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Eyasu Derbew Demeke
Addis Ababa University

Mekonnen Abebayehu Desta
Addis Ababa University

Yedifana Setarge Mekonnen (✉️ yedifana.setarge@aau.edu.et)
Addis Ababa University College of Natural Sciences  https://orcid.org/0000-0001-9331-7370

Research Article

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Potential of Industrial Sludge and Textile Solid Wastes for Biomass Briquettes with Avocado Peels as Binder

Eyasu Derbew Demeke¹, Mekonnen Abebayehu Desta², Yedilfana Setarge Mekonnen¹,*

¹Center for Environmental Science, College of Natural and Computational Sciences, Addis Ababa University, P. O. Box 1176, Addis Ababa, Ethiopia
²Department of Chemistry, College of Natural and Computational Sciences, Addis Ababa University, P. O. Box 1176, Addis Ababa, Ethiopia

*Corresponding author email: yedilfana.setarge@aau.edu.et

ABSTRACT

Producing biomass briquettes from industrial solid wastes is a more environmentally friendly way to provide alternative energy and is essential for Ethiopia to satisfy its growing energy needs while also ensuring efficient waste management in the expansion of industrial parks. The main objective of this study is to produce biomass briquette from a mixture of textile sludge and cotton residue using avocado peels as a binder. Avocado peels, sludge, and textile solid wastes (cotton residue) were collected at Addis Ababa and the Hawassa industrial park. They were then dried, carbonized, and crushed into powder. Briquettes made from the mixture of industrial sludge and cotton residue were combined in various ratios: 100:0, 90:10, 80:20, 70:30, 60:40, and 50:50 with the same amount of binder, avocado peels. Briquettes were then made using hand press mold and sun-dried for two weeks. The results showed that the formed biomass briquettes had moisture contents, calorific values, bulk densities, and burning rates that ranged from 5.03 to 8.04%, 11.19 to 17.2 MJ/kg, 0.21 to 0.41 g/cm³, and 2.92 to 8.75 g/min, respectively. The most effective briquette was proven to be 50:50. The binding and heating value of the briquette was greatly enhanced by introducing avocado peels. Hence, biomass briquette made from sludge and solid wastes using avocado peels binder is a promising source of energy for cooking and heating in homes and small enterprises. Additionally, it can also promote proper waste management and provide young people with employment prospects.
Keywords: Industrial sludge, cotton residue, solid waste, avocado peels, briquettes, calorific value, waste management, dense energy

1. Introduction

The majority of the world's growing energy demand is still being supplied by fossil fuel energy sources, specifically coal, crude oil, and natural gas (Tipantuna u.c., 2021). This causes a rapid depletion of reserves, and the day they will run out is becoming closer. Additionally, they are contributing to various environmental problems. Climate change and global warming, caused by \( \text{CO}_2 \) and other greenhouse gases (GHGs), have become an international concern in recent years (Martin u.c., 2021). In recent years, it has become increasingly popular to use renewable energy sources for various uses, such as solar, wind, geothermal, and bioenergy (Benti u.c., 2022; Degfie u.c., 2019; Erchamo u.c., 2021; Tiruye u.c., 2021). A briquette is a form of alternative bioenergy that is produced by densifying a variety of biomass feedstocks, including different organic solid wastes (Marreiro u.c., 2021; Onukak u.c., 2017; Simões u.c., 2022; Tumuluru u.c., 2021).

The number of industries in Ethiopia has been rapidly increasing in recent years as a result of the growth of industrial parks; consequently, a lot of industrial waste is dumped into the environment and causing environmental degradation. To alleviate this environmental issue, wastes must be transformed into a variety of useful forms, such as biomass briquettes and brick production (Beshah u.c., 2021). It is not recommended unmanageable use of forests as wood fuel, such as firewood and charcoal since trees are the main \( \text{CO}_2 \) absorbers and play a part in preventing global warming, in addition to releasing pollutants when burned (Yang u.c., 2022). Therefore, sustainable fuel charcoal development is necessary. The manufacturing of briquettes from surplus biomass resources, such as textile industry wastes (sludge and organic solid residue), offers a sustainable energy alternative to fossil fuels, charcoal, and firewood. If briquettes are produced at a cheap cost
and are easily accessible to customers, they could be widely used as an energy source in place of
firewood and charcoal for residential cooking and small industrial operations. Additionally, the
briquette is advantageous over fuel wood in terms of heat output, cleanliness, and suitability, and
requires less space for storage than the fuel wood (Yulei u.c., 2020).

Currently, firewood, agricultural waste, dung, and charcoal make up the majority of Ethiopia's
energy use, which accounts for over 87% of the nation's energy needs being met by conventional
biomass, with the remaining 13% coming from the national electricity grid and petroleum products
(Tiruye u.c., 2021; Wolde u.c., 2020). The heavy dependence on traditional biomass in Ethiopia
is leading to different environmental, health, and economic problems including deforestation, soil
erosion, water pollution, and indoor air pollution (Wassie, 2020).

Biomass and biomass wastes can be made into high-density, energy-efficient briquettes through
densification. As a renewable energy source, the densification of biomass into briquettes has
shown the potential to alleviate cooking energy poverty and offer environmental and economic
benefits in many developing countries (Akowuah u.c., 2012; Hakizimana un Kim, 2016; Kpalo
u.c., 2021, 2020). Biomass briquette production can be implemented at a small scale and will be a
business idea for micro and small enterprises. So, in addition to environmental benefits, similar
studies can contribute a lot to economic growth and social harmony by creating job opportunities
for many jobless youths in Ethiopia. Binder has a remarkable role in determining the binding, and
calorific. The manufacture of briquettes depends heavily on the briquette binder. The quality of
the briquette binder has an impact on both the quality and performance of briquettes. There are
three types of binder used in the briquetting process: organic, inorganic, and composite. Organic
binders have several great benefits, including strong bonding, efficient burning, and little ash. The
inorganic binders provide several great benefits, including a large supply, low cost, exceptional
thermostability, and good hydrophilicity. However, a key issue brought on by the use of inorganic binders is related to the considerable increase in ash. The composite binders are made up of at least two binders, each of which serves a particular purpose (Zhang et al., 2018). Additionally, the most crucial parameter is the briquette's calorific value. According to Lubwama et al., briquette made from waste materials like rice husk has a calorific value close to 14.69 MJ/kg. (Lubwama, 2020).

In this study, avocado peels are added to textile solid wastes to improve their capacity to bind, but it also boosts the calorific value, raising it to 17.28 MJ/kg.

In this work, we demonstrated how biomass briquettes made from industrial solid wastes (sludge and cotton residue) using avocado peels as a binder can effectively handle both the energy crisis and environmental issues. The sludge, cotton residue, avocado peels, and the produced biomass briquettes were characterized using different physicochemical and spectroscopy technics.

2. Methodology

2.1. Collection of samples

Sludge samples were collected from Hawassa Industrial Park. The water treatment plant produces 5000 kg of sludge per day, which makes it a sustainable resource for making briquettes. The cotton residue was collected from the leftover textile products of MNS Manufacturing PLC. Each day, on average 1200 kg of cotton waste is generated, which is a sustainable resource for making biomass briquettes. These wastes are sold to the local population at a reasonable price. In addition, the avocado peel wastes were collected from selected juice houses in Addis Ababa city. Figure 1 shows the raw materials used for making the briquette: sludge, cotton residue, and avocado peels, respectively.
2.2. Sample Characterization

2.2.1. Proximate Analysis

i) Moisture Content (MC)

Moisture content is the amount of water present in the sample. The moisture content of 2 g of each sample was determined using ASABE, 2003 method (Ikelle et al., 2020) in triplicate. Samples were dried in an oven set at a temperature of 110 °C for 4 hours and cooled in desiccators for half an hour to prevent further absorption of moisture. The samples were then weighed. The moisture content of each sample was calculated using equation (1).

\[ MC = \frac{A}{B} \times 100\% \]

Equation (1)

where A is the weight of oven-dried samples, B is the weight of sun-dried sample

ii) Volatile Matter (VM)

The volatile matter of each sample was determined using ASTM, 2003 method (Ikelle et al., 2020) in triplicate. A 2 g of each sample was placed in a muffle furnace set at a temperature of 550 °C
for 10 minutes and then weighed after cooling it in a desiccator for half an hour. The volatile matter was estimated using equation (2).

\[ VM = \frac{B}{C} \times 100\% \] .......................... (2)

where B is the weight of the sample after it has been in the furnace for 10 minutes and C is the weight of oven dried sample.

iii) Ash Content (AC)

Ash is a non-combustible component of biomass. The ash content of each sample (2 g) was determined using the AOAC, 1999 method (Olusanya u.c., 2020) in triplicate. The samples were placed in a muffle furnace and heated at 550 °C for 4 hours. Then the crucibles were taken out from the furnace and put into the desiccators to cool for an hour. After cooling, the weight was used to determine the ash content and was calculated using equation (3).

\[ AC = \frac{D}{B} \times 100\% \] ............................. (3)

where B is the weight of the oven-dried sample and D is the weight of the ash after furnace heating.

iv) Fixed Carbon Content (FC)

Fixed carbon is the total amount of carbon used for the production of heat energy of the fuel during combustion of the biomass briquette (Marreiro u.c., 2021). The percentage of fixed carbon was calculated using equation (4) by deducting the sum of percentages of moisture content (MC), volatile matter (VM), and ash content (AC) from 100%.

\[ FC = 100\% - (MC + VM + AC) \times 100\% \] .......................... (4)
2.2.2. Ultimate analysis

i) Heavy metal determination of feedstocks

Samples that had been sun-dried (sludge, avocado peels, and cotton residue) were then dried in an oven at 110 °C until they attained a constant weight, ground into fine particles for homogenization, and passed through a 90 µm sieve. The sample preparation procedure for heavy metal analysis was carried out according to EPA 3050B (Cittadino u.c., 2020). 20 mL of aqua regia (HNO₃: HCl =1:3 volume ratio) was used to digest 5 g of the dried sample over the course of 24 hours. A sample was cooked for 2.5 hours in 500 mL of the solution prepared by adding up to 400 mL of distilled water. After that, the solution was filtered using the Whatman number one filter paper. The filtrates were then collected to determine the concentration of heavy metals (Pb, Cd, Cr, Ni, Cu, Zn, and Cd). The heavy metals analysis was performed using a 4200 MP-AES (Microwave Plasma Atomic Emission Spectrometry) instrument.

ii) Elemental analysis of samples

The elemental analysis was performed using EA 1112 Flash CHNS/O- analyzer. The sun-dried samples were subjected to oven drying for 4 hours in GX-65B followed by grinding using RRH-200 grinder. The samples were then sieved with a 90µm sieve to make them ready for analysis.

2.3. Briquette Production

Collected industrial solid waste sludge, cotton residue, and avocado peels were sun-dried for a week in the open air. The process of carbonization was carried out in oxygen-limited conditions inside the furnace (Nazari u.c., 2020). After being fully dried, the sample was carbonized in a muffle furnace for 30 minutes at 500 °C. After it was cooled, the carbonized samples were grinded using RRH- 200 grinder. Avocado peels were employed to strengthen the binding, it also improved
the biomass briquette’s compactness, strength, and calorific value. Sludge to cotton residue compositions were prepared at weight percent ratios of 100:0, 90:10, 80:20, 70:30, 60:40, and 50:50, respectively. The same amount of binder and 50 g of avocado peels were added to each mixture. Avocado peels are used in a 1:5 ratio with sludge and cotton residue to produce a total mass of 3 kg. The three raw materials were mixed manually and a slurry is formed using 150 mL of water. Then a slurry was transferred into a briquetting machine (hand press molder) to produce a cylindrical beehive briquette with 12 holes at the center having 13 cm diameter and 4 cm length. It was then sun-dried for two weeks. To examine its potential as a biofuel for heating and cooking, the dried biomass briquettes were subjected to proximate analysis, ultimate analysis, and combustion testing. Figure 2 shows a flow chart of briquette production from biomass sludge, cotton residue, and avocado peels.

Figure 2: Flow chart for production of biomass briquetting from solid wastes
2.4. Calorific value and bulk density determination

2.4.1. Calorific value determination (CV)

For the determination of the calorific value, the higher heating value (HHV) was measured by an automatic bomb calorimeter, 6200 Oxygen Combustion Bomb Parr (Thapa un Engelken, 2020). 1 g of the sample was transferred into an ignition cup, wrapped with a fuse wire using cotton thread, and sealed before entering into the bomb calorimeter. The bomb calorimeter was put in a static jacket containing 2 L of water and 30 atmospheres of oxygen before being connected to the energy source. The calorific value was displayed on the screen of the calorimeter in MJ/kg units after combustion had occurred in roughly 15 minutes. The calorific value was calculated using equation (5);

$$H_c = \frac{W T - e_1 - e_2 - e_3}{m}$$  \hspace{1cm} \text{(5)}$$

where $H_c$ is the Gross heat of combustion, $T$ is the observed temperature rise, and $W$ is the energy equivalent of the calorimeter being used. Moreover, $e_1$ refers to the heat produced by burning the nitrogen portion of the air trapped in the bomb to form nitric acid, $e_2$ refers to the heat produced by the formation of sulfuric acid from the reaction of sulfur dioxide, water, and oxygen, $e_3$ indicates the heat produced by the heating wire and cotton thread, and $m$ is mass of a sample.

2.4.2. Bulk density determination (BD)

Bulk density is the density of a material when packed or stacked in bulk. Density depends on the solid density, geometry, size, surface properties, and the method of measurement (Attarzadeh u.c., 2020). Denser items are preferred in terms of handling, storage, and transportation. In comparison
to briquettes with lower bulk densities, those with higher densities can produce more heat energy. The BD was determined after two years of drying in the open-air using equation (6).

\[ BD = \frac{M}{V} \]  

\( BD \) is the density of the sample (Kgm\(^{-3}\)), and \( V \) is the volume of the sample (m\(^3\)).

**2.5. Combustion test**

2.5.1. Ignition time (IT)

The dried briquettes ignited when placed straight on the fired electrical stove. The electrical stove was left open from the beginning of ignition until it entered into its steady state burn phase. Compared to highly compacted briquettes, less compacted ones are more likely to ignite.

2.5.2. Burning time (BT)

Burning time is the time required to burn the given sample in the given duration of time (Ikelle u.c., 2020). Some samples burn in a short time but others may require a longer time to complete their combustion. Burning time was estimated by keeping track of the interval between the starting and ignition ending time using a stopwatch.

2.5.3. Burning rate (BR)

The burning rate determines the rate at which a certain mass of fuel briquette is combusted in a given time interval (Kpalo u.c., 2020). The fuel-burning rate was determined according to Ikelle et al.,(2020) (Ikelle u.c., 2020). A briquette sample of known weight was placed on wire gauze (briquette stove) for ignition. The briquette’s burning rate was monitored every 5 minutes during the combustion process until it was completely burned and a constant weight was obtained. BR was calculated using equation (7).
where BR is the burning rate (g/min), W1 is the initial weight of fuel before cooking (g), W2 is the final weight of fuel after cooking (g), and T is the total burning time (minute). Figure 3 demonstrates the final produced briquette, which has 12 holes, and when it was used for heating.

![Briquette and Briquette Use](image)

**Figure 3:** Burning test of briquettes, a) Produced briquette, and b) Application of briquette for heating

### 3. Results and discussion

#### 3.1. Proximate analysis of raw biomasses

As can be seen from Figure 4, the moisture content of textile sludge was higher than the cotton residue and avocado peels on a dry basis of biomass. This indicated that the amount of water in textile sludge was higher than that in cotton residue and avocado peels. Thus, this implies that removing the moisture from textile sludge takes more time and energy than it does from cotton residue and avocado peels. The volatile matter of cotton residue was greater than textile sludge and avocado peels on the dry basis of the biomass. This indicates that as compared to industrial sludge and avocado peels, gas emissions from cotton residue were higher, and when a briquette containing...
more cotton residue burns, more amounts of gases are released into the environment. Textile sludge had a larger amount of ash content than cotton residue and avocado peels. This indicates that a large portion of the textile sludge is inorganic and is not converted into energy during the combustion of the biomass briquette. To limit the excessive ash generation and produce the desired briquette, a much greater amount of cotton residue was added to the mixture.

![Proximate analysis of raw biomass (sludge, cotton residue, and avocado peels). AC refers to ash content, VM refers to volatile matter, FC refers to fixed carbon, and MC refers to moisture content.]

Figure 4: Proximate analysis of raw biomass (sludge, cotton residue, and avocado peels). AC refers to ash content, VM refers to volatile matter, FC refers to fixed carbon, and MC refers to moisture content.

3.2. Proximate analysis of sludge to cotton residue ratio of biomass briquettes

Figure 5 indicates the proximate analysis of the briquettes formed from different ratios of sludge to cotton residue at a fixed amount of binder. The moisture contents of raw sludge were higher than that of the biomass briquette produced at different ratios as shown in Figures 4 and 5. The carbonization process that took place during briquette production is what caused the decrease in moisture levels of the formed briquettes. The amount of moisture content in the briquette decreases
as the composition ratio of sludge decreases from 100% to 50%, while the composition ratio of
cotton residue increases from 0% to 50% in the fixed mass of avocado peels. As shown in Figure
4, the raw materials, sludge, avocado peels, and cotton residue contain considerable amounts of
volatile substances, making the briquettes made from them highly reactive fuel with a rapid
combustion rate. Among raw materials, the cotton residue has higher volatile matter than the
others, indicating that it can easily ignite when combusted. The amount of volatile matter can be
reduced significantly by carbonization (Marreiro u.c., 2021). Similarly, the carbonization process
decreases the volatile matter of produced briquettes more than that of the raw materials. As a result,
briquettes offer increased bulk density and heating values compared to raw materials.

Ash is the non-combustible component of biomass (Gruber u.c., 2021). The ash influences heat
transfer and oxygen diffusion to the surface during char combustion. Fuel with low ash content is
better suited for thermal utilization than fuel with high ash content. Ash content is highest in the
briquette with the highest ratio of industrial sludge to cotton residue (100:0), compared to the other
ratios. This implies that both the sludge's combustible content and its level of energy output are
quite low. The briquette formed at a 50:50 ratio contained a lower amount of ash content—it
provides a greater amount of energy than other proportions.

Fixed carbon is the total amount of carbon used for the production of heat energy in the fuel during
the combustion of biomass. The fixed carbon content increases when the composition changes
from 100:00 to 50:50. The briquette with a higher amount of fixed carbon can offer a more calorific
value. Generally, the ratio of 50:50 of sludge to cotton residue in the fixed mass of avocado peels
as a binder is preferable. Because it has lower moisture content, lower ash content, higher fixed
carbon, and lower volatile matter.
3.3. Ultimate analysis of the biomass briquette

3.3.1. Heavy metal determination

Heavy metals are threats to human beings when they are present in briquettes (Lau un Tsai, 2022). Most of them cause different health problems including respiratory issues, heart problems, and skin allergies. If their concentration in the briquettes exceeds is beyond the standard limit it causes environmental problems like damaging vegetables, water bodies, and plants and human health problems like respiratory problems, heart case problems, and some allergic problems on the skin.

The heavy metals in the sludge come from the dyeing of cloths and cotton residue and avocado peels absorb from the soil using their roots. Heavy metals present in raw materials are Pb, Cr, Cu, Zn, and Ni with a concentration in ppm below the standard limit, EPA method 1699 (ElGhamrawy, 2022).
Table 1: Concentration of heavy metals of biomasses and USEPA limitation

<table>
<thead>
<tr>
<th>Heavy metals</th>
<th>Concentration in ppm</th>
<th>USEPA Limit (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sludge</td>
<td>Cotton residue</td>
<td>Avocado peels</td>
</tr>
<tr>
<td>Pb</td>
<td>0.004</td>
<td>0.10</td>
</tr>
<tr>
<td>Cr</td>
<td>BDL</td>
<td>BDL</td>
</tr>
<tr>
<td>Cd</td>
<td>0.070</td>
<td>0.280</td>
</tr>
<tr>
<td>Cu</td>
<td>0.214</td>
<td>0.090</td>
</tr>
<tr>
<td>Zn</td>
<td>3.858</td>
<td>0.598</td>
</tr>
<tr>
<td>Ni</td>
<td>0.06</td>
<td>BDL</td>
</tr>
</tbody>
</table>

BDL- 0.0007 ppm (BDL- Below detection limit)

As shown in Table 1, the value of each heavy metal is below the USEPA's limit, and for some of them, it is also below the instrument's detection limit. As a result, the high concentration of these heavy metals has no negative effects on the environment or human health.

3.3.2. Elemental analysis of samples

Elemental analysis is a mechanism that is used to identify the composition of the different biomass samples (Masnadi u.c., 2014). After the samples were dried, the analysis was conducted using EA 1112 Flash CHNS/O- analyzer. The concentration of carbon in the sludge, cotton residue, and avocado peels was 15.67%, 43.71%, and 56.02% respectively. Similarly, the concentration of hydrogen in sludge, cotton residue, and avocado peels was 3.77%, 6.91%, and 7.10% respectively. The other elements only made up a very minor portion of it. The outcome shows that there was a lot of carbon in the samples, which is directly tied to energy.
3.4. Calorific value and bulk density determination

3.4.1. Calorific value determination (CV)

The higher heating value is the entire energy content released when the fuel is combusted in the
open air, including the latent heat contained in the water vapor, and therefore denotes the maximum
amount of energy potentially recoverable from a given biomass source (Ikelle u.c., 2020). The
calorific value of raw biomasses sludge, cotton residue, and avocado peels was 6.74 MJ/Kg, 16.70
MJ/Kg, and 24.6 MJ/kg, respectively. Industrial sludge has a lower amount of calorific value than
cotton residue and avocado peels. When examined in terms of calorific value, avocado peels have
an average calorific value that is significantly higher than cotton waste and industrial sludge. In
this work, biomass briquettes are produced using a waste-driven binder and a variety of industrial
solid wastes as source materials. Additionally, a binder made from avocado peels raises the energy
content of the briquettes. The energy value will rise if the briquettes include more sludge and less
cotton residue while maintaining the same amount of binder. Figure 6 shows the calorific value of
briquettes made with various ratios of sludge and cotton waste with a fixed amount of avocado
peels (50 g) as the binding agent. The briquette produced from 100% industrial sludge was shown
to have a lower calorific value than the briquette made from 50% cotton waste and 50% sludge,
which had the highest volatile matter content and lowest moisture content. The calorific value of
the 50:50 briquette can be effectively compared to the heating values of previously reported
biomass briquettes such as wheat straw (17.99 MJ/kg), rice husk (14.69 MJ/kg), sugar cane
bagasse (18.73 MJ/kg), and sugar cane straw (17.19 MJ/kg)(Erol u.c., 2010; Yin, 2011).
3.4.2. Bulk density determination (BD)

Bulk density is a measurement of the weight of solid fuel briquettes per unit volume that can be used to determine how much heat or strength they can provide (Tumuluru un Fillerup, 2020). The briquette with the highest bulk density should be chosen. As can be observed in Figure 7, bulk density increases as cotton residue increase at a constant amount of binder. Due to the fiber character of cotton residue, in addition to being used as a primary component, it also helps to improve the binding of briquettes. The 50:50 briquette achieved the highest bulk density and the longest burning time. Figure 7 demonstrates that briquettes with higher bulk density (50:50) burn at lower rates, indicating that fewer briquettes will be used per minute and will last longer when used.
Figure 7: Bulk density determination of biomass briquettes of sludge and cotton residue. S refers to industrial sludge and CR refers to cotton residue.

3.5. Combustion test

Ignition time indicates how much time it takes to begin the briquette will be ignited with a steady-state combustion (Yulei u.c., 2020). It takes longer to ignite the combustion if the briquette's particles are tightly packed (Olagbade u.c., 2019). Table 2 shows that the igniting time for briquettes made from various compositions ranges from 7.02 minutes (100:0) to 12.15 minutes (50:50). As the quantity of cotton residue rises, the briquette's density rises and the particle arrangement gets more compact—which results in increasing the ignition time. For example, the 50:50 briquette needs more time to begin the combustion than the 100:0 briquette.

As shown in Table 2, the burning time of briquettes ranges from 35 to 95 minutes in the ratio of 100:0 to 50:50. This suggests that higher cotton residue mix (50:50) briquette burns longer when used, for example for cooking purposes. Cotton residue raises the briquette's density, which
lengthens the burning time. The boiling test of water utilizing waste-derived briquettes is comparable to other energy sources. On a 50:50 briquette, one litter of water boiled for 17 minutes. It took 16 minutes to boil the same quantity of water using the same amount of regular charcoal.

According to Oladeji reports, rice husk that had been bound with glue and starch took 28 minutes to boil water, but sawdust briquettes bound with glue and starch took 26 and 28 minutes, respectively, to reach boiling point. Melon shell briquettes that were bound with glue and starch took 22 and 24 minutes, respectively, to boil the water, but cassava peel briquettes that were bound with glue and starch took 20 and 22 minutes, respectively. To boil the same volume of water, kerosene and firewood took 14 and 18 minutes, respectively. Thus, earlier findings demonstrated that biomass briquettes are reliable substitutes for kerosene and firewood (Oladeji, 2013).

The burning rate is an indicator of the intensity of the combustion, i.e., the rate of fuel combustion influences the rate at which energy is delivered (Ikelle u.c., 2020). The biomass briquette will be consumed quickly because of the shorter burning time caused by the greater burning rate. As Table 2 indicates the burning rate of the briquette decreases as the amount of cotton residue increases while the amount of industrial sludge decreases. This shows that the interconnection of particles increases and it takes more time to burn in the composition 50:50 ratio of sludge and cotton residue than 100:0.
Table 2: Combustion test of briquettes

<table>
<thead>
<tr>
<th>No.</th>
<th>Composition ratio S:CR</th>
<th>Ignition time (min)</th>
<th>Burning time (min)</th>
<th>Burning rate (g/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>100:0</td>
<td>7.02</td>
<td>35</td>
<td>8.57</td>
</tr>
<tr>
<td>2</td>
<td>90:10</td>
<td>7.46</td>
<td>46</td>
<td>6.52</td>
</tr>
<tr>
<td>3</td>
<td>80:20</td>
<td>8.24</td>
<td>56.5</td>
<td>5.31</td>
</tr>
<tr>
<td>4</td>
<td>70:30</td>
<td>9.20</td>
<td>65</td>
<td>4.61</td>
</tr>
<tr>
<td>5</td>
<td>60:40</td>
<td>10.30</td>
<td>73</td>
<td>4.11</td>
</tr>
<tr>
<td>6</td>
<td>50:50</td>
<td>12.15</td>
<td>95</td>
<td>3.16</td>
</tr>
</tbody>
</table>

S= Sludge, CR= Cotton residue

4. Conclusion

This study revealed that biomass briquettes produced from the mixture of industrial sludge and cotton residue using avocado peels as binders were identified as potential substitutes for charcoal, firewood, and petroleum-based fuels for domestic uses as a source of energy in Ethiopia. The briquette made from a higher proportion of cotton residue (50:50) was found to be the most effective composition over other proportions considered in the study. So, as the composition of cotton residue in the proportion increases the calorific value, fixed carbon content, bulk density, and burning time of the briquette increase. Utilization of industrial wastes as a source of biomass briquette delivers alternative energy, and reduce indoor air pollution, and respiratory and infectious disease that occurred due to the release of smoke during cooking. Moreover, the addition of avocado peels as a binder significantly improved the briquette's binding and heating properties. Therefore, biomass briquette produced from industrial sludge and textile solid waste can solve the
rural and urban household energy shortage by supplying alternative renewable energy. Additionally, it prevents forest degradation and offers young people employment possibilities in the country.

**Declaration of Interest**

The authors declare that there is no conflict of interest regarding the publication of this paper.

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**Authors’ contributions**

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**Availability of data**

All data generated or analyzed during this study are included in this published article.
Compliance with ethical standards

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