Determining the basic density of wood chips

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ABSTRACT *Imprecise measurement of basic density—the ratio of oven-dry wood mass to its green volume—is caused by variation in the measured values for green volume. This value is determined by reading the apparent weight of a presoaked wood sample while it is immersed in water. Inaccurate readings occur when the amount of water displaced by the sample is affected by extraneous factors. Chief among these are the presence of water or air bubbles on chip surfaces as well as air voids within the chips, which can absorb water during the procedure. Accurate measurement of green volume is achieved by presoaking the wood sample, removing it from the bath, and then eliminating surface water by careful centrifugation before immersing and weighing it. Insufficient removal of surface water by hand wiping and removal of water from the voids within the chips by overly powerful centrifugation are the primary causes of variation in measurement of green volume. These conclusions are experimentally verified. A calibration procedure for determining a suitable centrifugation speed is provided.*

KEYWORDS
Chips
Density
Density measurement
Volume
Wood

Wood basic density—the ratio of oven-dry mass to green volume—is commonly used as a basis for documentation, characterization of a wood population, determination of wood-chip bulk density, estimation of wood consumption in a pulp mill, or comparison between labs. Accurate determination of wood basic density is obviously important and desirable.

All of the laboratories in Sweden use the same approach in measuring the basic density of wood chips. The green volume is determined by weighing a wood sample immersed in either water or mercury. While the laboratories operate on the same principle, there is no such consistency in the procedures used to implement the measurements. A comparative test with various Swedish laboratories established the fact that there was enough variability in results from different laboratories to justify a fundamental study of the problem. This article presents the results of this study.

Comparative test with 11 laboratories

Basic density is defined as the ratio between the oven-dry mass of a wood sample and its green volume.

$$D = M/V \quad (1)$$

where

D = basic density, kg/m^3

M = oven-dry mass, kg

V = green volume of a wood sample in equilibrium with surrounding water, m^3

Oven-dry wood mass can be determined accurately, but calculation of green volume is another matter. Using Archimedes' principle, the apparent weight of the water-immersed chips is taken as a measure of their green volume. **Figure 1** depicts the two methods of determining green volume.

Four years ago we noticed that two laboratories provided different measurements for basic density of wood based on samples from the same lot. The measurements deviated by about 15 kg/m^3, or 3.5%. While we could not explain this difference, we knew that the laboratories had used different methods to remove water from the surfaces of the chips prior to determination of green volume. We concluded that the lack of a standard procedure was probably resulting in imprecise measurements of basic density of wood in other laboratories as well.

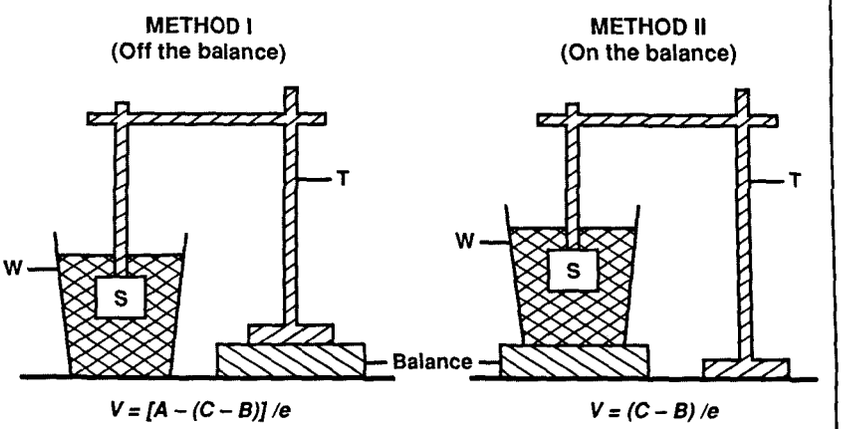
We invited ten Swedish laboratories to participate in a comparative test. It was apparent that such a test would require meticulous sample preparation. We cut 25-mm disks from a well-barked pine log and

numbered each disk. After a 3-day water soak, the green volume of each disk was determined by weighing them while immersed in water. (Surface water was carefully wiped off the disk before it was immersed and weighed.) Every sixth disk was dried, and then the disk's basic density was calculated. The remaining disks were manually cut into chips, with the chips from each disk maintained as a discrete sample. The fines generated by hand chipping each disk were collected, dried, and weighed. Chips from five adjacent disks were sent to each participating laboratory, which then determined basic density according to its own routine and reported the result and the dry weights to our lab. We calculated the basic density of each disk using the dry weight reported to our lab together with the dry weight of the fines that had been collected at the time of chipping.

The procedure used to analyze the results from the participating laboratories permits comparison without presuming that our lab had the "true" values. The range of basic-density values obtained was 33 kg/m^3, as seen in **Table I**. The results from the three laboratories that used the mercury method (Labs I, J, and K) were similar. However, the mercury method cannot be recommended because all of the density values obtained were on the lower end of the scale. Two laboratories (Labs A and B), both of which used centrifugation to remove water from the sample surface, provided results that were somewhat high. However, the conditions used during the centrifugation cannot alone explain their results.

A second comparative test also was conducted using numbered disks from another pine log. Hand-cut chips were prepared in our lab, with the chips from each disk maintained as a discrete sample. Samples from three adjacent disks were sent to each laboratory, while every fourth sample was kept by our lab. Basic density was determined according to the routine of each laboratory (including water soak in those laboratories where this was part of the routine procedure). The second test trial confirmed the results given in Table I.

1. Two methods of determining the green volume of wood chips.



$V = [A - (C - B)] / e$ $V = (C - B) / e$

S = Sample basket
W = Water container
T = Support

V **= green volume of wood chips, cm^3**
A **= mass of wood chips before C-mass determination, g**
B **= mass of empty sample basket when immersed in water, g**
C **= mass of wood chips and sample basket when immersed in water, g**
e **= density of water surrounding sample basket, g/cm^3**

I. Differences in basic density of chips and disks from which chips were cut

Laboratory	*Difference in basic density (P–Q)*, kg/m^3*	*Liquid medium used to determine green volume*	*Method used to remove water from surface before measuring volume*
A	-18	Water	Centrifuge
B	-11	Water	Centrifuge
C	-1	Water	Centrifuge
D	0	Water	Centrifuge
E	0	Water	Wiping
F	+2	Water	Wiping
G	+4	Water	Wiping
H	+5	Water	Wiping
I	+11	Mercury	...
J	+12	Mercury	...
K	+15	Mercury	...

*P = basic density as calculated in Lab F, which prepared and distributed the chip samples. [Basic density calculated from dry mass of chips (determined by participating laboratories) and volume of disk (determined in Lab F).]
Q = basic density of chips from each disk (determined by participating laboratories).

II. Dry content and basic density of pine disks after 1-7 days presoak in water

Dry content, %						*Basic density*, kg/m³*				
0 day	*1 day*	*2 days*	*3 days*	*6 days*	*7 days*	*1 day*	*2 days*	*3 days*	*6 days*	*7 days*
					Fresh tree					
45.7	44.0	43.8	43.5	42.9	43.4	424	424	426	424	422
46.3	44.8	44.6	44.5	43.7	44.2	437	437	438	433	436
46.3	44.2	44.0	43.9	43.0	43.3	418	420	420	420	419
45.4	43.8	43.6	43.4	42.5	42.8	419	420	420	421	420
45.7	43.8	43.6	43.5	42.7	43.0	421	419	421	422	412
					Dry tree					
78.3	62.6	60.5	59.8	58.4	58.0	478	478	478	477	479
78.3	63.0	60.8	60.0	58.5	57.8	482	481	482	480	481
78.2	63.1	60.9	59.9	58.5	57.8	479	479	479	479	481
78.2	62.7	60.6	59.8	58.3	57.4	479	480	481	479	481
78.4	62.5	60.4	59.6	58.4	57.7	481	481	482	481	482

*Green volume determined after wiping water off disk surface.

III. Physical condition and simulated equivalent

Physical condition	*Simulated equivalent*
Oven-dry chips	Empty jar with cover
All chip voids completely filled with water	Water-filled jar
Chip voids partly filled with water (the rest being air)	Partly water-filled jar
Water on chip surfaces	Water-filled rubber balloon fixed to outside of jar
Air on chip surfaces	Air-filled rubber balloon fixed to outside of jar
Water penetrates all air-filled chip voids during volume determination	Partly water-filled jar before volume determination and water-filled jar during volume determination

Parameters to consider during green-volume determination

If a true value for basic density is to be obtained, the following parameters must be considered when determining green volume:

- Water on chip surfaces
- Air bubbles on chip surfaces
- Air in chip voids
- Density of water surrounding the chips.

These parameters are easily controlled when determining the green volume of a wood disk (thickness>15 mm) that has been presoaked at least 4 h. Water on the surface of the disk is simply removed by careful wiping. Small amounts of water remaining on the surface can be neglected because the disk's surface area is small relative to that of the chips cut from the disk. **Table II**, which depicts basic density of fresh and dry pine disks after presoak time of 1-7 days, shows that the presence of air in the voids of a presoaked disk does not affect

IV. Basic density as determined under various simulated conditions

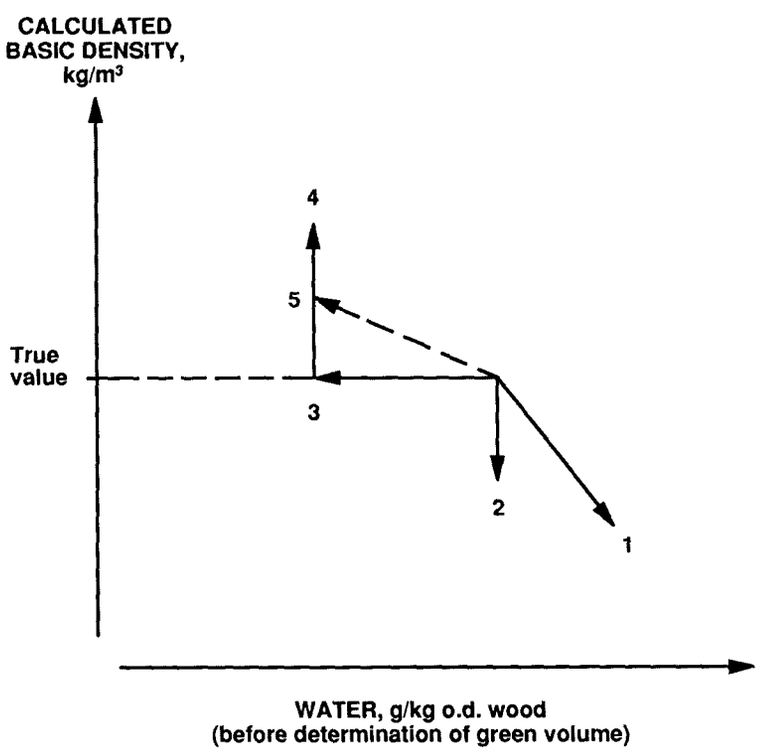
Water in jar	*Air in jar*	*Water balloon outside jar*	*Air balloon outside jar*	*Mass of chips before volume determination, (A), g*	*Mass of chips and basket immersed in water (C), g*	*Green volume (V), cm³*	*Basic density (D)*, kg/m³*	*Water, g/kg o.d. wood*
3/4 filled	Yes	No	No	1129.6	449.8	1264.5	380	1352
		Yes	No	1182.9	449.1	1318.5	364	1463
		No	Yes	1130.9	312.2	1403.4	342	1355
		Yes	Yes	1184.2	312.3	1456.6	330	1466
Filled	No	No	No	1471.9	786.5	1270.1	378	2066
		Yes	No	1525.2	786.6	1323.3	363	2177
		No	Yes	1473.2	649.7	1408.2	341	2067
		Yes	Yes	1526.5	649.7	1461.5	329	2179
3/4 filled (*A*) and filled (*C*)	No	No	No	1129.6	786.5	927.8	518	1352

*Basic density, $D = (M/V)\,1000 = \{M/[A - (C - B)]\}\,1000$
M = o.d. wood mass = mass of empty jar and ocver = 480.2 g
B = mass of empty sample basket immersed in water = 584.7 g

basic density and thus, by extension, does not interfere with determination of green volume. The relative air content in the voids of the fresh pine disks after a 7-day water soak was 23%. The corresponding value for the dry pine disks was 48%.

An experimental model was constructed to illustrate how measurement of green volume can be affected by such disruptive factors as water or air on the chip surface and the abrupt absorption of water in air-filled chip voids. These various physical conditions were simulated with a covered jar and a rubber balloon. **Table III** lists the physical condition of interest and the simulated equivalent. The quantitative results of the experiment are given in **Table IV**, while the conclusions that can be drawn from these data are illustrated graphically in **Fig. 2**. The presence of either water or air on chip surfaces reduces the true value of the basic density, as illustrated by vectors 1 and 2 in Fig. 2. The opposite effect occurs when water abruptly penetrates into the chip voids while the green volume is being measured. Air in the voids of the chips has no effect when the rate of water penetration during the green-volume determination is retarded by a reasonable water presoak. (The rate in Table II was very low,<1 g/15 min.) The aim of the presoak is to achieve a "practical water equilibrium," meaning that the rate of water penetration into the voids of the wood sample during the volume determination is close to zero.

2. Influence of disruptive factors (air or water on chip surfaces and water penetration into air-filled voids) on calculated basic density.



1. Water on chip surfaces
2. Air bubbles on chip surfaces
3. Air in chip voids – no water penetration
4. Air in chip voids – water penetration (arrowhead represents full penetration)
5. Air in chip voids – partial water penetration

V. Influence of water-removal method on calculated basic density and dry content of wood disk and chips of the same disk

	Disk		Chips		
	Wiped off	*Drained off*	*Centrifuged (465 g)*	*Wiped off*	*Drained off*
	Calculated basic density, kg/m³				
Spruce a	374	371	380	371	348
Spruce b	375	372	379	369	354
Pine a	484	480	489	481	457
Pine b	483	480	489	479	447
	Basic density difference, kg/m³				
Spruce a	0	-3	+6	-3	-26
Spruce b	0	-3	+4	-6	-21
Pine a	0	-4	+5	-3	-27
Pine b	0	-3	+6	-4	-36
	Wood dry content prior to volume determination, %				
Spruce a	52.9	52.4	50.0	47.9	44.1
Spruce b	52.5	51.9	49.2	47.0	44.7
Pine a	57.6	57.1	55.6	53.6	50.7
Pine b	56.9	56.4	55.0	52.8	48.9

VI. Test conditions for centrifuge

Revolutions, rpm	*Centrifugal force*, g*	
	R_i = 4.5 cm	R_y = 9.7 cm
480	12	25
930	43	94
1525	117	252
3020	458	988

*Wood chips were kept between radius 4.5 cm and 9.7 cm during centrifugation.

Air bubbles on the surface of the wood sample must be removed as completely as possible by twisting and turning the immersed sample basket just prior to the volume determination. The effect of the temperature of the water surrounding the chips during the green-volume determination can be neglected if it is below 20°C. (At 20°C, the true basic density value is 0.18% lower than the value calculated without considering the influence of the water temperature. The corresponding deviation at 30°C is 0.43%.) The removal of water from chip surfaces, however, poses a more difficult challenge. We thus conducted tests to determine the most effective way of dealing with this problem.

Removal of surface water

Two disks of spruce and two disks of pine were soaked in water for three days. The green volume of the disks was determined twice, after they were drained and then after they were carefully wiped off. Hand-cut chips were made from each disk, and the fines were collected, dried, and weighed. The chips were then soaked in water for three days. The green volume of the chips from each disk was determined three times, once after simply draining the chips, once after draining and wiping them, and once after the chips had been centrifuged for 2 min at the relative centrifugal force of 465 times the acceleration due to gravity (465 *g*). After the test with centrifuged chips, the wood samples were dried. The results obtained are shown in **Table V**.

From Tables II and V, it can be concluded that the truest value of basic density is obtained when the presoaked wood disk is carefully wiped off prior to determination of the green volume. The explanation is that the wiped-off disks contain practically no surface water together with practically no water penetration into air-filled voids of the disk during the volume determination. This is true despite a higher air content of the voids in the disks compared with the voids in the chips for the same wood sample (according to the dry contents shown in Table V).

Drained-off disks and wiped-off chips gave values for basic density that were slightly low. The drained-off chips resulted in values that were significantly lower. All of these low values were caused by adherence of surface water to the chips prior to the volume determination. Centrifugation, on the other hand, resulted in basic-density values that were too high. While powerful centrifugation removes all surface water, it also expels water from the voids, allowing repenetration of water as the volume is being determined. Consequently, when working with wood chips, the problem is to find centrifugation conditions that will remove surface water without removing water from the voids of the presoaked chips.

Centrifugation conditions

Presoaked hand-cut or mill-cut wood chips were centrifuged in a drum centrifuge at four different speeds prior to volume determination. Test conditions are shown in **Table VI**.

Barked wood disks were water soaked and their green volume determined after surface water had been carefully wiped off. Each disk was then hand-cut into chips. (Fines were collected, dried, and weighed.) The chips were water soaked, and green volume was determined after carefully wiping off the surface water.

VII. Calculated basic density of wood samples from five species subjected to various levels of centrifugation, kg/m³

Sample*	Disk (wiped off)	Chips: Wiped off	Chips: Centrifugation (2 min) 12-25 g	43-94 g	117-252 g	458-988 g
X 1	407.7	404.9	...	409.1	408.6	414.9
X 2	403.9	399.2	398.6	403.5	...	411.0
X 3	407.3	403.8	402.0	406.6	...	414.7
TR 1	409.8	400.2	404.4	410.8	...	420.4
TR 2	499.5	493.7	...	497.9	500.3	503.7
TR 3	459.5	456.6	453.9	459.4	...	465.0
TM 1	435.6	431.2	...	437.8	443.9	455.1
TM 2	456.8	451.5	450.2	455.3	...	463.6
TM 3	395.3	391.1	388.9	394.5	...	399.6
B 1	444.6	440.4	439.2	442.7	...	446.3
B 2	481.2	476.5	476.1	480.5	...	485.5
B 3	514.6	512.6	...	516.2	517.2	521.2
G 1	404.3	403.1	...	405.4	407.4	409.9
G 2	398.4	396.3	393.9	398.8	...	405.6
G 3	407.6	406.5	403.6	407.4	...	412.8
Average deviation from disk	...	-3.9	-5.4	0.0	+3.1	+6.9

*X = aspen (*Populus tremula*); TR = pine from the base of the tree (*Pinus silvestris*); TM = pine from the middle of the tree (*Pinus silvestris*); B = birch (*Betula verrucosa*); G = Spruce (*Picea abies*).

Green volume of the chips was determined three more times, with surface water removed by progressively higher centrifuge speeds. (Centrifuged chips were not wiped off.) In each case, the chips were presoaked before being centrifuged. Finally the wood-chip samples were dried. The study was carried out with three disks from each of five wood lots. Each disk was obtained from a different log. The calculated basic density values for all of the samples are listed in **Table VII.**

The results in Table VII indicate that the best agreement with the basic density of a disk is obtained by centrifuging the chips at 43-94 *g* prior to determination of green volume. The chips that were wiped as well as those that were centrifuged at low speed (12-25 *g*) apparently had enough water on their surfaces to affect the results, and their basic densities are too low. Surface water is entirely removed by centrifugation at 43-94 *g* and at the higher levels (117-252 *g* and 458-988 *g*). However, powerful centrifugation also removed water from the voids of the chips. This allowed water to repenetrate the chip voids during the volume determination, resulting in high basic density values.

Mill-made softwood and hardwood chips were fractionated in the lab. Green volume was determined with well-wiped samples as well as at three centrifugation speeds. The results are shown in **Table VIII.** The samples were water soaked prior to each green volume determination and dried only after the last volume determination. Basic density differences with a careful centrifugation (43-94 *g*) as a reference are shown in **Table IX.** The main fraction, slot 3-8 mm, behaves similarly or slightly worse than hand-cut chips. Fines, with their greater surface area, are no doubt more sensitive to disruptive factors during the green volume determination. The conclusion is that unless a correct centrifugation speed is used, a considerable error can be introduced.

VIII. Calculated basic density of mill chips fractionated in the laboratory, kg/m³

Sample	Wiped off	Centrifugation (2 min) 12-25 g	43-94 g	458-988 g
		Softwood		
Slot 3-8 mm	397	399	405	416
Slot 2-3 mm	404	409	419	435
Hole 3-7 mm	394	400	414	436
		Hardwood		
Slot 3-8 mm	483	484	489	497
Slot 2-3 mm	477	480	489	500
Hole 3-7 mm	455	466	484	505

Calibration procedure

Basic density values of adjoining disks from the same log are normally not identical. This is partly explained by

IX. Differences[a] in calculated basic density for samples in Table VIII, kg/m³

Sample	Wiped off	Centrifugation (2 min) 12-25 g	Centrifugation (2 min) 458-988 g
		Softwood	
Slot 3-8 mm	-8	-6	+11
Slot 2-3 mm	-15	-10	+16
Hole 3-7 mm	-20	-14	+22
		Hardwood	
Slot 3-8 mm	-6	-5	+8
Slot 2-3 mm	-12	-9	+11
Hole 3-7 mm	-29	-18	+22
Hand-cut chips[b]	-4	-5	+7

[a]Values obtained at 43-94 g centrifugation are used as a reference.

[b]Average values from Table VII.

a trunk gradient or the knot content. Consequently, for a calibration procedure, it is recommended that the green volume be determined both for the disk as well as for chips hand cut from the same disk. The main steps are:

1. Soak disk in water 4-72 h.
2. Determine green volume.
3. Manually chip the entire disk. Collect, dry, and weigh the fines.
4. Soak chips in water 4-72 h.
5. Centrifuge chips for 2 min at an appropriate speed. (Chips should be charged as closely as possible to the periphery of the centrifuge drum.)
6. Determine green volume of the chips.
7. Dry chips at 105°C to constant weight.
8. Calculate basic density of disk and chips. Dry mass of disk = dry mass of chips + fines.
9. Repeat steps 1-8 for 2-4 disks.

If the average deviation of disk and chips exceeds 2-4 kg/m³, adjust the centrifuge speed and repeat steps 1-9. As an alternative, proceed with steps 1-6 followed by steps 4-6 one or several times with different centrifuge speeds. Finish with steps 7-9.

The results presented in this report are the groundwork for a SCAN test procedure in progress (Scandinavian Pulp, Paper and Board Testing Committee). The TAPPI test method (TAPPI T 258) prescribes a pycnometer procedure for determining the green volume of wood chips. After a short water soak, surface water is sponged off with paper towels. However, the results presented here show that wiping the chips does not completely remove this water. It is possible to obtain true green-volume values with TAPPI T 258. However, the results outlined in Tables III and IV indicate the necessity of controlling surface water, surface air, and penetration of water into the chip voids during the volume determination.

Conclusion

Basic density—the ratio between oven-dry mass and green volume—can be determined accurately for wood disks as well as wood chips. Green volume is determined by weighing the wood sample while it is immersed in water. (Basic density values obtained using mercury instead of water are too low.) Accurate determination of green volume depends on the following items:

- A water presoak of 4-72 h
- Removal of excess water adhering to the chip surfaces prior to determination of green volume
- Retention of water in the voids inside the chips prior to determination of green volume
- Removal of air bubbles adhering to the chip surfaces before determining green volume
- Maintenance of water temperature below 20°C while determining green volume. (If water temperature is above 20°C, density values must be adjusted by a temperature-dependent factor.)

The true green volume of a wood disk is determined by first soaking it and then carefully wiping off surface water before measuring green volume. The disk is presoaked so that the rate of water penetration into the voids of the sample will be near zero during the volume determination. The air remaining in the voids of wood samples that have been suitably presoaked must not be removed prior to determination of green volume. A careful centrifugation (50-100 g) permits removal of water from the chip surfaces without removing any water from the voids within the chips.□

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