(Research note)

Calorific Value of Japanese Coniferous Wood

By

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Summary : Calorific value is one of the most important factors for the evaluation of fuels. It is inevitable for combustion calculation, furnace designing, commercial fuel trading and potential estimation of forest resources.

But there is only limited information on common Japanese wood species, especially on coniferous wood.

In this paper, calorific values of nineteen Japanese coniferous species were determined and the mean value, the standard deviation, and the coefficient of variation were culculted as 4,972 cal/g, 161.3 and 3.2% respectively. These values agree with SATONAKA's data for twelve coniferous wood samples produced in Hokkaido.

The correlation between chemical constituents and the calorific value was also examined, and a linear correlation was found between content of alcohol-benzene extracts and the calorific value.

The author also presented a convenient figure that shows the relationship between calorific value and moisture content of broad leaved and coniferous wood.

1. Introduction

Calorific value is one of the most important factors for fuel evaluation. It is essential not only for trading commercial fuels, designing combustion furnaces, and selecting a suitable fuel for burning apparatus but also for estimating forest potentials.

Working in the Fuel Chemistry Laboratory with the main subject being Energy from Forest Biomass, the author frequently receives inquiries about the calorific values of wood and woody materials from the outside.

It is well known that the calorific value of coniferous wood is higher than that of broad leaved wood because the coniferous one has relatively higher contents of resinous material and essential oils. SATONAKA in his previous paper[1] determined the calorific value on twelve coniferous and fifty-nine broad leaved species produced in Hokkaido. He obtained 4820 minimum, 5170 maximum, and the mean value of 4960 cal/g, OD* wood from measurement of coniferous samples; this mean value was about 200 cal/g higher than that of broad leaved wood, that is 4730 cal/g, OD wood. Surprisingly enough, we cannot see only a few official data of the determined calorific value, especially on the Japanese coniferous species, except SATONAKA's[1].

The calorific value of wood varies according to 1) place of production, 2) individual trees in the forest, 3) position in each tree; e. g. leaf, trunk, twig etc. Since it is very difficult to collect all kinds of sample classes for determination, we have to accumulate as much actual data of calorific values as possible in order to get precise, universal value.

In this paper the author determined the calorific value on nineteen Japanese coniferous

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samples provided from undermentioned project and in addition, a Japanese alpine tree, ***Pinus pumila*** and five foreign coniferous samples. The first nineteen samples were selected from the samples used in a project carried out in our institute[2]. This project named "The properties of the Important Japanese Woods" started in 1963 and has been continuously carried out for more than ten years. The wood samples for this project were collected from many parts of Japan. Sampling from each log was conducted very carefully, and the physical and chemical properties of each sample were proved through intensive analyses over many items. This project, however, started more than ten years before the 1972 Energy shock. At that time only a few people had an interest in the forest biomass fuels which might have been one of the important alternative energy resources.

Next, the correlation between calorific value and content of chemical constituents which have been determined[3] in the above project was estimated. A linear correlation was found between the contents of alcohol-benzene extracts or α-cellulose and calorific value.

Fig. 4 shows that the calorific value declines according to the increase of moisture content. This figure is simple and convenient for evaluation of combustion characteristics for practical purposes.

2. Method of determination and representation of the measurement values

Calorimetrical determination was carried out in accordance with JIS M 8814-1985, and obtained values were represented by integral numbers. The apparatus used was Automatic Bomb Calorimeter CA 3, manifactured by Shimazu Corporation.

Simultaneously, the moisture content was determined by drying sample with an electric oven, keeping the temperature at 105°C, until the weight of the sample became constant, and percentages of weight loss were presented on a green wood basis. Then calorific value was expressed on a basis of oven dry wood. The advantages of this way is to normalize the calorific value and to make it easier to compare the determined value with that of the other woody materials.

3. Results and discussion

Obtained calorific value and moisture content from **1 J** *Taxus cuspidata* to **24 F** *Thujopsis dolabrata* and that of the other six samples are presented in Table 1. Twenty-four determined values are presented in the second column on the right of this Table, ranging from 4589 to 5356 cal/g : the mean value is 4972 cal/g, OD wood, and the standard deviation and the coefficient of variation are 161.1 and 3.2% respectively. These figures agree with SATONAKA's data[1] on twelve coniferous species produced in Hokkaido (Table 2). As indicated in Table 2 the coefficient of variation are quite small except that of the bark sample : they are 1% on the broad leaved and 2~3% on the coniferous wood. On the other hand, the coefficient of the bark sample is 8%. Thereby two histograms can be provided on thirty-six fast-grown and other broad leaved trees; 1) the coefficient of variation of wood is 1% (Fig. 1) 2) that of the bark connected with the wood is 8% (Fig. 2). There are two distribution patterns of the calorific values measured on the sample wood and bark. Owing to these histograms, a difference among these distribution patterns can be seen quite clearly.

Next, the correlation between the chemical constituents and the calorific value was examined. These chemical constituents had been difined by the successive analyses in the above-

Table 1. Calorific value of coniferous wood.

No. and produced area**	Species	Sap- (S) or heartwood (H)	Actual calorific value (cal/g, air dried basis)	Moisture (%, green wood basis)	Calorific value (cal/g, oven dry basis)	Mean of sap- and heartwood (cal/g, oven dry basis)
1 J	ICHII *Taxus cuspidata*	S	4533	8.09	4932	
		H	4733	7.74	5130	5031
2N	KAYA *Torreya nucifera*	S	4511	8.38	4923	
		H	4611	9.24	5080	5002
3M	INUMAKI *Podocarpus macrophyllus*	—	4482	10.45	5004	—
4M	MOMI *Abies firma*	—	4393	10.77	4923	—
9 J	KARAMATSU *Larix leptolepis*	S	4418	8.27	4816	
		H	4522	10.40	5047	4932
11C	AKAEZOMATSU *Picea Glehnii*	—	4433	8.38	4839	—
12 J	TŌHI *P. hondoensis*	S	4299	11.09	4835	—
		H	4412	10.44	4926	4881
13M	TOGASAWARA *Pseudotsuga japonica*	—	4462	9.54	4933	—
14M	TSUGA *Tsuga Sieboldii*	Outer part of wood	4349	10.29	4848	
		Center of wood	4441	10.80	4979	4914
15L	AKAMATSU *Pinus densiflora*	—	4646	10.21	5175	—
16K	HIMEKOMATSU *P. pentaphylla*	S	4521	9.28	4984	
		H	4524	8.56	4947	4967
17N	KUROMATSU *P. Thunbergii*	S	4081	11.06	4589	—
18G	SUGI *Cryptomeria japonica*	S	4461	9.97	4955	
		H	4468	10.37	4985	4970
19 J	KŌYAMAKI *Sciadopitys verticillata*	—	4804	10.32	5356	—
20 J	HINOKI *Chamaecyparis obtsusa*	—	4585	—	—	—
21 J	SAWARA *C. pisifera*	S	4443	9.43	4906	—
		H	4793	9.90	5320	5113
22 J	NEZUKO *Thuja Standishii*	—	4772	—	—	—
23 J	ASUNARO *Thujopsis dolabrata*	—	4633	—	—	—
24 F	HINOKIASUNARO *T. dolabrata* (var.)	S	4369	10.70	4893	
		H	4735	—	—	—
	HAIMATSU *Pinus pumila**	H	4647	10.89	5215	
		Except resinous part	4424	—	—	—
	Spruce *Picea* sp.*	—	4289	10.26	4779	—
	Europian spruce *P. excelsa**	—	4368	10.29	4869	—

Table 1. (Continued)

No. and produced area	Species	Sap- (S) or heartwood (H)	Actual calorific value (cal/g, air dried basis)	Moisture (%, green wood basis)	Calorific value (cal/g, oven dry basis)	Mean of sap- and heartwood (cal/g, oven dry basis)
	Radiata pine *Pinus radiata**	—	4524	10.04	5028	—
	Douglas fir *Pseudotsuga menziesii**	S	4391	11.05	4936	
		H	4474	9.92	4967	4952
	Western hemlock *Thuga heterophylla**	—	4364	10.13	4855	—

* Market species are out of series of the project.

** Produced area ; C : Obihiro (Regional Forestry Office, the rest is omitted.), F : Aomori, G : Akita, J : Nagano, K : Nagoya, LLOsaka, M : Kōchi, N : Kumamoto.

Table 2. Representatives for determined calorific values (cal/g, oven dry basis) on several reports.

Sample	n	Calorific value			Standard deviation	Coefficient of variation (%)	Author
		Max.	Min.	Mean			
Coniferous wood	24	5356	4589	4972	161.3	3.2	ABE, in this paper
Coniferous wood produced in Hokkaido	12	5170	4820	4963	114.7	2.3	SATONAKA[1]
Broad lieved wood produced in Hokkaido	59	4970	4610	4727	60.3	1.3	ditto
Wood from fast-grown and other broad leaved tree	36	4882	4624	4710	54.7	1.2	ABE[4]
Bank form fast-grown and other broad leabed tree	36	5581	4052	4814	380.4	7.9	ditto

mentioned project[8]. When single correlations were calculated, the analytical percentage of chemical constituents were to be the independent variables $X_1 \sim X_6$ and the calorific value was to be the dependent variable Y (Table 3). The first column on the right in Table 3 indicates the mean calorific value of sap- and heartwood presented in Table 1, If the first column lacks these values, the second column provides for them.

As for the chemical constituent, although there is no data on ash content on Table 3, its values have been reported in the original paper[8]. The ash content ranges from 0.14% (*Pseudotsuga japonica*) to 0.73% (*Thujopsis dolabrata*) and the mean value is 0.38%. These percentages are much lower than that of fossil fuels like coal, and this is very important for fuel evaluation.

Correlation between each $X_1 \sim X_6$ and Y was calculated. It was found that the correlations between X_2 (alcohol-benzene extracts) or X_5 (α-cellulose) and Y were significant.

Regressions and coefficients of correlation are as follows; in a case of alcohol-benzene extracts;

$$Y = 29.0 X_2 + 4828.1 \qquad r = 0.588^* \text{ (degree of freedom : 14)}$$

* : Significant at 5% risk level.

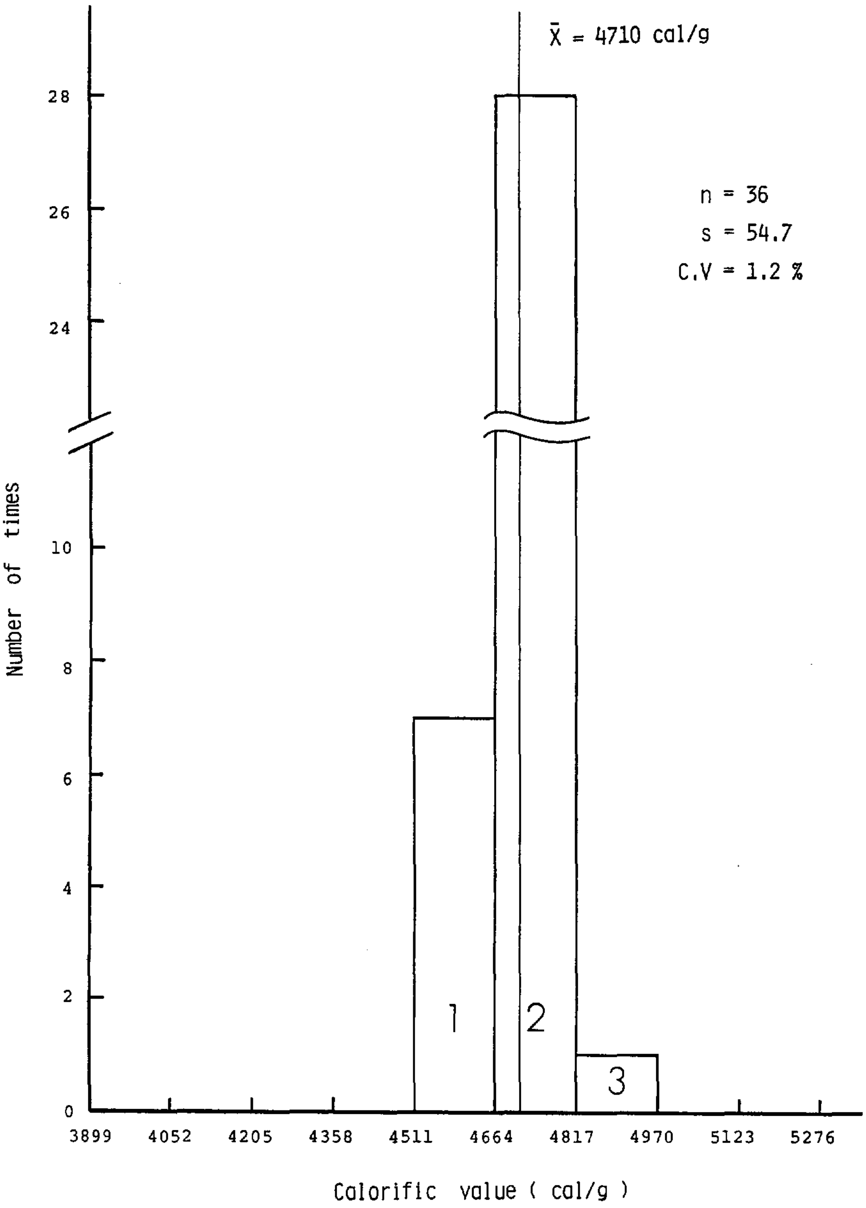

Fig. 1. Calorific value of wood from fast-grown and other broad leaved trees.

n : Number of samples, s : Standerd deviation, C. V : Coeffcient of variation.
Fig. 2 is same.

No.	Species
1	*Eucommia*, *Pterocarya*, *Ailanthus*, *Quercus acutissima* (Hamamatsu), *Q. serrata*, *Betula ermanii*, and *Prunus*.
2	*Robinia* (Asakawa and Kōma), *Alnus hirsuta* var. *mycrophylla* (Asakawa and Rokuhara), *A. hirsuta* var. *sibirica*, *A. japonica*, *Cornus*, *Styrax*, *Populus*, *Betula platyphylla* var. *japonica* (Rokuhara and Hokkaidō), *B. ermanii*, *Liriodendron*, *Acacia* (A and B), *Eucalyptus* (A), *Quercus acutissima* (Chiyoda), *Q. myrsinaefolia*, *Q. mongolica* var. *grossesrrata*, *Castanea*, *Myrica*, *Acer*, *Toisusu*, *Carpinus*, *Ulmus*, *Maackia*, *Kalopanax*, and *Liquidambar*.
3	*Eucalyptus* (B).

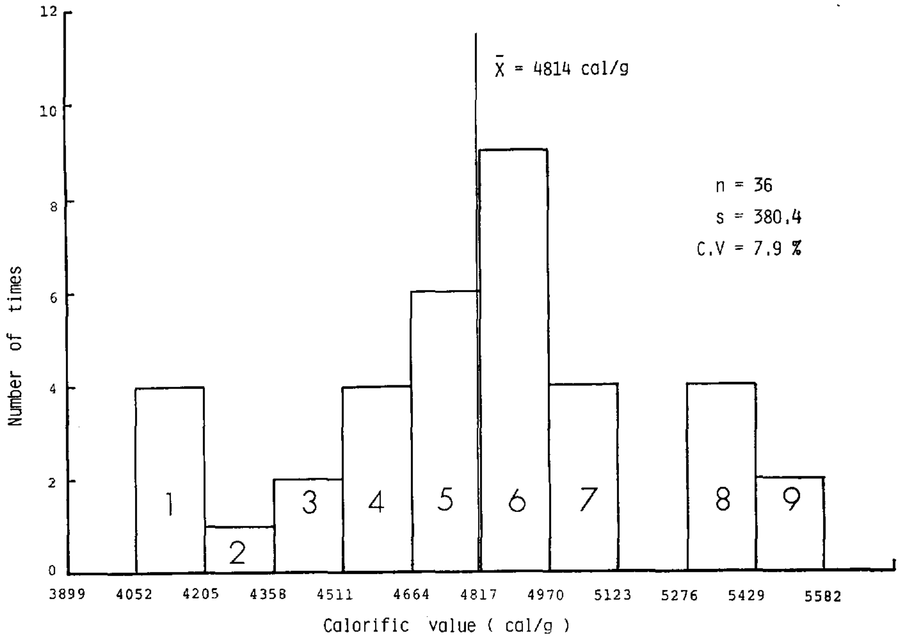

Fig. 2. Calorific value of bark from fast-grown and other broad leaved trees.

No.	Species
1	*Eucalyptus* (A and B), *Ulmus*, and *Liquidambar*.
2	*Acer*
3	*Pterocarya* and *Quercus myrsinaefolia*.
4	*Cornus*, *Liriodendron*, *Myrica*, and *Toisusu*.
5	*Eucommia*, *Populus*, *Quercus serrata*, *Castanea*, *Betula ermanii* var. *japonica*, and *Kalopanax*.
6	*Alnus hirsuta* var. *microphylla* (Asakawa), *A. japonica*, *Styrax*, *Robinia* (Kōma), *Acacia* (A and B), *Quercus acutissima* (Chiyoda and Hamamatsu), and *Betula ermanii*.
7	*Robinia* (Asakawa), *Alnus hirsuta* var. *sibirica*, *A. hirsuta* var. *microphylla* (Rokuhara). and *Quercus mongolica* var. *grosseserrata*.
8	*Betula platypyilla* var. *japonica* (Rokuhara). *Ailanthus*, *Carpinus*, and *Prunus*.
9	*Betula platyphlla* var. *japonica* (Hokkaidō) and *Maackia*.

and, in a case of α-cellulose;

$$Y = -18.6 X_5 + 5814.8 \qquad r = 0.456^* \text{ (degree of freedom : 14)}$$

* : Significant at 10% risk level.

In Fig. 3, the correlation of $X_2 - Y$ was illustrated. No significant correlation was found between lignin content and calorific value : obtained coefficient of correlation was only $r = 0.059$ (degree of freedom : 14).

In general, about 6% of hydrogen is contained in oven dry wood, and in combustion with sufficient oxygen, the hydrogen escapes as water, which causes lowering calorific value about 300 cal/g on moisture free wood. Fig. 4 shows the straight decline of calorific value in proportion to an increase of the moisture content of the wood.

This decline, that is, H_N (net calorific value) can be calculated using the following equation.

$$H_N = H_G - \frac{600\,(9h + w)}{100} \qquad \text{(cal/g)}$$

Table 3. Chemical constituents and calorific value of sample wood.

No. and produced area**	Species	Wood analysis (%*)						Calorific value (cal/g*)	
		Soluble in		Pentosan	Hollocellulose	α-cellulose	Lignin		
		Hot water X_1	Alc-benzene X_2	X_3	X_4	X_5	X_6	Y	Ref.
1 J	*Taxus cuspidata*	11.1	11.5	5.5	58.5	38.2	28.1	5031	Heartwood
2N	*Torreya nucifera*	6.7	6.6	4.9	63.8	45.3	34.5	5002	
3M	*Podocarpus macrophyllus*	3.2	1.5	10.9	65.0	49.4	35.7	5004	
4M	*Abies firma*	3.6	2.3	5.2	69.8	49.0	33.5	4923	
9 J	*Larix leptolepis*	9.5	3.2	5.6	68.5	47.8	28.0	4932	
11C	*Picea Glehnii*	2.8	2.0	6.7	73.5	49.9	27.8	4839	
12 J	*P. hondoensis*	3.3	2.2	5.2	64.4	41.9	28.8	4881	
13M	*Pseudotsuga japonica*	4.4	3.5	5.1	68.1	47.1	33.1	4933	
14M	*Tsuga Sieboldii*	4.1	3.0	4.3	71.0	51.0	31.1	4914	
15L	*Pinus densiflora*	3.9	4.1	7.0	65.8	43.6	26.1	5175	
16K	*P. pentaphylla*	3.2	8.1	4.7	68.4	44.5	27.1	4967	
17N	*P. Thunbergii*	3.0	3.3	6.7	62.9	44.0	25.8	4589	
18G	*Cryptomeria japonica*	3.1	2.6	7.3	73.3	48.6	32.3	4970	
19 J	*Sciadopitys verticillata*	6.6	11.0	4.7	60.8	38.7	28.5	5356	
21 J	*Chamaecyparis pisifera*	7.4	9.4	5.1	60.2	41.0	30.7	5113	
24F	*Thujopsis dolabrata* (var.)	4.5	4.2	5.9	75.2	48.4	33.0	4893	

*: Oven dry basis,
**: See Table 1.

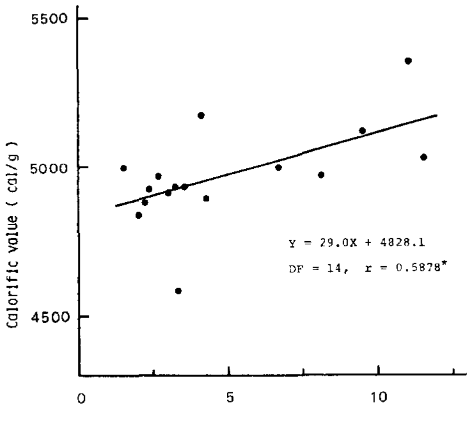

Fig. 3. Correlation between alcohol-benzene extracts and calorific value.

* Significant at 5% risk level.

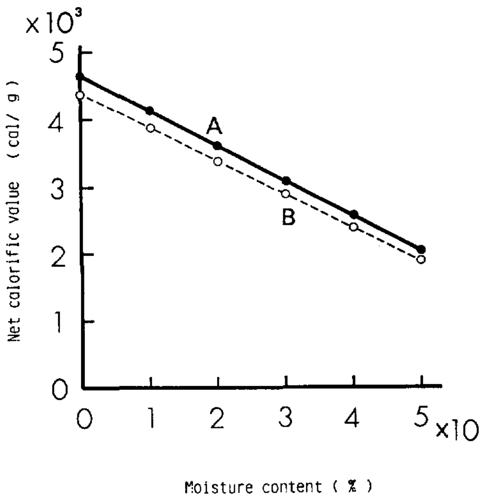

Fig. 4. Decline of calorific value with increasing moisture content.

Note : Calculated with gross calorific values of 4970 and 4710 cal/g for oven dried coniferous and broad leaved wood respectively.

A : Coniferous wood, B : Broad leaved wood.

there, H_G : gross calorific value (cal/g)

h : amount of hydrogen (%) and

w : amount of moisture (%)

According to Fig. 4, calorific value is about 2000 cal/g when the moisture content is 50%, and when moisture content is 10～20% (air dry wood), the calorific value is 3800～4100 cal/g. Fig. 4 provides practical information for the combustion of wood fuels.

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（研 究 資 料）

日本産針葉樹材の発熱量について

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摘 要

木質エネルギーを考える上で，木材の発熱量は欠くことのできない燃料評価上のパラメータである。実燃焼の際の燃料の選択，燃焼装置の設計または商取引だけでなく，エネルギー資源量調査における林分のポテンシャル推定に際しても必要な計算基礎となる。

一般に針葉樹は樹脂・精油分が多く広葉樹より発熱量が高いことが知られている。里中によれば，北海道産針葉樹材12種について最小4,820，最大5,170，平均4,960 cal/g（全乾ベース）が得られており，これは同じく北海道産広葉樹59種の平均値4,730 cal/g より約200 cal/g 高い。しかし既往文献には意外と国産材，とくに針葉樹材についての実測発熱量の記載が少く，産地や個体，個体内の部位その他の諸ファクター別に，それらを網羅した試料の収集は難しいので，やはり数多くのデータの積み重ねによる普遍的な数値の推定が必要である。林業試験場では1963年より10年計画のプロジェクト「日本産主要樹種の性質」の対象試料として針葉樹24種，広葉樹46種を収集しており，それらの材の採取地，木取り，比重，容積密度数，平均年輪幅をはじめ物理的，物理化学的および化学的諸性質が，極めて，ことこまかに調査されている。このプロジェクト用試料の中より針葉樹19種を供試し，同時に比較のための国産ハイマツ材および外国産針葉樹材計6樹種についても発熱量を実測した。

試料の番号・記号は上記プロジェクトと共通である。発熱量測定と同時に試料水分を測定し，実測値と全乾ベース換算発熱量とを併記した。発熱量測定は JIS M 8814-1985 に準じて行った。使用機種は島津製作所製自動ボンブ熱量計 CA-3 である。

Table 1 の 1 J イチイ～24 F ヒノキアスナロについて得られた数値は，最大5,356，最小4,589，平均4,972 cal/g で，標準偏差161.3，変化率3.2％で，これらは前述した里中の北海道産材12種の値と極めてよく一致している（Table 2）。Table 2 に同時に掲げた他の試料を含めて，樹皮以外の材についての変化率は極めて小さく，広葉樹材で1％，針葉樹材で2～3％である。なお樹皮では変化率8％である。出現頻度を示す発熱量の階層別棒グラフを早生樹およびその他の広葉樹の材と，材に附着していた樹皮とについて作成したものを参考までに示せば Fig. 1，2 の通りで，変化率1％の場合（材）と8％の場合（樹皮）との分布の差が明らかである。

つぎに前記したように今回の試料は一連の試験・分析がすでになされているので，その中から木材分析値を Table 3 に表出し（X_1～X_6 とする），今回実測した発熱量 Y との相関関係を調べた。材の発熱量は Table 1 の右端の列の辺・心材平均値とした。辺心材別の測定値を欠くものについては同表右から2列目の値を使った。

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(1) 林産化学部

なお木材分析値の中，灰分%は表中に掲げているが，0.14%（トガサワラ）～0.73%（ヒノキアスナロ）で平均0.38%である。この灰分値は石炭などに比べ非常に小さく，燃料評価上見逃せないことを附記する。X_1～X_6 と Y との単相関の中，危険率5%で X_2 のアルコールベンゼン可溶分%と発熱量 Y との相関関係が有意であった。α-セルロース%との相関は負で，危険率10%で有意であった。

前者を Fig. 3 に示す。なおリグニン%との相関は $r=0.059$ で有意でなかった。

つぎに，全乾木材中には約6%の水素が含まれ，十分な酸素存在下の燃焼時には当量の水が生成するため，全乾時でも約300 cal/g の発熱量低下がある。Fig. 4 に材の水分と発熱量の関係を示す直線を示した。縦軸はいわゆる低発熱量で，次式により計算される。

$$\text{低発熱量 (cal/g)} = \text{高発熱量 (cal/g)} - \frac{600(9h+w)}{100}$$

h，w はそれぞれ水素%および水分%である。Fig. 4 によれば水分50%のときの低発熱量は1,900～2,000 cal/g である。また材の気乾水分10～12%の場合低発熱量は3,800～4,100 cal/g である。