in the samples. According to IPS, the fibre composition and the visual appearance are typical for tropical woods which is also described by Ilvessalo-Pfäffli (1995, S. 59). In contrast to this, the term "mixed tropical hardwood" (MTH) was correctly avoided because the samples contained too few (maximum of five) different tropical woods.
- IPS correctly differentiated between "unknown tropical" and plantation woods (acacia, eucalyptus). In two samples, TUD claimed to find plantation species (acacia, eucalyptus) even though these were not contained in the samples.

Conclusion of the interpretation of results:

Laboratories with qualified staff can identify recycled paper and the wood species typically used in pulp production world-wide. Industrial paper production uses wood species which are available in sufficient quantities. They usually originate from commercial forests or plantations. Their diversity is therefore usually limited to a relatively small number of different wood types. The blind study has shown that familiar hardwoods (to a limited extent: oak) as well as plantation wood (acacia, eucalyptus) can be identified by skilled staff even under difficult conditions (large freeness value).

However, raw material for paper production originates not just from commercial forests and plantations, but also from primeval forests. Such paper is characterized by a large variety of processed wood species, i.e., mixed tropical hardwood (MTH). MTH can also be detected by laboratories (large number of different species, characteristic features of tropical woods). This is also valid if the paper contains MTH shares. In the study, MTH was simulated by a maximum of five tropical wood species. Although the possibility to identify genera from MTH is at present still limited due to limited morphological knowledge, the visual appearance in the fibre analysis provides laboratory staff with a clear indication of MTH. Experienced laboratory staff are already able to identify mixed tropical hardwood. One reason for the reliability of IPS compared to TUD is the existence of a reference database of around 40 tropical woods at IPS, whereas TUD did not yet have a comparable reference database at the time of the blind study.

The identification of individual tropical wood genera is at present possible in exceptional cases only. Further research in the field of wood fibre analysis is necessary in order to enable future, reliable statements regarding individual tropical wood genera in industrially produced paper.

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