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ADOPTING THE USE OF CYPRESS AS A WOODY BIOMASS OF CHOICE IN CAMEROON BASED ON AN ANALYTIC DETERMINATION OF THE NET CALORIFIC VALUE (NCV)

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ABSTRACT

Wood biomass stands out as the most important renewable energy source in Cameroon especially among the rural population. The favourable climatic conditions enhance the sustainability of wood biomass and consequently the potential of further expansion. Cypress is a common coniferous wood species abundantly distributed over the entire national territory of Cameroon. It does not require any special care for its growth and proliferation. In what follows the energy content of cypress would be evaluated to demonstrate the expected energetic efficiency based on a newly developed analytical scheme. The calculations make use of the: chemical composition, equilibrium moisture content (EMC) and the relative humidity (RH) of the surrounding atmosphere. The analysis enables us to calculate the calorific value of cypress wood in the different regions of Cameroon all the year round. As an outcome, it is hoped that this publication will spur a renewed interest in farmers, forest owners and Government authorities and decision makers to promote the growth of cypress as an energy carrier for sustainable heat supply especially amongst the rural communities of Cameroon.

Keywords- Calorific value, cypress wood, Biomass, Relative humidity, Equilibrium moisture content.

1. INTRODUCTION

Energy is one of the main uses of biomass in the form of wood. Wood furnishes about 14 percent of the global total supply of energy. It is being used by more than 2 billion people around the globe for heating and other energy needs [1]. Bio-energy still occupies a place of choice in the energy consumption chain of developing countries. Consequently the demand for wood-based energy is very high in such countries for activities like heating and cooking.

The Cameroonian commercial energy sources are dominated by petroleum, hydropower and coal. In the residential sector, about 90 percent of the population rely on the use of traditional biomass fuels like fire-wood and charcoal for domestic energy needs like cooking, lighting and heating. In the 2009 energy consumption distribution in Cameroon, the residential sector alone, contributed by about 71 %[2]. Further development of the use of biomass and extension of national electricity grid would reduce this consumption greatly.

Figures 1 & 2 shows Cameroon's primary energy supply and Cameroon's final energy supply according to IEA Country Energy Balance for 2009. It can be deduced from the two figures that Cameroon's energy balance shows a clear predominance of renewable energies and, primarily, a marked dependence on biomass in the country's energy supply.

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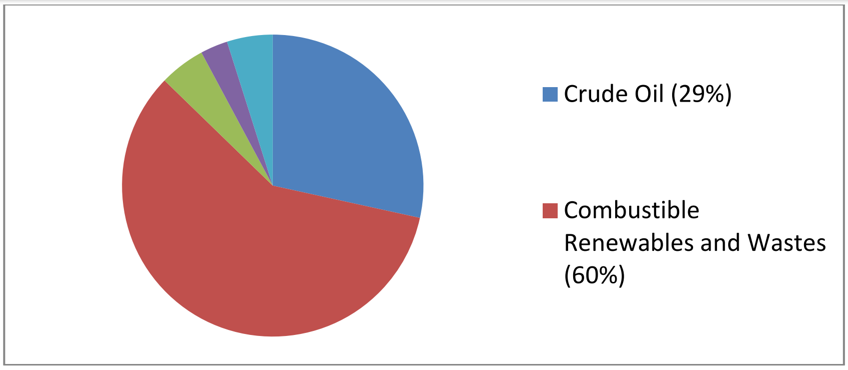

Figure1. Cameroon primary energy supply, 80.6 TWh
Source: IEA Country Energy Balance, 2009

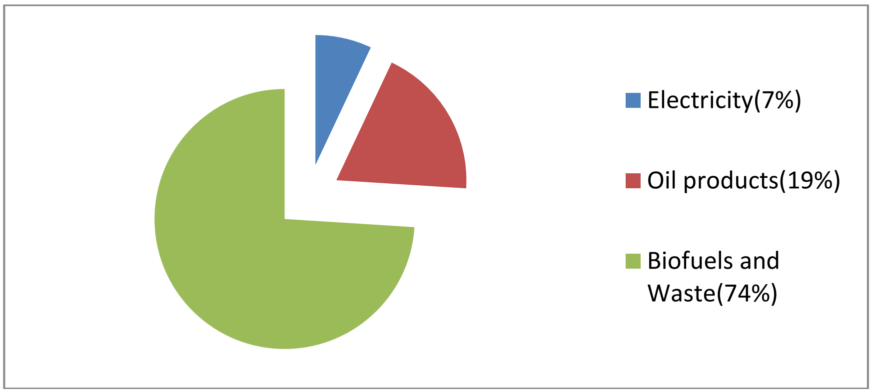

Figure 2. Cameroon final energy supply, 67.0TWh
Source: IEA Country Energy Balance, 2009

Cameroon is an African country situated at the south of the Sahara has abundant biomass resource, with 25 million hectares of forest covering three-quarters of its territory [3]. However, this resource is unsustainably used resulting to significant deforestation throughout the country, with the forest being cleared at a rate of 200,000 hectares per year and the annual regeneration is only 3,000 hectares per year. Biomass is used in the country primarily for heating and light for the major part of the rural population

A study presented in reference [3] on firewood and natural resources management consumption in Maroua town of the Extreme North region of Cameroon came out with some important considerations and conclusions. The research on firewood consumption in Maroua town targeted some 299 households in urban Maroua and 160 households in the surrounding rural areas. Satellite images were analysed and a systematic counting of the amount of wood fuel entering Maroua from sale points was done. From 1991 to 1996 the price of wood had quadrupled. The pressure on wood consumption is very high in Maroua and the wood cutting area reduced from 31.4% to 22.5 %. The management of the wood resources in the region of Maroua in particular and the Far North region in general is an indication of the general scenario in Cameroon. It is necessary to device strategies that can render the supply of wood sustainable.

The purpose of this paper is to highlight cypress trees as a potential source of wood fuel. Cypress wood is a potentially promising material both as wood because it exhibits some interesting characteristics. It is sustainable and regenerates naturally with very little human involvement. In effect, cypress tree is a deciduous conifer that produces needles and cones that are shed in the dry season, spreading their seeds. The spread seeds would eventually germinate when conditions become favourable in the rainy season. In addition cypress trees may regenerate from cut stumps. Hence on an average, more trees will always be growing than are harvested even without an organized planting or reforestation scheme.

Cypress trees like most other trees is a carbon neutral healthy tree that extracts carbondioxide from the atmosphere and uses it in

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the process of photosynthesis, while oxygen is released into the atmosphere.

Cypress is environmentally friendly because virtually every part of the tree is used as wood fuel, lumber or other by products and finished products are re-useable, recyclable and biodegradable. Cypressene, a chemical produced in cypress heartwood, makes it resistant to insects, rot, decay, and other damaging elements. Treatment of cypress with chemicals that can be detrimental to the environment, a common practice required for other tree types to sustain their strength and appearance, is not needed [13].

The outcome of the following research is to encourage the planting of coniferous cypress which in addition to the above advantages is well adapted to the local climatic conditions of Cameroon; takes relatively short period of time to mature for burning and above all is a very common species of wood in Cameroon. To highlight the importance of cypress wood-based energy, we will examine the potential energy value of the woody biomass, all the year round for different regions of Cameroon. This is achieved by developing some analytical scheme that takes in the relative humidity and ambient air temperature as in put parameters.

2. ANALYTIC CALCULATION OF THE CALORIFIC VALUE OF LOG CYPRESS WOOD

The calorific value of a wood species is the amount of energy released when a unit mass of the fuel undergoes complete combustion. An estimation of the calorific value of wood requires knowledge of its chemical composition and physical properties. The moisture content in wood has a negative effect on the calorific value. When wood is burnt, part of the energy released is lost as latent heat in evaporating the moisture contained in the wood. In this regard three types of calorific value can be distinguished: The net calorific value (NCV), the oven dry calorific value (NCV_0) and the gross calorific value (GCV).

In NCV, the water released is treated as a vapour and consequently the latent heat of vaporisation of water at 25^{0}C is subtracted from the obtained value. In GCV the water in the combustion products is treated as liquid. When not specified, the calorific value is to be intended as net calorific value. The NCV_0 of different wood types vary within a narrow range from 18.5 to 22 MJ/kg [4]. In conifers it is 2% higher than in broad-leaved trees which give conifers some slight advantage over the later.

The calorific value of different wood types does not vary much; there are some differences attributed to the varying chemical components of the tree species. Softwoods like cypress generally, have higher calorific values than hardwoods. Even though softwoods have higher heating values than hardwoods they are known for burning hotter initially, but burns up more quickly.

We present in this section an analytical scheme to determine the calorific value of Log Cypress wood that incorporates both its physical and chemical properties.

2.1. Moisture content

A major component of wood mass in a growing tree is made up of water commonly called sap. Although sap contains a number of elements in solution, from a drying point of view, sap is considered to be plain water. It is mandatory to eliminate most of this water to improve on the heating value of wood. The tendency for all woods is to eliminate or gain moisture in order to attain a state of equilibrium with the conditions of the surrounding air. This state of balance is influenced by the temperature and the relative humidity of the surrounding air. The amount of moisture in wood referred to as the moisture content, affects the calorific value of wood: the drier the fuel, the higher the calorific value as can be observed in Table 1[5]

For most wood species, a common and accurate method for determining moisture content is the oven dry method or oven test. This method is however inaccurate for species with a high extractive content. In oven drying all the water in the wood is evaporated from a wood section by heating. The weight of the wood is measured before and after oven drying in order to calculate the moisture content.

Moisture content is calculated as a percentage either on dry basis or on wet basis. Moisture content on dry basis u(%), expresses the mass of water present in relation to the mass of the oven dry wood

$$u = \frac{W_W - W_0}{W_0} \times 100 \qquad (1)$$

Moisture content on wet basis, M(%) expresses the mass of water present in relation to the mass of the fresh wood

$$M = \frac{W_W - W_0}{W_W} \times 100 \qquad (2)$$

Where W_W is the weight of wet wood and W_0 is the weight of oven dry wood.

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Table 1. Heating Values for Types of Woody Biomass [5]

Fuel type	Moisture content (M)	Net calorific value (NCV) (MJ/kg)
Green Wood	50%	9.5
Seasoned Wood	20%	15.5
Dry Sawdust	13%	16.2
Wood Pellets	10%	16.8
Dry Wood (non-resinous)	0%	19.0
Dry Wood (resinous)	0%	22.5
Dry Stem-wood	0%	19.1
Dry Bark	0%	19.6
Dry Branches	0%	20.1
Dry needles	0%	20.4

Even though the moisture content can be obtained experimentally using equations (1) and (2); for practical applications of wood for fuel, the oven test procedure is not the best. This is the case because the tendency would be for wood to regulate its moisture content proportionally to the environmental relative humidity. The amount of moisture at the point of balance between the wood and the environment is called the equilibrium moisture content (EMC). The EMC varies as a function of the relative humidity and the ambient temperature of the surrounding air. The relationship between the EMC and the relative humidity is shown at three different temperatures ($70\ ^oF \equiv 21.1\ ^oC$; $141\ ^oF \equiv 60.6\ ^oC$ and $212\ ^oF \equiv 100\ ^oC$) in fig.3[6]. We can deduce from the fig.3 that for a given value of relative humidity, the moisture content in wood decreases as the environmental temperature increases.

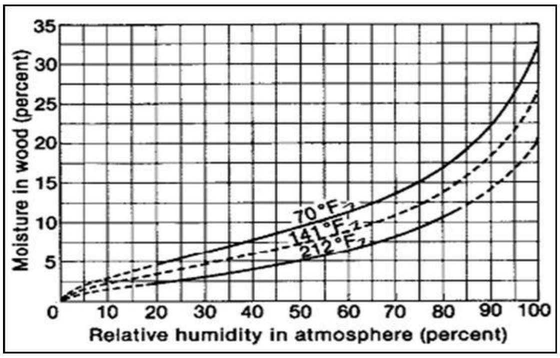

Figure 3. Relation of the equilibrium moisture content of wood to the relative humidity of the surrounding atmosphere at three temperatures (where $T_{^oF} = \frac{9}{5}T_{^oC} + 32$).[6]

2.2. Equations for Relating Temperature, Humidity, and Moisture Content

In this sub-section, we establish the relationship between the wet bulb temperature, the dry bulb temperature and the specific and relative humidities. The connection between the equilibrium moisture content (EMC), the relative humidity (RH) and the temperature is also outlined.

2.2.1 Wet-bulb Temperature and Relative Humidity

To regulate the EMC through oven drying, the relative humidity and the temperature of the oven are registered using two thermometers. One thermometer with a dry bulb measures the temperature with the bulb uncovered while the other measures the temperature with the bulb wrapped with a wet wick. Two temperatures result known as the dry bulb temperature and the wet bulb temperature. The dry bulb temperature is higher than the wet bulb temperature. The difference between the two temperatures is known as the wet bulb depression temperature and enables the relative humidity of air to be determined. In effect, the wet wick wrapped around the bulb of the thermometer allows water to evaporate proportionally to the relative humidity and temperature of the air. As latent heat is lost through the evaporation, a cooling effect results, the rate of which increases with the rate of evaporation.

When unsaturated air is brought in contact with water it gains humidity and cools as a consequence. If the process progresses such that there are no heat exchanges with the surroundings it is said to be adiabatic. If the process is adiabatic, the temperature of the water stays fixed and the latent heat of evaporation is furnished by the air while it is cooling. The cooling proceeds until thermal equilibrium is established between the air and the water. The common equilibrium temperature is referred to as the adiabatic saturation temperature or the thermodynamic wet-bulb temperature.

We also distinguish the true wet-bulb temperature achieved by passing unsaturated air current over a thermometer whose bulb is wetted. The wetted bulb provides the latent heat of evaporation for the water resulting in a temperature drop. The thermodynamic wet-bulb and true wet-bulb temperatures are not absolutely equal in magnitude but exhibits a negligible difference. The two temperatures fall in the range($215\ ^oF \equiv 102\ ^oC$) to ($300°F \equiv 149\ °C$) [6,7]. Relative humidity (RH) can therefore be measured based either on the difference between the dry bulb temperature and the thermodynamic wet-bulb temperature or on the difference between the dry-bulb temperature and the true wet-bulb temperature. The average difference is +0.25 percent RH while the maximum difference is 0.54 percent RH [6,7].

Relative humidity can be calculated from the adiabatic saturation temperature by the following procedure [6]. By writing energy and mass balances for the process of adiabatic saturation given as

$$Y = Y_s - \frac{(0.24+0.44Y_s)(T_{db}-T_s)}{1094+0.44T_{db}-T_s} \quad (3)$$

Where

Y is the specific humidity (Weight of water/Weight of dry air)

Y_s is the specific humidity for saturation at T_s (Weight of water/Weight of dry air)

T_{db} is the dry-bulb temperature

T_s is the adiabatic saturation temperature

The specific humidity for saturation at T_s , Y_s is expressed as

$$Y_s = \frac{\rho_s}{1.61(\rho_t-\rho_s)} \quad (4)$$

Where:

ρ_s is the vapor pressure at T_s (mmHg) and ρ_t is the total pressure(mmHg)

To calculate relative vapour pressure at T_{db}, it is necessary to calculate partial pressure ρ at T_{db} as follows:

$$\rho = \frac{1.61Y\rho_t}{1+1.61Y} \quad (5)$$

and relative vapor pressure h is

$$h = \frac{\rho}{\rho^*} \quad (6)$$

where ρ^* is saturated vapor pressure at T_{db} (mmHg).

The RH is then defined as

$$RH = h \times 100 \quad (7)$$

2.2.2 Relative Humidity and Equilibrium Moisture Content

The EMC and RH temperature relationships can be expressed using the equation [6,7]

$$M = \frac{1800}{W}\left[\frac{kh}{1-kh} + \frac{k_1kh+2k_1k_2k^2h^2}{1+k_1kh+k_1k_2k^2h^2}\right] \quad (8)$$

Where; M is moisture content (percent), h relative vapour pressure.

For temperatures in °F [6]:

$$W = 330 + 0.452T_{db} + 0.00415T_{db}^2 \quad (9)$$

With:

$$k = 7.91 \times 10^{-1} + 4.52 \times 10^{-1}T_{db} - 8.44 \times 10^{-7}T_{db}^2 \quad (10)$$

$$k_1 = 6.34 + 7.75 \times 10^{-4}T_{db} - 9.35 \times 10^{-5}T_{db}^2 \quad (11)$$

$$k_2 = 1.09 + 2.84 \times 10^{-2}T_{db} - 9.04 \times 10^{-5}T_{db}^2 \quad (12)$$

For temperatures T in °C [7]:

$$W = 349 + 1.29T_{db} + 1.35 \times 10^{-2}T_{db}^2 \quad (13)$$

$$k = 8.05 \times 10^{-1} + 7.36 \times 10^{-4}T_{db} - 2.73 \times 10^{-6}T_{db}^2 \quad (14)$$

$$k_1 = 6.27 - 9.38 \times 10^{-3}T_{db} - 3.03 \times 10^{-4}T_{db}^2 \quad (15)$$

$$k_2 = 1.91 + 4.07 \times 10^{-2}T_{db} - 2.93 \times 10^{-4}T_{db}^2 \quad (16)$$

Where W, k, k_1 and k_2 are obtained from a linear regression analysis of data presented in tables (1.6) of [6] and (1.7) of [7].

2.2.3. Determination of calorific value of wood biomass

The calorific value of a biomass is measured experimentally in terms of the gross calorific value (GCV) using a bomb calorimeter. A sample of biomass is burnt in the presence of oxygen inside the bomb. Some mass of fluid (air or water) surrounding the container absorbs the heat liberated from combustion within the bomb. The calorific value is obtained by multiplying: the mass of fluid, the specific heat of fluid and the net rise in temperature. Precautions are often taken to account for heat losses. The experimentally measured calorific value is considered gross calorific value (or high heating value) at constant volume because the biomass combustion in the container occurs at a fixed volume [10]. The resulting gross calorific value can be expressed based on dry mass content of the sample biomass as,

$$GCV_0 = \frac{GCV(100-M)}{100} \quad (17)$$

The oven-dry gross calorific value can be estimated from the composition of the fuel [8], as:

$GCV_0 = 0.35C + 1.18H + 0.10S - 0.02N - 0.10O - 0.02Ash$ (18)

where C is the mass fraction of Carbon, while H, S, N, O and Ash are the respective mass fractions of Hydrogen, Sulphur, Nitrogen, Oxygen , and ash content .

The NCV or net heating value (NHV) is deduced from the measured GCV_O by subtracting in the products the latent heat of evaporation of water. Hence, for given moisture content (M), the net calorific value of wood biomass and in particular that of cypress is given by [9]:

$$NCV = \frac{GCV_O(100-M)-2.447M}{100} \quad (19)$$

The constant 2.447 is the latent heat of evaporation of water in MJ/kg at 25°C. A better approximation of the net heating value takes into consideration the heat released by the combustion of the hydrogen content of the biomass. In practice, the gases evolving from combustion of a biomass are expanded very easily. During combustion the pressure in the combustion zone remains almost constant while the volume expands, but the change in volume is not considerably. This is often the case in a boiler combustion chamber with open exhaust system. For these cases equation (21) developed from constant volume measurement is converted to heating value at constant pressure expressed as[10,11],

$$GCV_P = GCV_O - 0.212H - 0.0008(O + N) \quad (20)$$

where GCV_P is the gross calorific value at constant pressure for dry biomass. H, O and N are the mass fraction (percent dry mass) of the biomass.

For wet biomass, the net heating value at constant pressure is calculated from

$$NCV_{P,W} = \frac{GCV_P(100-M)-2.447M}{100} \quad (21)$$

M is the wet basis moisture content (mass fraction decimal). $NCV_{P,W}$ is the net heating value of biomass at constant pressure per unit of wet biomass.

For the case of cypress, ultimate analysis results in the following tabulated values [12].

Table 2. Ultimate analyses for typical biomass materials (wt%)

Material	C	H	O	N	S	Ash
Cypress	55.0	6.5	38.1	-	-	0.4

Using equations (18) and (20) the following values are calculated for cypress:

Table 3. The gross calorific value on dry mass basis and that at constant pressure for cypress wood.

Material	$GCV_0(MJ/kg)$	$GCV_P(MJ/kg)$
Cypress	23.102	21.69

The variation of the $NCV_{P,W}$ against the moisture content, M is presented in fig.4 for which $GCV_0$is taken to be 23.102 MJ/kg. We observe that the lower the moisture content, the greater the net calorific value.

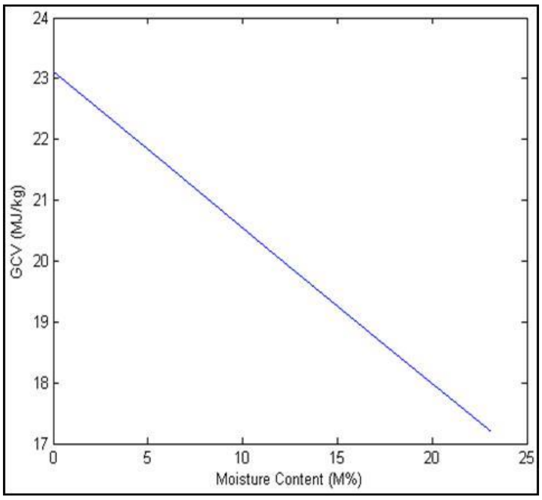

Figure 4. Variation of the GCV_0 as a function of the moisture content

3. RESULTS AND DISCUSSIONS

In the rest of this paper, data for the NCV and EMC will be calculated based on the environmental air temperature(T_{db}) and relative humidity (RH) data obtained from the RETScreen software tool provided by CANMET Canada for 2012 for some regions of Cameroon. The calculations of EMC and $NCV_{P,W}$ are done using equations (7) to (21) presented above for cypress wood. Table 4. presents results of the EMC and $NCV_{P,W}$ calculated using the air temperature and the RH data of Ngaoundere in the Adamowa region of Cameroon. Similar results for representative towns in the other nine regions of Cameroon (fig.5) are presented in

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fig.6.

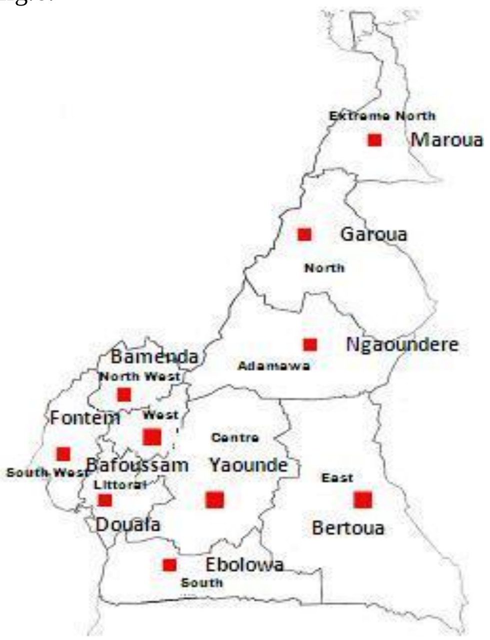

Figure 5. Map of Cameroon showing regions of study

Hence, fig.6 presents the variation of the $NCV_{P,W}$ (MJ/kg) for representative towns of different regions of Cameroon all the year round. The heating values fall within a narrow range from 20.6 to 20.9 MJ/kg all the year round and for the different regions of Cameroon. The best results are exhibited by the towns of Maroua, Garoua and Ngaoundere; all situated in the Northern part of Cameroon, from November to March which coincides with the dry season. It should be noted that these three northern regions present the Sahel climate characterized by low RH. Figure 6 shows that cypress wood can be a viable source of woody biomass for all the regions of Cameroon throughout the year.

The heating values calculated in this paper are the expected or actual heating value of the wood when burnt because no prior oven drying has been practised. For most practical situations wood would not be oven-dried before being burnt for fuel. As such the heating values of based oven-dried wood do not always reflect the actual or practical reality. The methodology of this paper can be applied in any geographical location once the prevalent air temperature and relative humidity are known to get the actual heating value specific for the location.

Table 4. Heating value of cypress wood all the year for Ngaoundere in the Adamawa Region

Cypress data Ngaoundere in the Adamawa Region				
Month	$(T_{db})^{o}$ C	RH %	EMC %	$NCV_{P,W}$ (MJ/kg)
January	24.8	21.9	3.7341	20.7908
February	26.2	22.5	3.7613	20.783
March	26.6	45.7	4.1537	20.6767
April	25.2	68.5	4.2918	20.6394
May	24.1	76	4.3483	20.6288
June	23	79.7	4.3859	20.6218
July	22.1	81.7	4.4096	20.617
August	22	82.4	4.4148	20.6161
September	22.4	80.5	4.3997	20.619
October	22.8	73.9	4.3581	20.6258
November	24.1	46.8	4.1916	20.6677
December	24.7	27.7	3.9257	20.7413
Annual	24	58.9	4.2763	20.7908

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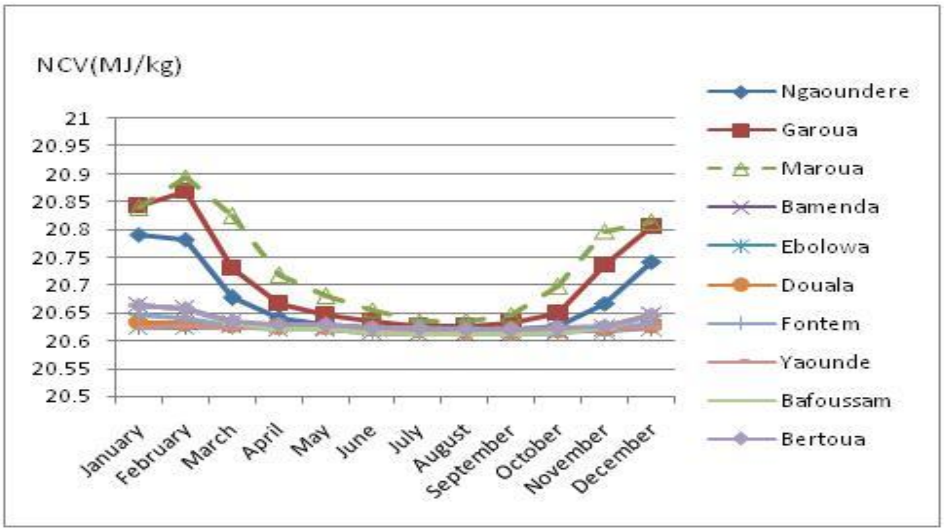

Figure 6. Variation of the $NCV_{P,W}$ (MJ/kg) for representative towns of different regions of Cameroon all the year round.

4. CONCLUSION

We have presented a new analytical scheme for calculating the calorific value of cypress wood. The scheme uses both the physical and chemical properties of cypress wood to generate the calorific value of cypress wood at different moisture contents. Based on the relative humidity and air temperature data we have calculated and tabulated the heating value of cypress wood all the year round for different regions of Cameroon. The heating values fall within a narrow range from 20.6 to 20.9 MJ/kg all the year round and for the different regions of Cameroon. This shows that cypress wood can be a viable source of woody biomass for all the regions of Cameroon

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