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Production of Recycled Paving Stones from Spent Bleaching Earth

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Abstract. The Garoua branch of cottonseed oil refinery (SODECOTON) uses in its process a significant amount of bleaching earth for discoloration of cottonseed oil. After usage, this bleaching earth is qualified as solid waste and considered to be one of the major problems of waste management encountered by this cottonseed oil refinery. The Garoua branch of cottonseed oil refinery uses about 768 kg of bleaching earth per day to decolorize its oil and rejects an average of 949.22 kg of used earth. SODECOTON therefore daily rejects out of the process an average of one ton of Spent Bleaching Earth (SBE). For the sake of upgrading this solid waste by manufacturing recycled paving stones and simultaneously protecting the environment, it was treated through waste inerting process. The amount of fat, the pH value, and relative humidity of the spent bleaching earth are the main physicochemical characteristics that were determined. From physicochemical characterization, it appeared that fat has an average value of 19.68%, while pH and relative humidity are presenting average values of 8.04 and 12.64% respectively. Recycled paving stones produced showed physicochemical recycled paving with a compressive strength of 28.81 MPa, a resistance force of 815.03 kN, a water absorption rate of 11% and economic advantages than concrete cement pavers encountered in the local market.

Keywords: Fat, Relative humidity, Plastics, Spent Bleaching Earth, Recycled paving stones

Introduction

Industrial waste occupies a significant place among the waste produced each year around the whole world. They belong to waste of economic activities which are distinguished from household waste (Adepoju & Kumuyi, 2010). Among the activities that generate large quantities of industrial waste, agricultural and food industries having as their object the transformation, exploitation and packaging of products of agricultural origin into foodstuffs intended for human consumption and animal occupies an important place (Tchindjang *et al.*, 2011; Mathieu, 2015; Ngambi, 2015; Ograh *et al.*, 2020).

In developing countries like Cameroon, a policy has been put in place to cope with the degradation of the environment which is closely linked to waste management. However, many studies realized from 2000 in some African cities showed that strategies adopted by governments to manage urban wastes were not effective (Ngnikam, 2002; Elong, 2003; Sotamenou, 2010; Tchikoua, 2010; Tchindjang *et al.*, 2011; Mathieu, 2015; Ngambi, 2015; Ograh *et al.*, 2020).

Cameroon is a developing country where agriculture and livestock occupy a very significant place. Cotton culture has developed rapidly due to the presence of SODECOTON company in the northern regions. Indeed, SODECOTON company, which produces edible oils, generates high amount of solid waste such as packaging waste and spent bleaching earth that contribute to pollute Garoua, Maroua and bordering towns.

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Bleaching is a very important unit operation during oil refining process. Bleaching in crude oil refining process, preceded by neutralization, generates Spent Bleaching Earth (SBE) used to remove the discolored pigments that neutralization has partially destroyed. Spent Bleaching Earth (SBE) is therefore released in large quantities into the environment without any treatment. SBE have been upgraded in various ways in many studies such as their use into bio-organic fertilizer (Loh *et al.*, 2013), in clay brick production (Suhartini *et al.*, 2011; Heidari and Ghazizade, 2021), in biomass briquette production (Srisang & Sinthoo, 2017; Srisang & Srisang, 2020), in foamed concrete production (Rokiah *et al.*, 2019), etc. Among solid waste valorization processes, paving is used as a solution for industrial and solid waste management (Sayed, 2012; Sellakuty, 2016; Ramaroson *et al.*, 2017; Agyeman *et al.*, 2019; Saïffoullah, 2020). Hence, the aim of this research work is to explore some physicochemical characteristics of recycled paving stones produced from residual spent bleaching earth with plastics PET as binder.

Material and Methods

Bleaching Earth

Bleaching earth used with chemical formula $Al_2O_3.4SiO_2$, nH_2O, consists of smectite, montmorillonite and attapulgite. It comes in powder or cake form, odorless, tasteless and non-toxic with a dark brown color. It used for cottonseed oil bleaching. It has a pH between 7.5 and 8.04; an apparent density of 500g/L; an exchange capacity of 45meq/100g.

Thermoplastic Polymer

Non-compliant plastics PET bottles come from the bottle manufacturing workshop of SODECOTON company, they show several irregularities. These non-compliant bottles are made of Terephthalate polyethylene (PET) of the crude formula $(C_{10}H_8O_4)_n$. They have a glass transmission temperature of 70°C; a melting point of 245°C; a solubility of 20.5 $J^{1/2}cm^{-3}$; their density is between 1.34-1.39 $g{\cdot}cm^{-3}$; and a thermal conductivity of 0.5 $W.m^{-1}{\cdot}k^{-1}$.

Molding

The mold (Figure 3), is a multiform frame in which the hollows are placed. Each hollow is cut to the shape of the outline of the paving block. Self-locking metal molds were used. Three different types of pavers were obtained related to the shape of the used mold and the value of PET/SBE ratio. Thus, molds used for paving are polygonal star shaped molds, each 4.8 cm thick; 19.5 cm long and 15.0 cm wide (Figure 3), all made of steel from iron.

Figure 1. Sample of mold used for paving

Paver Manufacturing Process

The binder at a liquid state was obtained through heating a known weight of plastic material (PET) at 270°C in a baking tray during 45 min. While agitating gently at the same temperature, the Spent Bleaching earth is then gradually poured into the liquid binder obtained previously until the mixture is homogeneous. Three different mass ratios of PET/SBE as follows 3/3 (sample-A), 2/3(sample-B) and 1/3(sample-C) were considered. This operation favored the degradation of fats. The molding process consisted of pouring the hot liquid mixture into molds of predefined shapes. Prior to the unmolding, the filled molds are left at atmospheric conditions during 1 hour. The obtained pavers are then left under atmospheric conditions for 24h before being packed into palettes.

Physicochemical Characterization of SBE and Pavers

Relative humidity (Hr)

To measure the rate of water absorption, we recorded the weight before and after immersion in water. To do this we use the expression:

$$\mathrm{Hr} = \frac{m_f - m_i}{m_f} \times 100 \quad (1)$$

With, m_f = final mass; m_i = initial mass

Fat content (Wg)

$$\mathrm{Wg} = \frac{M_2 - M_1}{M_0} \times 100 \quad (2)$$

M_0: mass of the sample to be analyzed; M_1: mass of empty balloon; M_2: mass of balloon + oil

The pH of the solution was determined by a brand X pH meter.

Results and Discussion

Physicochemical Characterization of Spent Bleaching Earth (SBE)

Amount of Spent Bleaching Earth produced

Analyzes carried out in the field allowed to collect daily data of the production of Spent Bleaching Earth (SBE). It appears that the quantity SBE is high the 1st, the 2nd and the 3rd day (respectively 964.2 kg, 971.16 kg and 960.11 kg) as well as on the 5th day with a value of 967.2 kg (Figure 2). For other days including the 4th, 6th and 7th, the amount of SBE is moderately low. The increase in the amount of SBE can be explain by the dysfunction of the process or the great amount of oil treated. When crude oil from the extraction workshop with a high quantity of fatty acids is produced, the operating time of the filters increases, consequently bleaching earth adsorbs a sufficient quantity of oil for its discoloration which can increases the mass of spent earth. The considerable amounts of Spent Bleaching Earth vary between 914.61 kg and 971.16 kg with an average of 949.22 kg. Bleaching earth generates a large amount of waste after use.

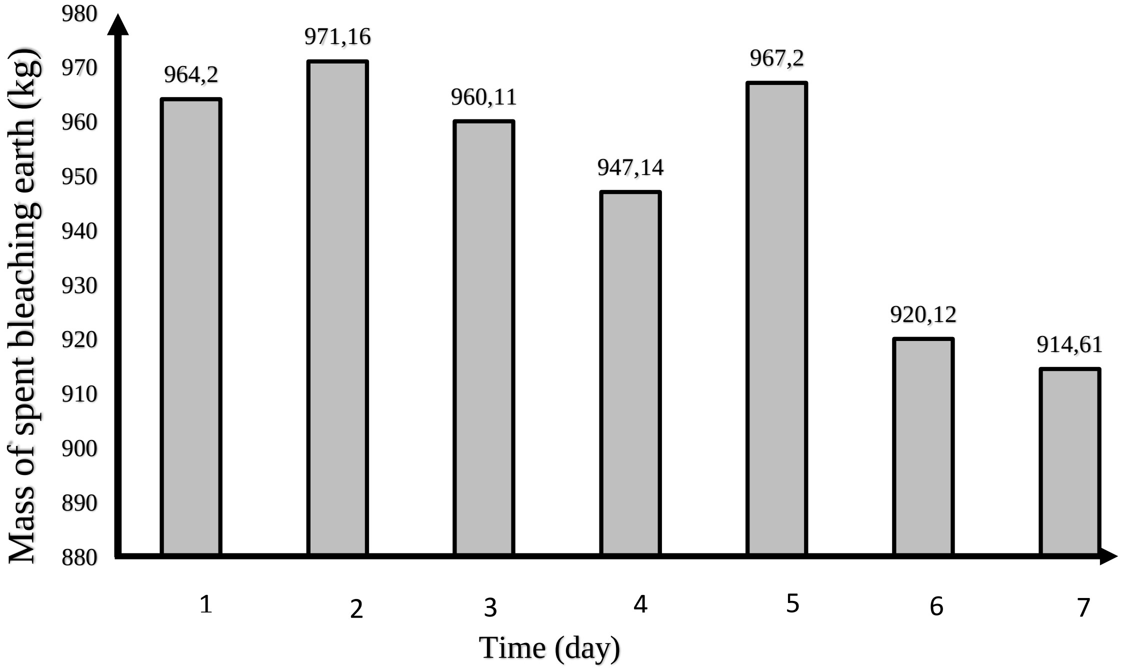


Figure 2. Daily amount of SBE produced

Fat content in Spent Bleaching Earth

Analyzes carried out in the field allowed us to collect daily data on the fat content of SBE to know the level of oil contained in the used bleaching earth, for a period of seven (07) days.

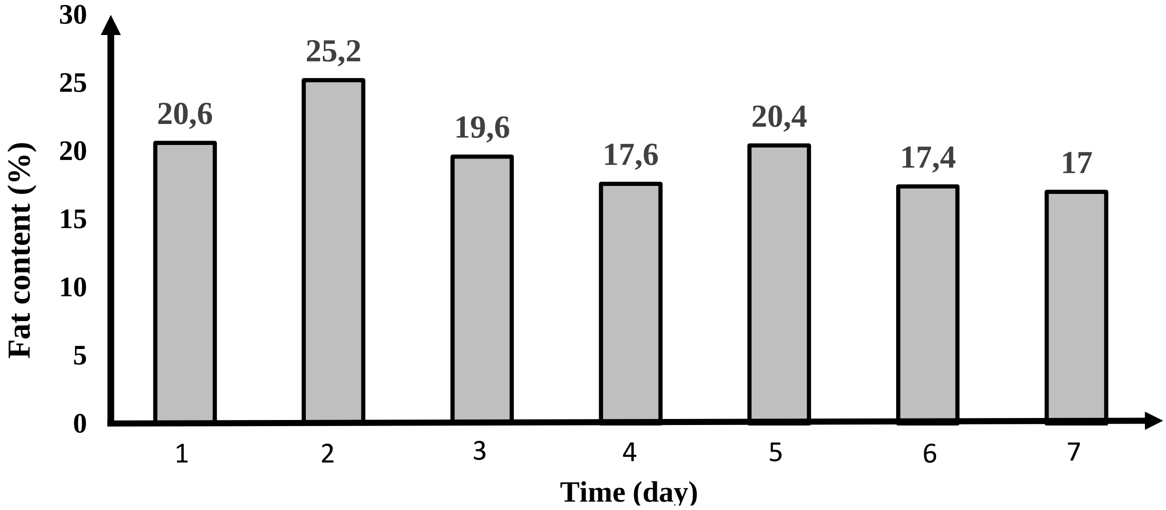


Figure 3. Evolution of fat content in SBE

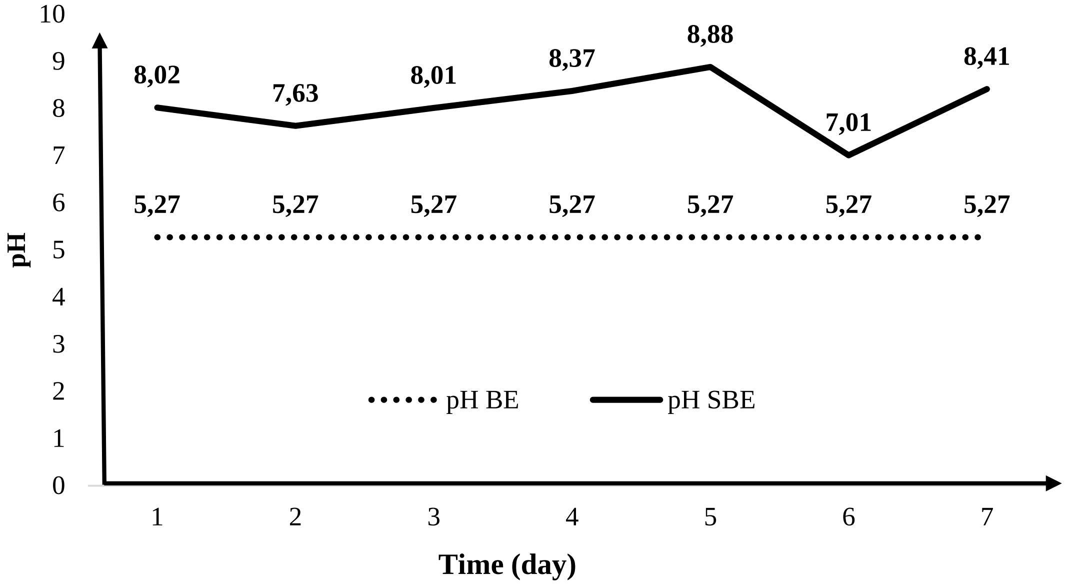
It emerges from Figure 3 that the variation of the oil rate in SBE is high between the 1st and the 2nd day (20.6% and 25.2% respectively), just as much as the 5th day with a value by 20.4%. For the rest of week oil level is less than 20% with a minimum reached on the 7th day.

It is therefore interesting to note that this fairly high presence of fat is justified by the oil coming out of the bleaching earth throughout the discoloration process of edible oils.

These earths are adsorbents used in these bleaching oil processes. This earth considerably made of clays, by virtue of their physicochemical properties and their abundance, remain a qualitative material in industrial food and water treatment processes. Based on previous work by Mariam (2008), these analyzes show that the average of fat is 8.11%. In this work the average is around 19,7% which is very high. This could be explained by the fact that clays used in for the bleaching process are different and crude oil may have a high amount of non-desired compounds.

pH of Spent Bleaching Earth

Analyzes carried out in the field allowed us to collect daily data on the various pH measurements of the Spent Bleaching Earth, for a period of seven (07) days. The results are shown in Figure 4.



BE: *Bleaching Earth;* ***SBE:*** *Spent Bleaching Earth*

Figure 4. Evolution of the pH of Spent Bleaching Earth (SBE) and Bleaching Earth (BE)

It emerges from Figure 4 that, the pH decreases slightly between the 1st and 2nd day while it increases from the 2nd to the 5th day to then have a decreasing peak on the 6th day and then finally increase again around the 7th day.

Thus, over a week of analysis low pH value was observed on the 6th day with a value of 7.01 while the highest one is at 8.88 obtained on the 5th day. These changes in pH showed that the amount of fat is very high in SBE. The average pH value of around 8.30 allows to understand in general that environment has a strong basic connotation.

Relative humidity of Spent Bleaching Earth

The analyzes carried out in the field allowed us to collect daily data on relative humidity to know the water content in the used soil, for a period of seven (07) days. Results are shown in Figure 5.

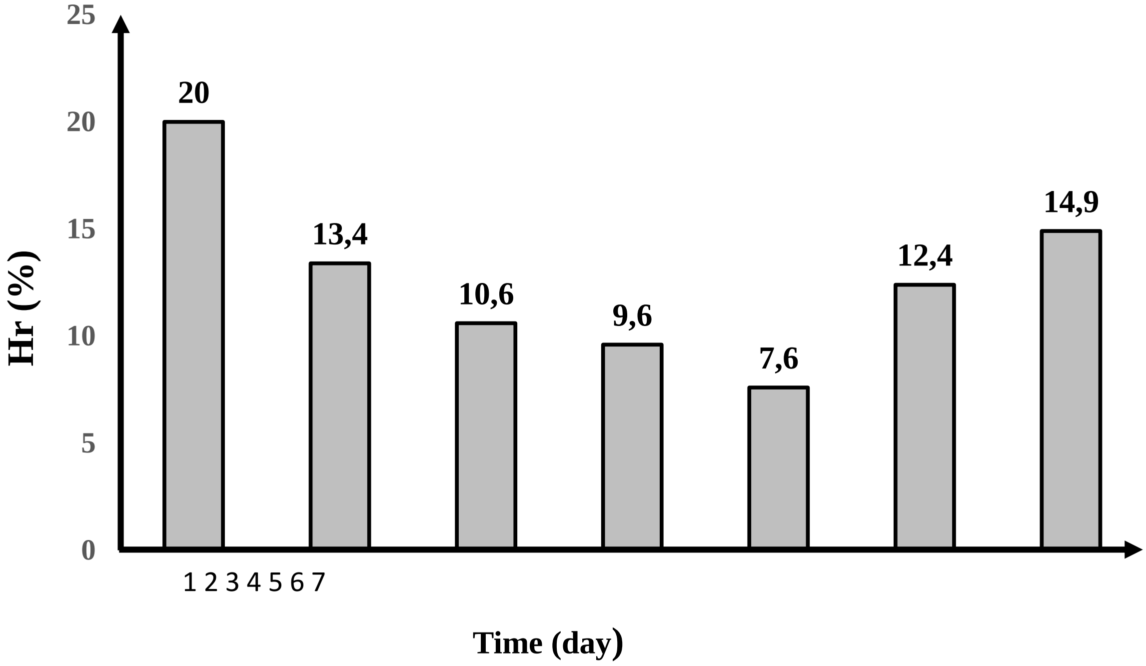


Figure 5. Evolution of relative humidity in SBE

It appears from Figure 5 that, humidity rate is greater than 10% in the recovery tank exposed to the open air at an ambient temperature (28°C) weekly for city of Garoua, the average humidity rate is approximately 12.64%.

The fall in the rate upon leaving the workshop (20%) to a minimum value of 7.6% on the 5th day can be directly associated to the ambient temperature and the time of exposure. SBE mainly made by swelling clays it adsorbs a quantity of water present in crude oil and atmosphere leading on the 7th day to an increase in the humidity level of around 7.3%. So, there is almost 100% moisture uptake, this leads to the process of eutrophication and leachate production. Therefore, moving towards a process of energy recovery from this waste by recycled paving stones production is preferred.

Production and Characterization of Pavers

Paving stone production

Basic constituents are on the one hand plastic binder and on the other hand the aggregate which is the Spent Bleaching Earth (SBE). We established the plastic/SBE ratio, according to the ratio 3/3, 2/3 and 1/3 respectively 50%, 20% and 10% (by weight) of plastic binder.

Figure 6. Sample of Recycle pavers produced

Figure 6 shows a sample of recycled paving stones produced. The different pavers have a relative thickness of 4.8 cm. While paving surface is 282.8 cm^2 respectively for sample-A, B and C. The concrete cement pavers produced have a relative thickness of 5.0 cm and their surface is 281.0 cm^2. Interlocking recycled paver obtained are generally used for small surfaces exposed to traffic, in the framing of the gutters or the coverings of the courtyards.

Water absorption test

Water absorption test gives an idea on the internal structure of pavers. Pavers having more absorption are more porous in nature and are generally considered unsuitable, unless found to be acceptable based on strength, impact and hardness test (Table 1). The water absorption rate increases form average 1.1 to 4.5% respectively for 3/3 pavers; 1/2 and 2/3 (Table 2). Hence there is a increase of water absorption as far as the ratio of binder decreases for each sample and respectively for the types of recycle paving stone. These values are far lower than that of the ordinary concrete cement paver which gives an absorption rate of 7% according to International standard. This confirms the strength and elasticity of our pavers linked to the quality of the binder (PET) due to the high temperature (270°C) of the cobblestones. The cooling of these paving stones made by quenching contributes significantly to the stabilization of our various material (Bhatia *et al.*, 2019).

Table 1. Pavers water absorption ratio test (%)

Pavers	Test 1	Test 2	Test 3	Test 4
Sample (A)	1.2	1.3	1.2	1.1
Sample (B)	3.1	3.2	3.1	3.3
Sample (C)	4.6	4.5	4.7	4.5
Concrete Cement pavers	7	7	7	7

Compressive strength test

Table 2 shows the compressive strength applied to recycled pavers. For sample (A), (B) and (C) the average is respectively 28.8, 17.61 and 15.81 MPa considering the test did after 7 days. Concrete cement paver usually has a compressive strength that varies from 15 MPa to 28 MPa for international standards (Navya and Ventkateswara, 2014), the interlock concrete cement paver used had 29,41 MPa.

Deduced pressing force has shown that the 3/3 block (sample -A) has an ability to withstand a load around 815.03 kN, while the 2/3 (sample-B) and 1/3 (sample-C) portion blocks are left with lower force values (498.02 kN and 447.37 kN). On the other hand, ordinary paving stones end up with a value of 826.42kN. Concrete cement paver has the highest compressive strength although the presence of plastic binder increases the thermoplastic properties of our various recycled paving stones. Compressive pressure exerted on each paver shows that the greater source and the smaller the rate of binder, the smaller the required force to compress the paving stone. Thus, 3/3 blocks require a higher compressive force compare to 2/3 and 1/3 ratio blocks.

For concrete, abrasion resistance has been defined in terms of its ability to resist being worn away by rubbing and friction. As abrasive particles achieve relative motion, shear forces are formed on the surface of the abraded material along with a normal load. While normal load helps abrasive particles penetrate into the specimen surface, shear force helps the formation of grooves and scratches on the surface. Thus, material transfer from the specimen surface occurs by a combination of normal load and shear forces (Gencel *et al.*, 2012).

Table 2. Compressive strength of pavers (MPa)

Pavers	Test 1	Test 2	Test 3	Test 4
Sample (A)	28.82	28.84	28.82	28.83
Sample (B)	17.60	17.62	17.61	17.61
Sample (C)	15.81	15.81	15.82	15.82
Concrete Cement paver	29.42	29.41	29.41	29.43

Drop impact test

This test method provides means to assess the drop impact resistance of water filled, blow-molded thermoplastic container, which is a summation of the effects of the material manufactural conditions, container design and other factors. In the case of recycled paving stones produced, distances of 3, 6, 9 and 12m were used to estimate de damages that can occurred to each different block. Sample (A) was found to be the most resistant to the impact when sample (C) was the less resistant to impact (Table 3) (Bhatia *et al*., 2019).

Table 3. Drop impact test of pavers

Pavers	Drop height 3m	Drop height 6m	Drop height 9m	Drop height 12m
Sample (A)	No visible deformation	No visible deformation	No visible deformation	No visible deformation
Sample (B)	No visible deformation	No visible deformation	No visible deformation	Surface disintegration at edges
Sample (C)	No visible deformation	No visible deformation	Surface disintegrations at edges	Sample broke in tree
Concrete Cement	No visible deformation	Sample broke in two	Crumble and broke	Total disintegration

Efficiency of recycled paving stones

Comparison of recycled paving stones according to some criteria obtained on local market are presented in Table 5. It appears that recycled paving stones are less polluting from the point of view of the production of volatile organic compounds (VOCs) in the atmosphere; the manufacturing time is shorter (about 6 hours) while that of ordinary pavers can go beyond 24 hours; the mass of our pavers is less heavy while that of ordinary pavers are heavier since. The production cost of our pavers is cheaper than that of ordinary pavers as the cost of binder and labor are low (Table 4). The commercial price of each block is €0.35 and €10.90 for 1 m^2 of surface. The lifetime of recycled paving stone is much longer than concrete cement ones. This can be directly associated to properties the plastic binder and their relative non-degradability.

Table 4. Comparison between recycled pavers and concrete pavers

Criteria	Recycled paving stones	Concrete cement
Production cost	Cheaper	Expensive
Lifetime	High	Average
Weight	Less heavy	Heavy
Pollution level	Low	High
Manufacturing time	Short	Long

Conclusion

It appeared that the Garoua oil refinery uses around 768 kg of bleaching earth per day during the production of its oil and rejects an average of 949.22 kg of used earth. In order to determine the physicochemical characteristics of the used bleaching earth, parameters such as pH, fat and relative humidity were determined. Analyzes shown that the spent bleaching earth has a basic pH, contained an average of 19.68% of fat, 12.64% of relative humidity. Three types of pavers of ratio 3/3, 2/3, 1/3 were produced.

In the case of recovery in materials science, our study revealed that the manufacture of pavers with a ratio of 50% of spent bleaching earth and 50% of non-compliant bottles, produces a recycled paving with a compressive strength of 28.81 MPa and a resistance force of 815,03 kN, with an absorption rate of 11% which is of good quality, very efficient and strong compared to 2/3 and 1/3 ratio. The evaluation of the production costs of the pavers showed that 1518 pavers can be produced per day at a selling price of €0.35 for a unit. Hence, spent bleaching earth from SODECOTON of Garoua enable the production of economical recycle paving stone.

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