

PHYSICAL AND CHEMICAL PROPERTIES OF TIMBER
BY-PRODUCTS FROM *PINUS LEIOPHYLLA*,
P. MONTEZUMAE AND *P. PSEUDOSTROBUS* FOR
A BIOENERGETICS USE

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This paper is dedicated to the memory of Alfredo Voirol Lara, the first Wood Technology Engineer graduated in Mexico.

ABSTRACT

This paper describes the chemical and physical properties of *Pinus leiophylla*, *P. montezumae* and *P. Pseudostrobus* timber by-products (wood chips, bark and wood-bark). The physical features determined were the initial moisture content, bulk density and calorific value whereas the determined chemical characteristics were pH, inorganic compounds, inorganic compounds microanalysis, extractives, lignin, and holocellulose. Such by-products were collected in the industrial complex at the Indigenous Community of Nuevo San Juan Parangaricutiro, located in Michoacán, México. The initial moisture content of the samples varied from 33.6 to 56%, while their bulk density ranged from 0.19 to 0.31 g·cm⁻³. The calorific value for the wood residues of the three different species of pines varied from 17.95 to 18.93 MJ·kg⁻¹. Regarding their chemical characteristics, barks were more acid than woods, and in general, the inorganic content was lower in woods than in barks. According to the X-ray microanalysis, the major inorganic compounds found in ash were calcium, magnesium, and potassium. No heavy metals were detected at all. For the three pine species, extractives levels in barks were higher than in woods. Also, barks contained a higher concentration of lignin than woods. The highest holocellulose content was found in wood residues rather than in barks. It is concluded then that the three pine species timber by-products present physic and chemical properties that make them suitable for the production of solid biofuel.

KEYWORDS: *Pinus* spp., wood chemistry, wood, bark, bioenergy.

INTRODUCTION

Today's society and economy depend greatly on the energy obtained from fossil fuels. Most of the world's energy (84 %) comes from fossil fuels and demand is expected to raise as the world's energy consumption increases up to 53 % by the year 2035 (EIA 2011). Since fossil fuels are a limited resource (Tanger et al. 2013), it has become an imperative to switch to the use of renewable energy generated from natural resources, which range from wind power, solar power, hydroelectricity, geothermal energy, tidal power, bioenergy, ethanol and hydrogen (Ghosh and Prelas 2011).

Biomass is one of the most abundant natural resources all over the world which provides us with the opportunity of using it for energy purposes, including fuels, heat and power generation, electricity and chemical products. Nowadays, biomass burning is one of the main sources of renewable energy with a 10.1% participation of the world total primary energy supply, with an environmentally insignificant emission of CO₂ to the atmosphere (Ghosh and Prelas 2011, Jeeban and Sea 2012). Forest residues such as branches, stumps, small trees from thinning and clearings, sawdust powder, shaving, wood chips, defective moldings, bark and sawdust, are a major source of biomass. In Mexico, one of the principal forest industries that generates large volumes of useful wood by-products is the sawmilling industry, which according to SEMARNAP (2000), produces about 0.35 m³ of pine sawdust per cubic meter of processed wood. A more recent estimation by SEMARNAT (2006) indicates that the sawmilling industry Mexico demanded 4.6 billion of cubic meters roll (m³r) of timber, generating 1,288 million of m³r of residues (28%). Out of the total amount of residues, 920,000 m³r were sawdust and 368,000 m³r were bark. As for the industrial complex where sample by-products were collected, the Forest Management Program in the Indigenous Community of Nuevo San Juan Parangaricutiro, in Michoacán, México (CINSJP 2009) reported that the harvested volume was 74,647 m³ total tree volume and 12% of that were

forest residues. By-products (sawdust, shavings and bark) are locally used to make compost, as fertilizer in avocado orchards within the indigenous community region and as fuel both in brick factories and the steam boiler of the community's resin plant (Correa et al. 2014). Therefore, the low price and high availability of these lignocellulosic by-products in such indigenous community encourage the research for new productive alternatives. Bioenergy is a cheap and environmentally feasible option (García et al. 2012), however it is necessary to evaluate some physical features as well as the chemical compounds of the timber species (García et al. 2004, García et al. 2012, Vassilev et al. 2012, Correa et al. 2014). Thus, the objective of this article is to determine both physical and chemical properties of timber by-products generated in the Indigenous Community of Nuevo San Juan Parangaricutiro to suggest their suitability for bioenergetics use.

MATERIALS AND METHODS

Timber by-products

Timber by-products of the *Pinus leiophylla*, *P. montezumae* and *P. Pseudostrobus* used for this study were collected in the industrial complex at Indigenous Community of Nuevo San Juan Parangaricutiro, geographically located between parallels 19° 21' 00" and 19° 34' 45" North latitude, and between meridians 102° 08' 15" and 102° 17' 30" West longitude, referring to Greenwich meridian (CINSP, 2011).

For each of the three pine species, about 50 kg of lignocellulosic residues were taken directly from the transformation processes (main saw, debarking, chipper) in the industrial complex at the indigenous community. The generated material in the main saw was sawdust. Bark was taken from the debarking machine. The woodchipper machine generates a material that contains wood and bark, thus it has been named wood-bark. The timber residues (wood, bark and wood-bark) were dried outdoors, and then milled. The resulting wood meal was sieved to obtain mesh 40 material (420 microns). This lignocellulosic material was stored in sealed plastic bag, until use.

Physical characteristics

Initial moisture content (%) was determined based on the UNE-EN 14774-1 (2010) standard and bulk density was determined according to the UNE-EN 15103 (2010) standard. In order to determine the calorific value of the samples, pellets were formed from 1.0g (dry weight) samples using a laboratory press at a pressure of 1.000 kg·cm⁻². The calorific value all samples was determined using the norm UNE-EN 14918 (2011) in a bomb calorimeter (Parr Model 6772). The samples were conditioned at an average moisture content of 8 %.

Chemical properties

Determination of pH (Moisture pH; M pH) was based on a method described by Sandermann and Rothkamm (1959). Mineral content was calculated gravimetrically in accordance with the standard UNE-EN 14775 (2010). Ash microanalysis was carried out with an X-ray spectrometer, coupled to a scanning electron microscope (Jeol JSM-6400) using 20 kV acceleration voltage and 8.5 seconds sampling time (Téllez et al. 2010).

To determine the total content of extractives, sequential extractions were performed with Soxhlet equipment in the followings solvents: cyclohexane, acetone, methanol, and finally, hot water under reflux (6 h in each case). Solvents were recovered in rotary evaporator while the aqueous extracts were recovered using a lyophilization equipment. The respective extract was stored in a desiccator until the weight was constant. After sequential extractions, wood meal designated extractive-free wood meal, was used to determine holocellulose (Wise et al. 1946) and Runkel lignin (Runkel and Wilke 1951).

RESULTS AND DISCUSSION

Physical properties

The initial moisture values found timber residues varied from 33.6% to 56% (Tab. 1) and they are similar to those reported for sawdust and pine shavings (Correa et al. 2014). Also, our results fall within the 10-60% range reported for biomass (Vassilev et al. 2010), though several authors coincide that a high moisture content in timber (greater than 25%) reduces its calorific value, temperature, efficiency in the combustion processes, thermochemical conversion, and gasification, among other factors (Oberberger and Thek 2010, Garcia et al. 2012, Tanger et al. 2013, Correa et al. 2014). Because of their values of initial humidity, wood and bark residues studied do not meet the limit values of $\leq 10\%$ to be used as pellets (Oberberger and Thek 2010) nor for briquetting $\leq 18\%$ (ÖNORM 7135, 2000), since a high moisture content in the biomass affects the energy balance (Islas 1991, Miranda et al. 2009, Correa et al. 2014). Thus, according to the moisture content values found in the wood residues of the three studied species and the maximum values allowed for a timber to be used in pellets and briquettes, it will be required to provide energy for the drying process (Correa et al. 2014).

Tab. 1: Physical properties of timber residues.

	<i>P. leiophylla</i>			<i>P. montezumae</i>			<i>P. Pseudostrobus</i>		
	Wood	Bark	W-B	Wood	Bark	W-B	Wood	Bark	W-B
IMC (%)	49.6 (± 1.0)	42.5 (± 1.5)	44.3 (± 0.8)	48.9 (± 0.5)	33.6 (± 1.2)	41.9 (± 1.0)	56.0 (± 0.7)	36.1 (± 1.3)	40.8 (± 0.7)
BD ($\text{g}\cdot\text{cm}^{-3}$)	0.19 (± 0.01)	0.30 (± 0.00)	0.31 (± 0.01)	0.20 (± 0.00)	0.19 (± 0.01)	0.22 (± 0.01)	0.19 (± 0.00)	0.25 (± 0.01)	0.24 (± 0.01)
CV ($\text{MJ}\cdot\text{kg}^{-1}$)	18.57 (± 1.1)	18.74 (± 6.5)	18.70 (± 0.9)	18.01 (± 4.2)	18.60 (± 5.3)	18.87 (± 2.1)	18.23 (± 2.0)	17.95 (± 4.7)	18.93 (± 6.6)

IMC = initial moisture content.

BD = bulk density.

CV = calorific value.

W-B = wood-bark.

As shown in Tab. 1, the highest bulk density values correspond to *Pinus leiophylla* bark and wood-bark. On the other side, wood residues of both *P. leiophylla* and *P. Pseudostrobus* reported the lowest values, the same as *P. montezumae* bark (Tab. 1). Bulk density values of bark residues are slightly higher than $0.18 \text{ g}\cdot\text{cm}^{-3}$, as reported for coniferous (Francescato et al. 2008). High-density materials have shown difficulty in starting combustion (Vale et al. 2002), however, the higher the bulk density, the more energy density contained per volume unit (Baptista et al. 2012).

Calorific values of the samples are also shown in Tab. 1. The highest values belong to the wood-bark mix of both *P. montezumae* and *P. Pseudostrobus*. On the contrary, the lowest registered values correspond to the *P. montezumae* wood residues and *P. Pseudostrobus* bark. All in all, heating power results for the studied timber residues varied from 17.95 to $18.93 \text{ MJ}\cdot\text{kg}^{-1}$, which means they fall within the range reported for: a) different woods (14.64 to $20.92 \text{ MJ}\cdot\text{kg}^{-1}$) (Islas 1991); b) for coniferous (17.82 to $19.62 \text{ MJ}\cdot\text{kg}^{-1}$) (Francescato et al., 2008); and c) for logs and branches of semi-arid climate species (17.15 to $18.61 \text{ MJ}\cdot\text{kg}^{-1}$) (Ngangyo et al., 2016). All the three-pine barks showed values within the range found in the bark of ten species of broad-leaf trees (15.00 to $18.87 \text{ MJ}\cdot\text{kg}^{-1}$) (Martínez et al. 2015). The results obtained in this study indicate that wood residues of the three pine species can be a potential source for biofuels, mainly for pellets or briquettes, once they have been dried out to meet the required moisture conditions mentioned above.

Chemical properties

Tab. 2 shows the results of the chemical analysis carried out in timber residuals. All the bark residues of the three pine species showed low pH values compared to wood, in concordance with literature (Fengel and Wegener 1984). pH values in the wood residues are similar to those found in *P. leiophylla* (4.2) and *P. montezumae* (4.4) (Bernabé et al. 2013). Regarding the barks, their pH is slightly more acidic compared to the values reported for *P. leiophylla* bark (4.16), *P. montezumae* bark (4.23), and *P. Pseudostrobus* bark (4.26) (Lima 2013). Because the acidity of wood might be affected by the location of the analyzed piece of timber along the tree, the season, climatic factors, and the amount and type of extractives, the pH values found in this study were more acidic than the values reported for European pines (4.9-6.0) (Fengel and Wegener 1984). Furthermore, a mildly acidic pH of wood can corrode metals (Kollmann 1959, Fengel and Wegener 1984), therefore, the acidity of timber by-products could have a negative effect on the combustion equipment.

Tab. 2: Chemical properties of timber residues.

	<i>P. leiophylla</i>			<i>P. montezumae</i>			<i>P. pseudostrobus</i>		
	WOOD	BARK	W-B	WOOD	BARK	W-B	WOOD	BARK	W-B
pH	4.09 (±0.02)	3.29 (±0.02)	3.46 (±0.07)	4.06 (±0.02)	3.14 (±0.01)	3.52 (±0.02)	4.04 (±0.04)	3.67 (±0.01)	4.05 (±0.06)
Ash1 (%)	0.23 (±0.06)	1.07 (±0.01)	2.61 (±0.1)	0.13 (±0.01)	0.64 (±0.00)	5.44 (±1.7)	0.19 (±0.1)	1.49 (±0.05)	1.05 (±0.01)
Cyclohexane ¹	1.12 (±0.06)	2.53 (±0.2)	2.44 (±0.07)	1.08 (±0.2)	2.19 (±0.3)	4.75 (±0.1)	1.21 (±0.2)	1.45 (±0.1)	1.95 (±0.04)
Acetone ¹	1.23 (±0.1)	3.35 (±0.2)	3.98 (±0.06)	1.27 (±0.1)	2.95 (±0.2)	11.02 (±0.7)	1.12 (±0.06)	2.98 (±0.2)	2.03 (±0.07)
Methanol ¹	1.91 (±0.5)	1.70 (±0.2)	1.93 (±0.07)	1.50 (±0.1)	1.67 (±0.05)	2.16 (±0.1)	0.71 (±0.1)	5.85 (±0.3)	1.57 (±0.01)
Water ¹	2.80 (±0.10)	2.08 (±0.10)	2.12 (±1.2)	2.82 (±1.1)	3.51 (±1.0)	2.46 (±0.09)	3.58 (±0.05)	6.79 (±0.3)	2.00 (±0.3)
Total extractive (%)	7.07 (±1.0)	9.66 (±0.7)	10.48 (±1.5)	6.68 (±1.6)	10.33 (±0.6)	20.41 (±1.1)	6.63 (±1.1)	17.09 (±1.1)	7.55 (±0.4)
Runkel lignin ² (%)	29.57 (±0.8)	51.11 (±3.2)	45.82 (±0.7)	29.76 (±1.2)	50.30 (±0.1)	53.09 (±2.8)	32.52 (±2.1)	50.46 (±0.5)	48.32 (±0.2)
Holocellulose ² (%)	73.25 (±0.9)	47.72 (±5.5)	58.07 (±2.4)	76.98 (±0.2)	48.32 (±1.0)	45.86 (±2.81)	71.92 (±1.3)	45.84 (±0.3)	61.46 (±2.3)

1. Percentage based on moisture-free wood meal.

2. Percentage based on moisture- free and extractive-free wood meal.

W-B = wood-bark.

Bark residues of the three conifers showed a high content of inorganic compounds compared to their correspondent wood residues (Tab. 2), which is in line with previous reports (Kollmann 1959, Fengel and Wegener, 1984, Campbell et al. 1990, Martínez et al. 2015). Particularly, the *P. montezumae* wood-bark mix showed the highest content (5.44). As for ash percentage, both the wood and bark by-products of three pine species were below the range (2.0-5.0 %) reported by Obernberger and Thek (2010). Nonetheless, the results of the wood-bark mix residues of *P. leiophylla* and *P. montezumae*, were within the range reported by Obernberger and Thek

(2010). Ash content in wood residues were lower than those reported for *P. leiophylla* (0.3%) and *P. montezumae* (0.3%) (Bernabé et al. 2013). Furthermore, the ash content values found for the three barks were lower than those reported for *P. leiophylla* (1.41%), and higher for *P. montezumae* (0.51%) and *P. pseudostrabus* (0.46%) (Lima 2013). These differences in the content of inorganics might be explained by the following factors: variation among species and within the same species (sapwood, heartwood), pith, early wood (springwood), and juvenile wood; by the season, weather conditions, and soil minerals availability. Factors that influence both on the amount and composition of ash (Kollmann 1959, Campbell et al. 1990). Moreover, high ash content in a fuel can affect the combustion equipment and residential users since it increases the cleaning requirements. According to our findings regarding inorganic compound percentages, it may be plausible to produce Class A2 pellets from both wood and bark residues of the three pine species, since the ash percentage is ≤ 1.5 . Additionally, it may be possible to produce Class B pellets from two wood-bark mixes, that of *P. leiophylla* and that of *P. pseudostrabus*, since the ash percentage ≤ 3.5 (Oberberger and Thek 2010).

Tab. 3 shows the relative percentage of ash microanalysis for timber by-products. The most abundant elements in the provided wood residues were calcium, magnesium and potassium in agreement with Fengel and Wegener (1984), Correa et al. (2014) and Martínez et al. (2015), who reported the same trend; whereas, calcium and potassium are frequently found in barks (Sjöström 1981). Thus, in a general way, our results go along with previous studies carried out on the same species of wood (Bernabé et al. 2013, Lima et al. 2013, Correa et al. 2014).

Tab. 3: Elemental microanalysis of the ash (Atomic %), determined by EDS.

Element (%)	<i>P. leiophylla</i>			<i>P. montezumae</i>			<i>P. pseudostrabus</i>		
	WOOD	BARK	W-B	WOOD	BARK	W-B	WOOD	BARK	W-B
Ca	42.46 (± 0.98)	47.54 (± 1.7)	43.13 (± 0.69)	42.44 (± 0.54)	35.89 (± 0.35)	26.45 (± 1.2)	25.48 (± 0.5)	35.02 (± 0.31)	34.13 (± 1.1)
K	13.16 (± 0.78)	18.05 (\pm 0.8)	18.11 (± 0.68)	21.1 (± 0.66)	20.52 (± 0.70)	26.33 (± 1.3)	12.23 (± 0.77)	12.14 (± 1.56)	21.39 (± 0.9)
Mg	21.64 (± 0.31)	15.90 (± 0.75)	20.91 (± 0.37)	13.08 (± 0.47)	22.10 (± 0.50)	27.88 (± 0.47)	10.82 (± 0.44)	13.56 (± 0.59)	16.33 (± 0.59)
P	5.37 (± 0.2)	4.00 (± 0.17)	5.19 (± 0.07)	4.06 (± 0.16)	5.22 (± 0.32)	5.8 (± 0.63)	9.35 (± 0.54)	5.65 (± 0.49)	5.62 (± 0.33)
S	3.8 (± 0.18)	2.31 (± 0.17)	3.28 (± 0.09)	2.59 (± 0.09)	2.04 (± 0.02)	4.19 (± 0.41)	1.7 (± 0.21)	1.66 (± 0.41)	2.25 (± 0.17)
Na	5.74 (± 0.61)	1.94 (± 0.54)	3.59 (± 0.20)	2.33 (± 0.29)	3.10 (± 0.43)	ND	2.17 (± 0.37)	1.98 (± 0.55)	1.96 (± 0.4)
Si	4.57 (± 0.43)	3.07 (± 0.21)	3.48 (± 0.13)	4.89 (± 0.61)	5.77 (± 0.77)	3.56 (± 0.22)	17.46 (± 0.70)	11.98 (± 0.69)	8.24 (± 0.85)
Al	3.22 (± 0.51)	4.30 (± 0.26)	2.28 (± 0.14)	6.26 (± 0.28)	3.09 (± 0.54)	3.63 (± 0.73)	12.7 (± 0.69)	11.66 (± 0.79)	5.94 (± 0.46)
Fe	ND	2.84 (± 0.16)	ND	3.21 (± 0.24)	2.23 (± 0.14)	2.11 (± 0.12)	7.01 (± 0.33)	5.73 (± 0.29)	4.08 (± 0.25)
Ti	ND	ND	ND	ND	ND	ND	0.50 (± 0.1)	0.58 (± 0.13)	ND

ND = no detected.

W-B = wood-bark.

Even though this study determined the atomic percentage of the chemical elements found in the ash of the lignocellulosic material, no absolute determination was made. Yet, it is convenient to provide general information about the effects that these chemicals can cause when burning solid biofuels. For instance, high calcium (Ca) content raises the melting point of the ash, but at the same time, reduces the amount of ash in the equipment (Van Loo and Koppejan 2002, Obernberger and Thek 2010). A high magnesium (Mg) percentage raises the melting point of the ash (Van Loo and Koppejan 2002, Obernberger and Thek 2010); while high levels of potassium (K) may grow the volume of aerosols formed during combustion, which can dust boilers and produce fine-particle emissions (Van Loo and Koppejan 2002, Obernberger and Thek 2004, Biedermann and Obernberger 2005, Van Lith et al., 2006). Moreover, high values of phosphorous (P) affect the combustion process, since this semi-volatile element can cause problems and melt the ash by forming phosphates (Obernberger and Thek 2010). Besides, high concentrations of sulphur (S) may cause problems with SO_x emissions, deposit formation and corrosion (Obernberger and Thek 2004). Further, high values of sodium (Na) lower the melting point of the ash and produce slag in the combustion chambers (Van Loo and Koppejan 2002, Biedermann and Obernberger 2005; Obernberger and Thek 2010), they also promote deposit formation when vapors are condensed inside the piping of combustion equipment (Werkelin et al. 2011). Likewise, silicon (Si) is the second most abundant element in the earth's crust, which is fixed in silicates (Gil 1995). Silicates can significantly lower the melting point of ash (Miles 1996). Finally, aluminum (Al), iron (Fe) and titanium (Ti) were also detected. These four elements could be related to the contaminants present in wood machinery (Correa et al., 2014), even though this elements' presence tends to be normal in wood (Fengel and Wegener 1984).

The results obtained for total extractives are collected in Tab. 2. Compared to wood residues, barks showed a higher solubility of total, which coincides with the fact that the bark contains high extractive contents (Rydholm 1965, Fengel and Wegener 1984). Particularly for the acetone extraction, the highest percentage of extractives was registered in the mix wood-bark residues of *P. montezumae*; while, the lowest percentage registered was with methanol in *P. Pseudostrobus* wood residues. Total solubility of *P. leiophylla* and *P. montezumae* wood residues is slightly lower than the values reported by Bernabé et al. (2013), 8.2% and 7.6% respectively. On the other hand, total extractives content of *P. Pseudostrobus* wood residues was slightly higher than that reported for sawdust (5.11%) by Fariás et al. (2015). The values of total extractives for the studied wood residues are partially similar to those reported for sapwood and heartwood of *P. leiophylla* (6.26-9.73%), *P. montezumae* (7.73-8.75%) and *P. Pseudostrobus* (5.41-17.28%) by Lima (2013). Regarding bark residues values of the three species they are lower than those described for *P. leiophylla* (33.73%), *P. montezumae* (36.32%) and *P. Pseudostrobus* (15.39%) by Lima (2013). Regarding extractives values for barks of the three species, they were lower than those reported for *P. leiophylla* (33.73%), *P. montezumae* (36.32%) and *P. Pseudostrobus* (15.39%) by Lima (2013). Such variations in total extractives content for wood and bark may be due to growth conditions; geographical location, part of the tree from which the sample was taken, tree height, pith, heartwood and sapwood, environmental factors, genetic factors, tree age, weather, amount of supplied water, available nutrients, pruning season, and type of solvent used (Fengel and Wegener 1984, Ramos et al. 2011). It is widely recognized that a high extractive content tends to raise the caloric value (Kollman 1959, Cunha et al. 1989, Jara 1989; Kataki and Konwer 2002, Ngangyo et al. 2016), which might be benefic in the materials studied.

Runkel lignin content is also shown in Tab. 2. In most cases, higher lignin values were identified in bark residues compared to wood residues of the three species of pine. This coincides with the fact that lignin concentration in general is higher in the bark than in wood (Sjöström

1981, Fengel and Wegener 1984). Lignin content in wood residues of the three pine species is similar to the one reported by Lima (2013) for sapwood and heartwood of *P. leiophylla* (29.1-29.8%), *P. montezumae* (28.3-28.4%) and *P. Pseudostrobus* (26.9-29.2%). As for the barks, lignin percentages are within the range (40-55%) reported for softwood bark (USDA 1971), but at the same time they are lower than the percentages reported by Lima (2013) for *P. leiophylla* (65.8%), *P. montezumae* (59.8%) and *P. Pseudostrobus* (54.9%). Usually, wood contains about 20% to 30% of lignin, which forms part of the cell wall and the middle lamella of wood fibers. However, lignin content may differ depending on the extraction method (Kurth and Smith 1954, Higuchi et al. 1967). Furthermore, Cunha et al. (1989) and Jara (1989) have stated that the calorific value is influenced by the chemical composition of wood, mainly because of the lignin content. In this research high lignin values were found in the bark by-products of the three pines. Therefore, it is considered that the high content of lignin explain the relatively high calorific value of the studied materials (Tab. 1).

Holocellulose content is exposed in Tab. 2. Wood residues have more holocellulose than barks, in line with the fact that polysaccharides content in the bark is lower compared to the content in the wood (Fengel and Wegener 1984). Holocellulose percentages in wood by-products of the three species are closer to the ranges for gender *Pinus* wood (44-71%) (Rowell 1984), (70-74%) (Fengel and Wegener 1984). Regarding the three pine bark residues, it was found that holocellulose content was within the range (51.6-83.4%) reported for different woods (Fengel and Wegener 1989), and within the range (30-48%) for coniferous bark (USDA 1971).

CONCLUSIONS

To sum up, the initial moisture content of lignocellulosic residues exceeds the recommended standards that allow their use as biofuels. Therefore, it will be required to provide energy to meet the required moisture standard. Bulk density of timber residues is low. However, calorific values of timber by-products of the three pine species is high compared to the values expected for pine woods in the literature. Therefore, they are a potential source for biofuels.

Regarding chemical properties, it was found that the studied barks are more acidic than the woods. Wood residues have less inorganic substances than the barks. Ten wood-typical elements were detected, but not a single heavy metal. By means of a sequential extraction, it was determined that barks have greater solubility than the woods. Also, barks have a higher concentration of lignin and lower holocellulose content compared to woods.

Finally, according to the physical and chemical analysis of lignocellulosic residues generated in the industrial complex of the Indigenous Community, it is concluded that they have the potential to be used for the production of solid biofuel.

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