Variation in Sapwood/Heartwood ratio, Density and Moisture Content in *Eucalyptus saligna*

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1.0 Introduction

Eucalyptus saligna is the dominant gum tree grown in the highlands, 1200 - 2400 m above sea level. It is used as transmission poles, posts, firewood timber for furniture, pulpwood and for veneer production.

The properties of *E. saligna* vary with the site where it is grown, height of the tree, cross section, and age of the tree. An understanding of its properties will help the user to utilize it more efficiently and understand the secondary processing which it need to be subjected to achieve good quality product. An understanding of Heartwood Sapwood ratio will guide the user in sawing, treatment. The moisture content and density will guide the user in seasoning, strength properties, shrinkage of wood, and uses which the wood can be used.

East African Tannin and Extract Company (EATEC) has been treating poles for overhead power transmission for the last 39 years. The species used are mainly Eucalyptus. The company has a wealth of experience in treatment of poles. However as technologies advance and consumers become more aware of the need for quality end products, the need for studying properties of Eucalyptus which influence its treatability is borne.

Eucalyptus cell contain cellulose, hemicellulose and lignin in the following proportions; cellulose 40-62%, hemicellulose 15-22%. The contents of the above vary between species and within species. The tree cross-section can be divided into pith region, heartwood, sapwood and bark. These vary with height, locality and within species.

The sapwood contain living cells that transport fluids. As the tree grows, sapwood is infiltrated with gums, resins and other materials. This makes heartwood more resistant to moisture flow than sapwood and so require longer drying time. It is also more susceptible to drying defects and so require milder drying conditions. The sapwood storage material is starch. The amount of starch decreases above dbh (Hulis et al 1962) and can be reduced by storage of the logs with bark attached for a period of one month or more

(Humpreys + Humpreys 1968). Due to high amount of starch, sapwood is susceptible to lytus attack unless it is treated. In heartwood, amount of phenolic extractives increase from pith to the outer heartwood with a lower amount in sapwood.

The moisture content in Eucalyptus vary. It steadily decrease from butt to the top of the stem (Frischts 1976). The moisture content decrease with age. Wood lose moisture or gain in an attempt to reach equilibrium with the surrounding. Moisture content information is necessary in knowing what happens to wood during drying, storage, fabrication and other uses. The water in wood can either be free water or bound water. Free water does not affect many wood properties except thermal conductivity and permeability. The bound water affects many physical and mechanical properties and its removal causes change that affects the use of wood.

The specific gravity indicates the amount of cell wall substance in wood. It is an important indicator of many physical properties of wood. It is widely used in studies of variation of wood properties in trees because it can be measured fairly easily and shows good correlations with both cellular characteristics and physical behaviour. The variation of cell wall substance in wood is as a result of changes in cell diameter, cell lengths and cell thickness. The specific gravity vary with stem cross section. In diffuse porous hardwoods changes in specific gravity depend on proportionate volume of vessels and fibre cell walls. Vessel diameter increase and number of vessels per unit area of x-section tend to decrease with increasing distance from the pith. The cell wall thickness and cell length account for over 75% of the variation in specific gravity in stem x-section with cell wall being the major factor (Michel Champaca L.). The wood density influence many properties and conversion processes including cutting, glueing, finishing and rate of drying. It provides good though not always direct indication of strength, stiffness, toughness (Chudnoff 1961).

2.0 LITERATURE REVIEW

2.1 **Basic Properties of Wood**

Eucalyptus cell contain cellulose, hemicellulose and lagnin in the following proportion cellulose 40-60%, hemicellulose 15-22%, Lignin 15-22%. The above contents vary between species and within species. The hemicellulose of eucalypts contain higher proportion of groupings that are potentially capable of producing acetic acid than do the hemicellulose of softwoods. The eucalypts contain varying amount of sapwood and heartwood.

The sapwood contains living cells that actively transport fluids necessary to life of tree. As the tree grows, sapwood inner layer die to become heartwood. The heartwood is infiltrated with gums, resins and other materials. The infiltration of gums make heartwood more resistant to moisture flow than sapwood and so require longer drying time. It is also more susceptible to drying defects and so require milder drying conditions. The sapwood storage material is starch. The starch contents vary during the year due to results of insect attack and demands of seed production, foliage growth and cambial division (Humpreys 1966). The amount of starch decreases above dbh (Hulis et al 1962) and can be reduced by storage of the logs with bark attached for a period of one month or more (Humpreys & Humpreys 1968). Due to the high amount of starch eucalyptus sapwood is susceptible to Lytus attack. In the heartwood; the amount of phenolic extratives increase from pith to the outer heartwood with a lower amount in sapwood.

The moisture content for eucalypts vary. It steadily decrease from butt to the top of the stem (Frischter 1976). The moisture content decrease with age. For *E. regnans* MC for sapwood was 118% while heartwood had 135%. Wood loose moisture or gains in an attempt to reach equilibrium with the surrounding. The state of balance depend on relative humidity and temperature of surrounding air. The moisture content information is necessary in knowing what happens to wood during drying, storage, facrication and uses.

The water in wood can either be as free water or bound water. Free water does not affect many wood properties except thermal conductivity and permiability. The bound water does affect many physical and mechanical properties and its removal causes change that affect the use of wood.

2.1.2 **Density of Wood**

Density vary between species, environment, within trees. Density vary more with increase in cambial age and distance from the pith at a given level than it does with height in wood of the same age from pith. The distance of the pith effect decrease with increase in height. wood density for a particular tree controlled more by a combination of environment factors than it does by the radial growth rate. Wood density has appreciable influence on many properties and conversion processes including cutting, glueing, finishing and rate of drying. It provides good though not always direct indication of strength, stiffness, toughness (Chudnoff 1961).

2.1.3. **Ash and Acidity**

Eucalyptus has ash content in vicinity of 0.1% rising to 0.6% and even 1.9% with *E. deglupta* (Dadwell et al 1962). Large resorption of potassium and phosphorus can occur when eucalyptus sapwood is transformed to heartwood. Acidity of freshly cut, undried wood can be high and for mature *E. diversicolour, E. delegatentis* and *E. regnans* PH value of 2.2, 3.5, and 3.3 respectively recorded (Dadwell et al 1962).

2.1.3 **Submiscroscopic and Mosphological Properties**

The behaviour of wood during use is correlated with its chemical composition, fine structure of fibre wall and its anatomy. Thickness of cell wall of fibre vary from species to species, late wood and early wood or normal and tenaron wood. Wall consist of secondary wall of which the S_1 layer is the main portion. The fibre length diameter and wall thickness increase with the age of the eucalyptus. Differences of fibre between woods formed at different ages of the trees are greater than those between woods of different eucalyptus species.

Vessels are important in impregnation drying, glueing, painting, cutting and other processes. The number of fibres produced by the cambium before vessel formation decrease from ground level upto half of the tree height (Amos et al 1950). The vessel diameter has been found to increase and vessels frequently decrease from pith outwards. Vessel walls are approximately 3.4 cm. The average frequency of vessels is between 5-7 vessels per m^2 for matured wood of *E. saligna* and the average maximum tangential diameter is more than 200 m.

The tyloses significantly affect the rate of movement of liquids into and out of wood. Tyloses are a feature of heartwood and uncommon for freshly cut sapwoods (but formed if stored under moist conditions).

2.1.4. **Shrinkage**

The main problem in eucalypts is that excessive shrinkage causes defects such as checks and splits. The defects are more pronounced in wood of low density. Excessive shrinkage is accelerated with the collapse of thin walled fibres particularly in earlywood. Collapse intensity decreases with height of tree but amount of variations differ from tree to tree (Pankericins 1961). Most collapse shrinkage can be removed by steaming timber that is nearly dry for several hours in saturated steam at 100^0C.

2.1.5 **Calorific Value**

The oven dry calorific value of eucalypts is 19800 KJ kg^{-1} (Humpreys 1956) but value vary due to differences in initial moisture content, rate of drying and final moisutre content.

2.2 Preservation and Preserved Wood

The mode of penetration in all treatments except in diffusion process is confined initially to movement in longitudinal direction along the vessels. Penetration from radial and tangential faces negligible unless assisted by sloping grain, checks incisions or fungal damage. Sapwood is usually narrow (less than 25 mm) and in most species liable to considerable checking. In most species it contains starch and so liable to attack by bestrychid or lyctid borers during and after drying.

The heartwood is typically difficult or very difficult to penetrate with preservative applied by conventional pressure treatment (upto 1500 Kpa). Penetration can be improved by applying high pressures with or without incising of wood or subjecting the dried wood to Boulton, drying (i.e. boiling in preservative oil under pressure) before treatment. Durability of heartwood vary with species with high density timber (over 800 Kg m^{-3} being most durable). Durability is often much reduced near pith and the size of this less durable, inner heartwood area increases with the age of the tree. To achieve penetration, loading of preservative in eucalyptus sapwood has to be higher than that of conifers.

2.2.1 Factors Affecting Treatment

The penetration is through the two ends where vessels are severed but not through lateral faces as in case of permiable conifers. Incising of heartwood to aid penetration for eucalypts is not as effective as in conifers. Except in permiable eucalypts, distribution of preservative in sapwood especially oils can be variable or unsatisfactory as compared to more uniform results obtained for conifers sapwood, particularly in eucalypts of high density. For low density eucalypts, gross oil retention in sapwood may exceed 300 $Kg.m^{-3}$ sometimes twice the void volume of vessels due to migration from vessels. Migration depends on species, type of preservative, density, specimen length, moisture content, pressure and period of application. Migration is assisted by adequate drying before treatment, heating sufficiently to lower viscosity of oil, keeping high pressures and continueing treatment upto refusal (Dickiason 1974).

The thickness of sapwood affects the treatability with sapwood treated for eucalypts being half that treated for conifers. Sapwood is likely to check during drying especially in low density where shrinkage is 2-3 times that of conifers. To counter the above, treat species whose heartwood is durable. The alternative is that sapwood should be treated effectively. This scan be achieved by careful reasoning to control check and reduce chances of further checking after treatment. Usage of 25-30% more preservative than for conifers can also be applied.

Heartwood is difficult to treat. The problem increases with increase in density. It can be treated under high pressures (7000 Kpa). For large timber incising followed by boulton drying enhance prenentration. High pressure treatment results to little damage to timber provided that temperatures are kept down (70-75°c). At high temperature, maximum pressure should not exceed 5000 Kpa. Diffusion treatment of heartwood is good where leaching hazard is low. It can be done by immersion for 24 hours or more. Dipping in a very concentrated solution followed by block stacking and cover for 3 weeks or more while diffusion proceeds has been found to be a better way for treating heartwood.

3.0 STUDY METHODS

3.1 Study site:

The study covered Rift Valley and Western Province where *E. saligna* is grown in plantations mainly for transmission poles and for fuelwood. Seven forest stations covered were as follows:

	STATION	DISTRICT
1	Kapsaret	Uasin Gishu
2.	Maji Mazuri	Baringo
3.	Elburgon	Nakuru
4.	Kitalale	Trans Nzoia
5	Suam	Trans Nzoia
6.	Saboti	Trans Nzoia
7.	Kaporet	Trans Nzoia

3.2 Experimental Procedure

Six trees were sampled at random from each station. The trees were felled after which sample discs were extracted as shown below:

USABLE LOG SECTION

The discs were labelled and put in polythene bags to avoid further moisture less. They were transported to the laboratory where further measurements and tests were carried out.

For each disc the following parameters were measured:

.Diameter

.Bark thickness

.Sapwood thickness

.Heartwood thickness

The specific gravity and percentage moisture content was determined for each of the disc. For each of the disc, variation of percentage moisture content (% m.c) and density across the cross-section was determined by determining the values of density and % m.c. in the pith, heartwood and sapwood region of the disc.

4.0 RESULTS AND DISCUSSIONS

4.1 Heartwood/sapwood Ration (Hw/Sw Ratio)

The Hw/Sw ratio correlates with the diameter of the tree which is slightly influenced by bark thickness. To understand the trend and variation in Hw/Sw Ratio; the diameter, bark thickness, sapwood and heartwood thickness were studied separately.

4.1.1 Diameter

The average diameter for all the sampled poles was 231.10 mm with a range of 118.5 to 403.0 mm. Trees in Saboti had the largest diameter while those in Kitalale had the least. The average diameter sampled at the bottom was 272.20 mm, 229.20 at the middle and 192.90 at the top. There was significant difference in diameter among the sites. The average diameter for the sites is shown in table 1.

4.1.2 Bark thickness

The average bark thickness was 8.10 mm with a range of 3.0 - 19.8 mm depending on site and height. The average bark thickness at the bottom was 11.70mm, 7.00 mm in the middle and 5.70 mm at the top. The bark for poles transmission is removed before treatment. However the determination of the volume of material sold is done with the bark. This means that the volume occupied by the bark does not go into direct volume of the poles. The proportion of the bark at the bottom was 8.6%, 6.1% in the middle and 5.9% at the top. If underbark volume is to be calculated the above proportion of volume occupied by the bark has to be deducted. The bark thickness for the seven sites is shown in table 1.

4.1.3 Sapwood thickness (S/W)

The average sapwood thickness in all the sites was 33.30 mm with a range of 20.5 mm to 85.0 mm. The sapwood thickness at dbh was 33.41 mm, 33.55 at the middle and 32.93 mm at the top. There was a significant variation of sapwood thickness among the sites, but no difference along the height. This shows that SW thickness remain constant irrespective of the height above the ground. The sapwood is the treatable part of the poles, so the penetration of the chemical is uniform along the height of the pole.

Table 1: Average Diameter, Bark thickness and HW/SW Ratio for the poles

Site Parameters	Kapsaret	Maji Mazuri	Elburgon	Kitalale	Suam	Saboti	Kaporet	Overall average
Diameter (mm)	218.28	207.00	190.92	233.97	246.00	269.67	254.08	231.12
BarkThickness (mm)	6.90	6.81	7.77	8.21	9.28	8.19	9.83	8.13
Heartwood (HW) Thickness (mm)	66.72	70.51	62.65	76.78	77.81	98.92	83.68	76.72
Sapwood (SW) Thickness (mm)	35.70	29.46	26.40	33.54	38.95	28.44	40.58	33.29
HW/SW Ratio	1.88	2.46	2.44	2.39	2.01	3.55	2.22	2.42

Table 2: Diameter, Bark thickness and HW/SW Ratio at DBH of the poles

Site Parameters	Kapsaret	Maji Mazuri	Elburgon	Kitalale	Suam	Saboti	Kaporet	Overall average
Diameter (mm)	254.75	245.17	211.42	269.17	302.20	309.00	319.08	272.76
Bark Thickness (mm)	9.83	9.20	9.77	11.55	13.67	11.12	16.82	11.71
Heartwood (HW) Thickness (mm)	82.23	80.65	70.78	92.87	93.75	114.32	110.07	92.10
Sapwood (SW) Thickness (mm)	35.1	30.68	26.43	31.12	44.25	29.78	36.48	33.41
HW/SW Ratio	2.38	2.66	2.72	3.00	2.15	3.98	3.05	2.84

Table 3: Diameter, bark thickness and HW/Sw Ratio in the middle of the poles

Site Parameters	Kapsaret	Maji Mazuri	Elburgon	Kitalale	Suam	Saboti	Kaporet	Overall average
Diameter (mm)	219.17	205.17	190.67	234.75	241.50	276.00	288.30	229.15
Bark Thickness (mm)	6.07	5.77	7.40	7.33	8.02	7.60	6.62	6.98
H/W Thickness	68.75	68.57	63.60	77.07	78.15	102.32	84.07	77.50
S/W Thickness	35.9	28.78	25.87	33.90	37.00	28.68	44.73	33.55
HW/SW Ratio	1.93	2.45	2.35	2.35	2.12	3.62	2.11	2.44

Table 4: Diameter, bark thickness and HW/SW Ratio at the top of the pole.

Site Parameter	Kapsaret	Maji Mazuri	Elburgon	Kitalale	Suam	Saboti	Kaporet	Overall average
Diameter (mm)	180.92	170.67	170.67	198.00	203.67	224.00	202.25	192.88
Bark thickness (mm)	4.80	5.45	6.15	5.73	6.17	5.85	5.52	5.67
H/W Thickness (mm)	49.18	62.32	53.57	60.40	61.53	80.12	56.90	60.57
S/W Thickness (mm)	36.1	28.90	26.90	35.60	35.60	26.87	40.52	32.93
HW/SW Ratio	1.38	2.27	2.05	1.81	1.77	3.08	1.52	1.98

4.1.4 Heartwood Thickness

The overall HW thickness in all sites was 76.7 mm with a range of 34.0 to 149.0 mm. The average heartwood thickness at dbh was 92.10 mm, 77.50 in the middle and 60.57 mm at the top. There was variation in HW thickness among the sites and along the height.

However variation along the height was four times significant than the variation among the sites. The HW thickness decrease with increase in height thus following the trend of the diameter of the pole.

The heartwood is the dead part of the wood. It is difficult to treat. It contains high proportions of extractives which make it more durable. The higher the proportion of heartwood in the tree, the more the value of the wood and the wood becomes more durable.

4.1.5 **Heartwood/Sapwood Ratio (HW/SW Ratio)**

The average HW/SW ratio was 2.42. At dbh the ratio was 2.84, middle 2.44 and 1.98 at the top. The ratio decreased with height following the trend of heartwood thickness. The higher the HW/SW ratio, the less susceptible the pole is due to presence of less amount of sapwood.

4.2 **Variation in density of *E. saligna***

The density was found to vary with site, height and cross section (cross section). A 3 factor anova analysis was done to understand how density varied.

The average density for the whole region was 0.481 g/cc. There was a significant difference in variation of density among the site (F value =21.58), along the height (F value=16.059) and across the cross section (F value =126.229). There was significant interraction between site and cross section, and height and cross section. The overall interaction between site, height and cross section was not significant.

There was a slight increase in density along the height with density at dbh being 0.468, in the middle it was 0.477 and 0.498 at the top. The density increased from pith outwards. Density at the pith was 0.452, at heartwood 0.459 and 0.531 at the sapwood.This is due to increasing wall thickness of fibres from pith to bark or increasing percentage of fibres without little change in cell thickness. Density varied more across the cross section than it did along the height. The average density in each of the seven stations is given in table 5.

Table 5: Average density per site

Site	Kapsaret	Maji Mazuri	Elburgon	Kitalale	Suam	Saboti	Kaporet
Density g/cc	0.456	0.474	0.535	0.467	0.500	0.462	0.472

Elburgon had poles with highest density 0.535 while Kapsaret had least density, growing conditions such as competition within the stand or soil fertility can cause major differences in trees, properties. Geographical Location denoted by latitude and altitude has an effect of variability of properties within a species. In this study the stations located high altitude had higher density compared with those in low altitude area.

As indicated above there was a significant difference on variation of density within various sites. A comparison was done to determine which sites gave significant difference. The following sites showed significant difference.

1 & 2, 1 & 5, 2 & 3, 2&5, 3&4, 3&5, 3&6, 3&7, 4&5, 5&6, 5&7.

The variation of density across the cross section was ten times the variation along the height. This can be explained by the fact that in diffuse porous hardwood, changes in density depend on changes of proportionate volumes of vessels and fiber cell walls. Vessel diameter tend to increase and number of vessels per unit area of the cross section tend to decrease with increasing distance from the pith. According to studies done with Indian species Michelle Champaca L, shows that cell thickness and cell length account for over 75% of the variation in specific gravity in stem cross section in the cell with cell wall thickness being the major factor. On comparison there was significant difference of specific gravity between pith and sapwood, sapwood and heartwood but no difference between pith and heartwood.

4.3 **Variation of moisture content**

The average % age MC for the whole region was 104.34%. Moisture content at dbh was 116.67%, 103.00% in the middle and 93.33% at the top. This shows a decrease in moisture content with increase in height. The moisture content at the pith was 107.07% at heartwood 105.79% and 100.15% in the sapwood. This shows a decrease in moisture content from pith outward.

There was significant difference in variation of moisture content among the sites ($F=8.618$), along the height ($F=62.196$) and across the cross section ($F=6.13$). The variation of moisture content along the height was 7.5 times the variation of mc with cross section. There was no interaction between site and cross section and cross section and height.

The average mc for the 7 regions is shown in table 6.

Table 6: Average moisture content

Site	Kapsaret	Maji Mazuri	Elburgon	Kitalale	Suam	Saboti	Kapuret
Site No.	1	2	3	4	5	6	7
% m.c.	111.11	100.21	98.88	115.07	101.82	102.07	102.4

The variation of m.c. along the height showed that variation was significant for all the combinations i.e. pith/Hw, Hw/Sw. Variation across the cross section was significant.

3.4 **Relationship between Density and % m.c.**

(1) Among the site

Site	Kapsaret	Maji Mazuri	Elburgon	Kitalale	Suam	Saboti	Kaporet
Density	0.456	0.474	0.535	0.467	0.500	0.462	0.472
%MC	111.11	100.21	96.88	115.87	101.82	102.07	102.41

As the M.C. increase, the density of the pole decreases. In Elburgon the poles had the lowest MC but highest density. This shows an increase relationship between density and moisture content.

(2) Along the height

Ht	Dbh	Middle	Top
Density	0.468	0.477	0.498
%MC	116.67	103.00	93.33

As the density increases upwards the M.C. decreases.

(3) Across the x-section

	Pith	Heartwood	Sapwood
Density	0.452	0.459	0.531
%MC	107.67	105.79	100.51

As the density increases from pit outwards, the M.C. decreases from pith outwards.

5.0 Conclusion and Recommendations

The average diameter of poles sampled was 231 mm comprising of 7% bark; 65% heartwood and 28% sapwood. Heartwood decreased along the height while sapwood was constant irrespective of the height of the pole. Sapwood is the treatable part of the pole and hence the penetration of the chemical is uniform along the height. The variation in properties among the site means that treatment of poles should be site specific.

The average density was 0.481g/cc. Density varied more with cross section than the height. Density of was 0.452, 0.459 at heartwood and 0.531 at sapwood. This has an effect on timber usage. To achieve better glueing results, the timber has to be of almost uniform density. This calls for quarter sawn technique in sawing which ensure that timber of the same distance from the pith is sawn together.

The average moisture content was 104.3%. Results showed a decrease in moisture content along the height and a further decrease from pith outwards. This has a relationship to drying of wood prior to treatment and usage. The wood has to be dried to a moisture content of below 30% before treatment. The drying period can be shortened by leaving the cut logs with branches. Density was inversely proportional to the moisture content.

The results gave data on sapwood, heartwood, moisture content and density which is useful in exploring alternative usage of Eucalyptus species.