Porous Maize Stalk Cellulose Fiber-Reinforced Geopolymer Composites for Heat Insulation at the Bottom Side of a Local Electric Stove

Addisu Workiye*, Eyassu Woldesenbet

Department of Mechanical Engineering, Addis Ababa Institute of Technology, Addis Ababa University, Ethiopia

Received 30 September 2021; received in revised form 24 January 2022; accepted 25 January 2022

DOI: https://doi.org/10.46604/peti.2022.8589

Abstract

The objective of this work is to develop porous maize stalk cellulose fiber-reinforced geopolymer composites for heat insulation on the bottom side of an electric stove using the solid impregnation method. Heat loss measurement is conducted using an infrared thermometer. Moreover, the temperature effect on the composites is investigated. The maize stalk cellulose fibers are very essential to anticipate the cracking phenomenon generated by high temperatures. The degradation of the fibers causes the formation of small cavities in the matrix, and thus leads to high temperatures. The experimental result shows that it takes 22 minutes to boil water using the proposed electric stove, whereas it takes 29 minutes using the existing local electric stove. By using the proposed electric stove to boil water, 113,793,148.104 KWh of energy per year at the national level can be saved.

Keywords: geopolymer, kaolin, insulation, composites, organic oil

1. Introduction

Environmentally friendly heat insulation materials are critical (especially for the structure of buildings and the components of stoves, furnaces, etc.) to sustain development in this era of construction and manufacturing industries. Geopolymer is a non-flammable material and has potential for the application of thermal insulation [1]. Geopolymer, which is a novel family of cementitious materials, is environmentally friendly due to less emission of CO_2 and less energy consumption during its formation. It is synthesized from different types of aluminosilicate materials.

Most of the existing local electric stoves have been manufactured by small facilities without any regard for energy efficiency standards and safety. These stoves have many disadvantages, such as poor insulation, lack of temperature regulation, bulkiness, and overall poor design that encourages wastage of heat. It is therefore vital to develop heat insulation materials for the stoves. Energy can be saved by applying locally available materials, such as clay, wood ash, and maize stalk cellulose fibers, for heat insulation at the bottom of local electric stoves.

The heat loss from the bottom side of a locally made electric stove is high due to the absence of heat insulation. The purpose of this study is to develop eco-friendly porous maize stalk cellulose fiber-reinforced geopolymer composites from locally available materials for heat insulation at the bottom of local electric stoves to save energy.

The study is organized as follows. Section 2 presents the detailed literature review. Section 3 describes the materials and methodology used to conduct the research work. Section 4 presents the results and discussion of the finding. Finally, the study is concluded.

* Corresponding author. E-mail address: natanium27@gmail.com

2. Literature Review

Kaolinite is among the most common minerals. It is a white and fine particle, which is a plate-like hydrated aluminum silicate crystalline mineral formed over millions of years by the hydrothermal decomposition of granite rocks [2]. Normally, suitable kaolin contains 70-73% of SiO_2, 18-20% of Al_2O_3, 0.4-1% of Fe_2O_3, and 0-0.8% of TiO_2, without MnO [3]. The main component of kandites is kaolinite, whose chemical formula is $A1_2Si_2O_5(OH)_4$ or $A1_2O_3{\cdot}2SiO_2{\cdot}2H_2O(AS_2H_2)$. The crystalline structure of kaolinite is classified as a two-layered sheet silicate. One layer contains aluminate groups ($AlO_4(OH)_2$ - octahedrons), and the other contains silicates (SiO_4 - tetrahedrons) [4-5]. Metakaolin is prepared from kaolin clay by calcination under well-controlled conditions and transformed into a highly reactive amorphous aluminosilicate [6]. Metakaolin is formed from very pure kaolin clay by calcination at low temperatures (700-800°C). The transformation of kaolin to metakaolin is an endothermic process, where a large amount of energy is required to remove the chemically bonded hydroxyl ions [7].

$$Al_2Si_2O_5(OH)_4 \text{----} Al_2Si_2O_7 + 2H_2O \text{ [8]} \tag{1}$$

The main requirement for developing a stable geopolymer is that the raw materials must be extremely amorphous, have adequate reactive glassy content with low water requirement, and can free aluminum. The alkaline solution is among the valuable things in producing a geopolymer. The alkaline activators such as sodium hydroxide, potassium hydroxide, sodium silicate, and potassium silicate are used to activate aluminosilicate materials. Geopolymer is synthesized by mixing the aluminosilicate materials with strong alkaline solutions [9-10]. It has advantages such as high mechanical strength, good thermal and chemical stability, etc. [11-13].

Recent research suggested developing highly porous and open-cell geopolymers by emulsion templating with vegetable oils for applications of acoustic and thermal insulators [14-16]. Moreover, H_2O_2, aluminum powder, and silica fume are often chosen as blowing agents to develop alkali-activated foams. The decomposition of H_2O_2 generates oxygen gas inside the cement matrix, resulting in the formation of macrospores in different sizes and shapes. However, the decomposition of aluminum powder and silica fume generates hydrogen gas. The potential problems arise when the porous structure produced by foaming agents is stable only for a short time and then falls for a while (before the bonding process—geopolymerization) [17]. Moreover, the repeatability of the results obtained on an industrial scale is still regarded as a challenge of using geopolymer materials as insulators in buildings and other applications [18].

Table 1 Previous studies using vegetable oils for the formation of highly porous geopolymers

Precursor	Alkali ion	Oil type and the amount added	H_2O_2 wt% added	Method	Ref.
Fly ash	NaOH	Corn (4-12 wt%)	-	Direct incorporation	[19]
Metakaolin	KOH	Olive (20-45 wt%)	0-20 wt%	-	[20]
Metakaolin	KOH	Sunflower, canola, and olive (0-10 wt%)	About 6 wt%	Pre-emulsification	[21]
Metakaolin	NaOH	Soy bean (20 wt%)	6 wt%	Direct incorporation	[22]
Metakaolin	NaOH	Canola (2-6 wt%)	0.5-1.5 wt%	-	[23]
Metakaolin and fly ash	KOH	Sunflower (25 wt%)	6 wt%	-	[24]

Table 1 shows the materials, amount incorporated, and methods used in previous studies for the formation of highly porous geopolymers. Vegetable oils were used for emulsion templating with saponification reactions. The three main processing methods of adding the organic liquid into the alkali-activated and ordinary Portland cement materials are direct incorporation into the reactive slurry, pre-emulsification ahead of the addition of the solid precursor, and solid impregnation ahead of the addition of the reactive mixture. These process routes are clearly described in Fig. 1. Usually, water is used to mix Portland cement powder, whereas alkaline silicate aqueous solutions are used to mix alkali-activated material powder [25]. The organic liquid can be added at different steps of composite manufacturing, using distinct approaches.

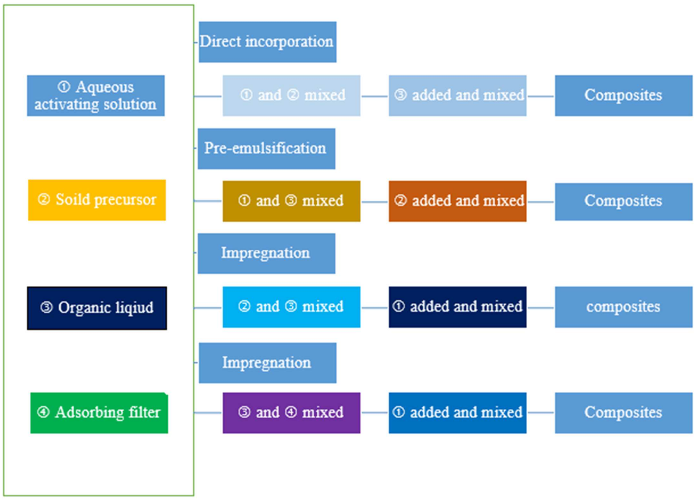

Fig. 1 Three processing routes of adding the organic liquid into alkali-activated materials or Portland cement [25]

In Ethiopia, the locally manufactured electric stoves are predominantly open resistor types and are used in households mainly for cooking or reheating "Wot", making tea, heating water for washing, etc. Cafes, restaurants, and hotels use these stoves rarely in the absence of kerosene, wood fire, and cylinder-based gas stoves [26].

The resistance of the heating element used in the stoves is measured during the assessment. It varies from 31.1 Ω to 39.9 Ω, which corresponds to the power diameter ($P = V^2 / R$), at 220 V of 1.6 KW to 1.2 KW respectively. The average power demand of the stoves is estimated to be 1.4 KW. The locally manufactured electric stoves use either single- or double-heating elements. The most common one, the 22 cm-diameter stove, is produced using single resistors with a diameter of 0.6 or 0.7 mm and a length of about 90 cm.

Most of the existing stoves in Ethiopia (Fig. 2) have been manufactured by small facilities without any regard for energy efficiency standards and safety. The stoves have many disadvantages, such as poor insulation, lack of temperature regulation, bulkiness, and overall poor design that encourages wastage of heat.

The heat loss intensities are caused by conduction, convection, and radiation at the bottom and the top of the stoves. There is significant heat loss at the bottom of the existing locally made stoves through radiation. The heat intensity measured at the bottom of the 22 cm-diameter stove reaches 395°C at the end of a cold-start test, for a duration of 27 minutes. The intensity further reaches 398°C at the end of a hot-start test. The temperature at the top of the stove on a vertical test plane 1.5 cm from the part body reaches 217°C at the end of the hot start test phase.

The input energy (Q_{in}) is the electric energy and is equal to the sum of the output energy (thermal, (Q_u)) and the losses.

$$\text{Input energy } (Q_{in}) = \text{Utilized energy } (Q_u) + \text{Energy loss } (Q_I) \tag{2}$$

The useful output may be electric power, mechanical work, or heat. The utilized energy is the properly consumed energy of the electric stove for cooking and it is determined as:

$$Q_u = (m_i - m_f) \times C_v + (T_f - T_i) \times m_f C_p \tag{3}$$

where Q_u is the heat utilized (kJ), m_i is the initial weight of water (g), m_f is the final weight of water (g), C_v is the water vaporized heat (2.260 kJ/g°C), T_f is the final water temperature (°C), and T_i is the initial water temperature (°C).

$$\text{Energy conversion efficiency} = \text{Useful output energy (utilized energy)} / \text{Input energy} \tag{4}$$

Fig. 2 An existing local electric stove [27]

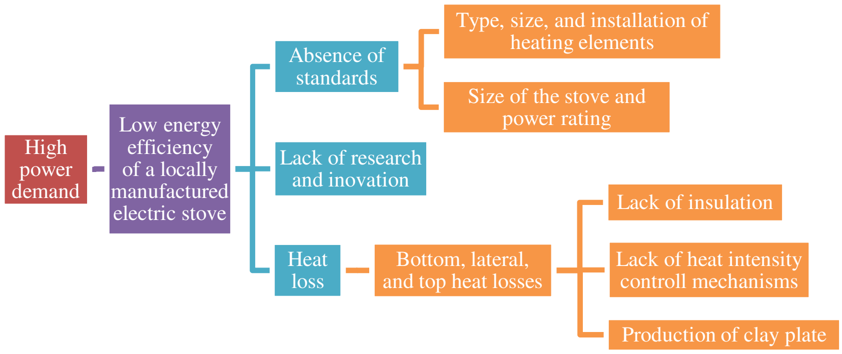

Fig. 3 The problem tree of a locally manufactured

The potential problems of a locally manufactured electric stove are illustrated in Fig. 3. To solve the heat loss problems, bottom heat insulation enclosure and clay plate support have been designed. Heat insulation using locally available materials are applied to minimize the heat loss due to radiation and conduction from the clay plate. The insulators could be fiberglass, lightweight pumice, or wood ash. Heat intensities at the bottom of the prototype stove have been reduced to 190°C. Ethiopian Standard ES 3406:2007 related EN 60335-2-6:2015 was used for measuring the performance of electric ranges, hobs, ovens, and grills for the households. The projected peak power demand and energy consumption of local stoves, including losses, in the 2019 Ethiopian fiscal year (EFY) are estimated to be 887 MW and 3,794 GWh respectively [27]. However, further research work is still needed to reduce the heat loss. Maize stalk cellulose fiber-reinforced calcined kaolin clay-based geopolymer composite has been developed in previous work [28]. What makes this research work different is that the porous network is developed by using the solid impregnation method with organic oils for the insulation at the bottom of a local electric stove.

3. Materials and Methods

This study emphasizes Ethiopian kaolinitic clay mineral and its ability to form a cement geopolymer after thermal and alkaline activation. Kaolinitic clay is abundantly available in Ethiopia and is used in the production of brick and ceramic industries. The raw material for this study is collected from Chagal around D/Libanose district in the North Shewa zone, as shown in Fig. 4. In this study, the chemical composition analysis of Chagal clay soil is done by atomic absorption spectrometer at the geological survey of Ethiopia. Apart from atomic absorption spectrometer (AAS), the $LiBO_2$ fusion, HF attack, gravimetric, and colormetric methods are carried out for the samples of Chagal clay soil to perform the complete silicate analysis at the geological survey of Ethiopia.

Calcination is conducted at Kombolcha Polytechnic College using a thermocomputer TC 60 type FL350 developed by Kilns & Furnaces Ltd. The maximum temperature of calcination is 1300°C. The kaolin clay calcined at 850°C is used as the precursor material. Sodium silicate with a factor of 2.17 (SiO2/Na2O) and NaOH M12 concentration are used as an alkaline activator in this research work [28]. Besides, the maize stalk cellulose fibers extracted from maize stalks using the retting process are used as reinforcement. The fiber surface morphology is modified using sodium hydroxide to reduce its hydrophilic behavior as shown in Fig. 5, where the tensile strength and Young's modulus of the single cellulose fiber are determined using the ASTM D 3822 standard. 1184 MPa and 16 GPa are achieved for tensile strength and Young's modulus respectively [28]. The sodium hydroxide treated short maize stalk cellulose fibers with a length of 2 mm are used as reinforcement in this research work.

Fig. 4 Clay raw materials collected from Chagal in Ethiopia

Fig. 5 Sodium hydroxide treated maize stalk cellulose fibers

3.1. Solid impregnation

The solid impregnation method is used to develop porous maize stalk cellulose fiber-reinforced geopolymer composites. This processing method is applied to introduce organic liquid into cementing materials. Usually, the alkaline-activated material powder is activated with an alkaline silicate aqueous solution.

The solid impregnation method consists of the process of impregnating solid powder with organic liquid. The cementing precursor itself is impregnated with the organic oil and then mixed with the activating solution. The organic liquid is adsorbed onto calcined kaolinite clay; the particle size of charcoal ash is 75 μm in the early stage. Then, dried maize stalk cellulose fibers (5 wt%) are added and mixed in a high shear mixer for 2 minutes at a high speed of 800 rpm, and sodium water glass is slowly added to the precursor and mixed until complete integration occurs. After that, the slurry is poured into a high-strength plastic mold and sealed using a plastic cover, being remolded after two days and cured after 28 days. The developed porous maize stalk cellulose fiber-reinforced geopolymer composites are shown in Fig. 6. Table 2 summarizes the materials, amount incorporated, and the method used for the development of porous maize stalk cellulose fiber-reinforced geopolymer composites with vegetable oils.

Table 2 Development of porous geopolymer composites using vegetable oils

Aluminosilicate source		Oil type	Fiber type	Alkali ion	Method used
Calcined kaolin (50 wt%)	Coal ash (50 wt%)	Sunflower (2-6 wt%)	Maize stalk cellulose fiber (5 wt%)	NaOH	Solid impregnation

3.2. Thermal behavior of maize stalk cellulose fiber-reinforced geopolymer composites

Thermogravimetric analysis is performed with SDT Q600 V20.9 build 20 (thermobalance universal V4.5A) developed by TA Instruments, Inc. The device consists of an electronic balance which is placed inside an oven. Also, the device is coupled with a control microprocessor. 35.5980 mg of samples in the form of fine powder are slid and placed inside the analysis equipment for testing, and then calcined to 750°C, increasing 10°C per minute. Moreover, the temperature effect on the geopolymer composites is investigated. The composite samples with the size of 15 × 10 × 600 mm (w × h × l) are heated in a ventilated furnace to assess the effect of temperature on the surface and microstructure. The heating process is carried out at a rate of 6°C/min for a duration of one hour until the target temperatures of 200°C, 400°C, 600°C, and 800°C are recorded.

3.3. Proposed electric stove

The heat loss at the bottom of the electric stove in a form of radiation constitutes the major portion of the heat loss. No heat insulator is used between the clay plate and the body of the 22 cm-diameter stove. The existing local stove needs modification due to the following limitations: lack of standards on the product, lack of heat intensity control mechanisms and the switch to control the heat level, the gap between the cookware base and the heating elements, frequent burning of a heating element due to spillage, poor quality of the heating elements, wear of the clay plate and the framework, sub-optimal/poor and inefficient design and workmanship, etc. [29].

In this study, maize stalk cellulose fiber-reinforced calcined kaolin-based geopolymer composites with a thickness of 25 mm are used as a thermal insulator at the bottom of the clay plate to reduce the amount of heat loss as shown in Fig. 6. The grooves made on the clay plate are made with four concentric circles having a “U” shaped section. The depth and width of grooves are 8 to 11 mm and 5 to 6 mm respectively. The wound resistor with a diameter of 4-4.5 mm rests at the bottom of the grooves. This layout lets much of the heat from the resistor be transmitted to the clay plate through conduction. Two ceramic connectors are used to connect the “Woraj” (connecting leads) coming from the resistor to a switch. The connecter is attached at the bottom of the thermal insulator plate. The prototype uses a bimetal strip with a knob having five levels to achieve heat intensity control. Heat intensity control enables users to utilize the heat retained in the stove and allows slow cooking. The proposed local electric stove heat insulation setup is shown in Fig. 7.

Fig. 6 Heat insulation composite

Fig. 7 Heat insulation setup

3.4. Heat level measurement using an infrared thermometer

The heat level is measured at the top, bottom, and side of the stove using an infrared thermometer for one hour with 10-minute time intervals as shown in Fig. 8. Besides, the time of boiling water is also recorded. The investigation is conducted by boiling a liter of water and measuring the required amount of time and energy to boil up the water.

Fig. 8 Heat level measurement on the proposed electric stove

4. Results and Discussion

One of the most significant findings of this work is that the calcined kaolin clay collected from Chagal in Ethiopia can be used as a potential precursor material to develop the geopolymer as a matrix for porous maize stalk cellulose fiber-reinforced composites. Chagal clay is calcined in the laboratory from the room temperature to 500°C at a rate of 7.9°C/min and from 500°C to 950°C at a rate of 7.9°C/min for two hours to obtain the precursor material. Table 3 shows the chemical or the oxide compositions of the sampled soils, which are characterized by $LiBO_2$ fusion, HF attack, gravimetric, colormetric, and AAS methods. The result confirms the availability of enough SiO_2 and Al_2O_3 to be used as a precursor for geopolymer formation. Since the calcination temperature rate and cooling rate are slow, the kaolinite clay has enough time to eliminate the crystalline bound water of hydration from the whole material in the furnace. The clay is in its most reactive state when the calcination temperature leads to a loss of hydroxyls and results in a collapsed and disarranged structure.

The result of differential scanning calorimetry-thermogarvimetric analysis (DSC-TGA) is shown in Fig. 9. The first peak under 126.40°C is related to the dewatering process. This process is related to the adsorbed free water or evaporable water on the surface and the porosity of the samples. At the second peak under 284.53°C, thermal degradation occurs due to the decomposition of maize stalk cellulose fibers which generate a total of 15.61% weight loss.

Fig. 10 presents the pictures of maize stalk cellulose fiber-reinforced metakaolin-based geopolymer composite specimens exposed to 600°C and 800°C. It can be seen that metakaolin-based geopolymers are reinforced by the 2 wt% chopped maize stalk cellulose fibers which do not develop serious cracks on the surface of geopolymer composites. This indicates that maize stalk cellulose fibers are very essential to anticipate the cracking phenomenon generated by high temperatures. The degradation of the fibers causes the formation of small cavities in the matrix, and thus leads to high temperatures. Fume is observed during the degradation process as the temperature increases to 800°C.

Table 3 Chemical composition of Chagal clay soil samples (%)

Soil type	SiO_2	FeO_3	Al_2O_3	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5	MnO	H_2O	LOI
Chagal 1	52.82	8.84	15.80	11.14	5.80	1.70	1.22	0.75	0.21	0.2	0.15	2.84
Chagal 2	51.32	8.86	16.10	11.08	5.90	1.82	1.14	0.76	0.22	0.2	0.18	2.88

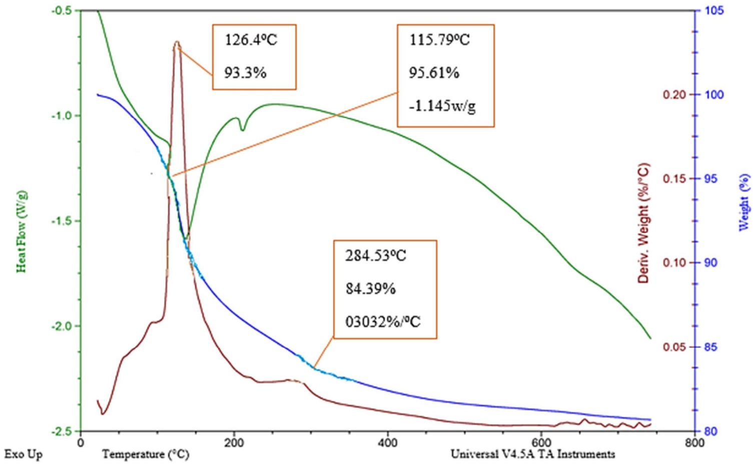

Fig. 9 DSC-TGA of maize stalk cellulose fiber-reinforced geopolymer composites

(a) Exposed to 600°C (b) Exposed to 800°C

Fig. 10 Maize stalk cellulose fiber-reinforced calcined kaolin-based geopolymer composites exposed to varying temperatures

The structure of the composites becomes more porous, and the expanded water vapor gets out without significant damage to the microstructure. Such degradation of the maize stalk cellulose fibers may be useful to the behavior of geopolymer composites under thermal exposure. At high temperatures, when water is not removed fast enough from the composites, internal vaporization may generate high pressure inside the matrix. The porosity and small channels built by the degradation of the maize stalk cellulose fibers may lower the internal vapor pressure and thus minimize the probability of cracking.

The existing local electric stove has several limitations in terms of heat loss, size, and lack of heat intensity control mechanisms according to the finding of Ethiopia Energy Authority [29]. The proposed electric stove uses porous maize stalk cellulose fiber-reinforced geopolymer composites as a thermal insulator which decreases the heat loss at the bottom. It is environmentally friendly and developed from locally available raw materials. The literature supports the potential of using organic oils to develop porous geopolymers from different precursors [19-24]. In this study, the porous network is formed by using the solid impregnation method with sunflower oil. The heat level at the top, bottom, and side is measured using an infrared thermometer for one hour with 10-minute time intervals. The result is shown in Fig. 11.

The measured heat level is 440°C, 63°C, and 62°C respectively. The result shows that the temperature level at the top increases and the temperature level at the bottom decreases when compared to the existing local stove. Moreover, the proposed electric stove has heat intensity control mechanisms and a switch to control the heat level. The size is also reduced to 100 × 260 × 260mm (h × l × w). The innovative contribution of this study is that the construction relevant material is applied to a non-construction work (i.e., the insulation for electric stoves).

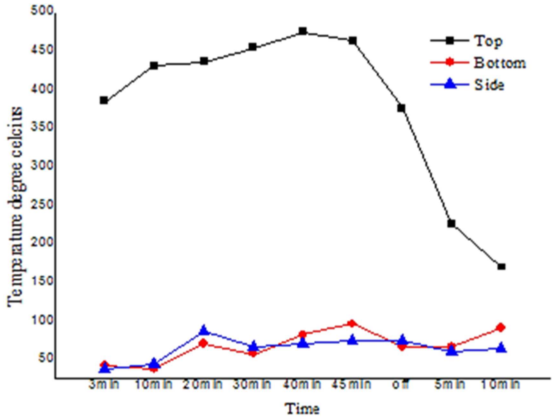

Fig. 11 Temperature level versus time

Table 4 Comparison of the insulation material, the heat level, and the time taken for boiling water

Stove type	Insulation material	Heat level (top)	Heat level (bottom)	Time	Ref.
Existing local electric stove	Without insulation	215°C	398°C	36 min	[27]
Existing local electric stove	Wood ash or lightweight pumice	217°C	190°C	29 min	[27]
Proposed local electric stove	Porous geopolymer composites	440°C	63°C	22 min	This study

Table 5 Comparison of the time and energy required for boiling water

Item	Existing stove	Proposed stove
Time taken	29 min (0.48 hr)	22 min (0.366 hr)
Power consumption	0.676 KWh	0.512 KWh
No. of stove (single)	635,212	635,212
Saved power per day	-	103920.68 KWh

Table 4 shows the comparison between the existing local electric stoves and the proposed local electric stove regarding the insulation material, the heat level, and the time taken for boiling water. The heat level at the bottom side of the proposed electric stove is reduced to 63°C, and the heat level at the top surface is increased to 440°C. This confirms that the porous maize stalk cellulose fiber-reinforced geopolymer composite is a better insulation material than wood ash or lightweight pumice.

Table 5 shows the comparison between the existing local electric stove and the proposed local electric stove regarding the time and energy required for boiling one liter of water. With the proposed electric stove, the amount of energy saved per year at the national level for boiling water is determined as follows.

$$\text{Total energy saved per year} = 103{,}920.68\ \text{KWh} \times 365\ \text{days} \times 3\ \text{times/day} = 113{,}793{,}148.104\ \text{KWh} \quad (5)$$

$$\begin{aligned}\text{Total amount of money} &= 103{,}920.68\ \text{KWh} \times 365\ \text{days} \times 0.5\ \text{birr} = 18{,}972{,}878.512\ \text{birr} \times 3 \\ &= 56{,}918{,}635.53\ \text{birr per year}\end{aligned} \quad (6)$$

5. Conclusions

Porous maize stalk cellulose fiber-reinforced geopolymer composites are successfully developed by using the solid impregnation method with vegetable oils, and are used as a thermal insulator at the bottom of the clay plate to reduce heat loss. The measured average heat loss at the bottom side within 45 minutes is 63°C. This value is the best when compared to the heat loss (190°C) under the cases using wood ash or lightweight pumice as thermal insulators. This confirms that the heat loss at the bottom side is below the thermal degradation temperature (284.5°C) of the maize stalk cellulose fibers inside the geopolymer matrix, as shown in the DSC-TGA results. Therefore, no fume or crack is observed on the surface of the geopolymer composites which are used as insulators.

The proposed electric stove has the following advantages: light weight, small size, and controllable heat intensity level. It takes 22 minutes to boil water using the proposed electric stove, whereas it takes 29 minutes to boil water using the existing local electric stove. This is due to the top surface temperature (440°C) on average of 45minutes. At the national level, 113,793,148.104 KWh of energy per year will be saved using the proposed electric stove to boil water.

Conflicts of Interest

The authors declare no potential conflicts of interest concerning the research, authorship, and/or publication of this article.

References

[1] J. Fen, et al., “Development of Porous Fly Ash-Based Geopolymer with Low Thermal Conductivity,” Materials and Design, vol. 65, pp. 529-533, January 2015.
[2] H. H. Murray, “Traditional and New Applications for Kaolin, Smectite, and Palygorskite: A General Overview,” Applied Clay Science, vol. 17, no. 5-6, pp. 207-221, November 2000.
[3] H. H. Murray, “Overview—Clay Mineral Applications,” Applied Clay Science, vol. 5, no. 5-6, pp. 379-395, March 1991.
[4] W. E. Worrall, “Clays: Their Nature, Origin and General Properties”, 1st ed., London: Maclaren and Sons, 1968.
[5] V. Srivastava, “Clays: Types and Applications,” Bulletin of the Catalysis Society of India, vol. 11, no. 5, pp. 56-77, 2012.
[6] G. Brindley, et al., “The Kaolinite-Mullite Reaction Series: II, Metakaolin,” Journal of the American Ceramic Society, vol. 42, no. 7, pp. 314-318, July 1959.
[7] V. M. Malhotra, et al., “Pozzolanic and Cementitious Materials,” 1st ed., Amsterdam: Gordon and Breach, 1996.
[8] B. B. Sabir, et al., “Metakaolin and Calcined Clays as Pozzolans for Concrete: A Review,” Cement and Concrete Composites, vol. 23, no. 6, pp. 441-454, December 2001.
[9] B. Singh, et al., “Geopolymer Concrete: A Review of Some Recent Developments,” Construction and Building Materials, vol. 85, pp. 78-90, June 2015.
[10] S. H. Sanni, et al., “Performance of Alkaline Solutions on Grades of Geopolymer Concrete,” International Journal of Research in Engineering and Technology, vol. 2, no. 11, pp. 366-371, November 2013.
[11] W. D. Rickard, et al., “Performance of Solid and Cellular Structured Fly Ash Geopolymers Exposed to a Simulated Fire,” Cement and Concrete Composites, vol. 48, pp. 75-82, April 2014.
[12] T. Bakharev, “Resistance of Geopolymer Materials to Acid Attack,” Cement and Concrete Research, vol. 35, no. 4, pp. 658-670, April 2005.
[13] P. Palmero, et al., “Geopolymer Technology for Application-Oriented Dense and Lighted Materials, Elaboration and Characterization,” Ceramics International, vol. 41, no. 10, pp. 12967-12979, December 2015.
[14] C. Bai, “High-Porosity Geopolymer Foams with Tailored Porosity for Thermal Insulation and Waste Water Treatment,” Journal of Materials Research, vol. 32, no. 17, pp. 3251-3259, September 2017.
[15] Z. Zhang, et al., “Geopolymer Foam Concrete: An Emerging Material for Sustainable Construction,” Construction and Building Materials, vol. 56, pp. 113-127, February 2014.
[16] C. Bai, G. Franchin, H. Elsayed, A. Conte, and P. Colombo, “High Strength Metakaolin-Based Geopolymer Foams with Variable Macroporous Structures,” Journal of the European Ceramic Society, vol. 36, no. 16, pp. 4243-4249, December 2016.
[17] M. Łach, et al., “Determination of the Influence of Hydraulic Additives on the Foaming Process and Stability of the Produced Geopolymer Foams,” Materials, vol. 14, no. 17, Article no. 5090, September 2021.
[18] M. Łach, “Geopolymer Foams—Will They Ever Become a Viable Alternative to Popular Insulation Materials? —A Critical Opinion,” Materials, vol. 14, no. 13, Article no. 3568, July 2021.
[19] S. K. Kaliappan, et al., “Effect of Pore-Forming Agents on Geopolymer Porosity and Mechanical Properties,” 3rd International Conference on Applied Science Technology, pp. 1-7, September 2018.
[20] C. Bai, et al., “Low-Temperature Fabrication of SiC/Geopolymer Cellular Composites,” Composites Part B: Engineering, vol. 137, pp. 23-30, March 2018.
[21] P. Hua, et al., “Adsorption of Acid Green and Procion Red on a Magnetic Geopolymer Based Adsorbent: Experiments, Characterization, and Theoretical Treatment,” Chemical Engineering Journal, vol. 383, Article no. 123113, March 2020.
[22] M. S. Cilla, et al., “Geopolymer Foams Obtained by the Saponification /Peroxide/Gelcasting Combined Route Using Different Soap Foam Precursors,” Journal of the American Ceramic Society, vol. 100, no. 8, pp. 3440-3450, August 2017.

[23] J. Fiset, et al., "Macroporous Geopolymer Designed for Facile Polymers Post-Infusion," Ceramic and Concrete Composite, vol. 110, Article no. 103591, July 2020.
[24] M. S. Cilla, et al., "Effect of Process Parameters on the Physical Properties of Porous Geopolymers Obtained by Gelcasting," Ceramics International, vol. 40, no. 8, pp. 13585-13590, September 2014.
[25] C. Shi, et al., "Recent Progress in Low-Carbon Binders," Cement and Concrete Research, vol. 122, pp. 227-250, August 2019.
[26] M. H. Kebede, et al., "Home Appliance Efficiency Improvements for Energy Conservation in Debre Berhan City: Ethiopia," American Journal of Energy Engineering, vol. 6, no. 2, pp. 10-14, July 2018.
[27] "Project Document on Locally Manufactured Electric Stoves: Energy Efficiency Standards and Labeling," http://196.188.108.86/images/Resources/Directorate/Energyefficiency&conservation/1-6%20Final%20project%20document%20Locally%20manufactured%20electric%20stoves%20April%2019%202017.pdf, 2017.
[28] A. Workiye, et al., "Development of Maize Stalk Cellulose Fiber Reinforced Calcined Kaolin Clay Geopolymer Composite," Proceedings of Engineering and Technology Innovation, vol. 16, pp. 30-38, August 2020.
[29] "Design of Prototype of Locally Manufactured Electric Stoves," http://196.188.108.86/media/attachments/EEA%20PUBLICAIONS/Energy%20related%20publications/21%20Locally%20manufactured%20electric%20stove%20Design%20of%20prototype%20and%20list%20of%20required%20materials.pdf, 2019.