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Utilizing Polyethylene Terephthalate (PET) In Insulation Fired Clay Bricks

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Abstract:
In order to improve the thermal insulation properties of fired clay bricks, the addition of polystyrene has been a common practice. However, in this study, we propose an alternative approach by substituting polystyrene with recycled polyethylene terephthalate (PET) derived from drinking water bottles. The PET is shredded and added to the brick composition, with a maximum inclusion level of 25%. Various tests were conducted to evaluate water absorption, apparent porosity, bulk density, cold crushing strength, and thermal conductivity of the bricks at temperatures up to 800 degrees Celsius. The results indicate that incorporating20% crushed plastic by weight yields bricks comparable to ASTM C155-97 standard bricks.

Key words: Insulation – Refractories – PET

1. Introduction:

The production of lightweight clay bricks with higher thermal insulation requires the incorporation of combustible components in specific proportions and particle sizes. Pore-forming materials are commonly added to the original mixture, with insulating fireclay bricks based on alumino-silicates being the most prevalent in the market. Polyethylene, polystyrene, poly-isocyanurate, and polypropylene are commonly used as pore formers, typically in the form of spherical beads. These additives effectively reduce the thermal conductivity of the bricks.

The conventional production process for insulating fire bricks involves firing kaolin clay at temperatures below 1000 degrees Celsius to obtain dehydroxylated kaolin (grog). The grog is then mixed with plastic clay, water, and pore-forming agents. The resulting mixture is shaped into bricks or blocks, dried, and fired at temperatures of 1250 to 1300 degrees Celsius to remove all organic substances and create the necessary pores. The firing process also initiates sintering and vitrification resulting in bricks with higher mechanical strength.

Polyethylene terephthalate (PET) is a widely used engineering polymer employed in various applications such as fibers, films, tapes, bottles, and composite materials. Although amorphous and unoriented PET exhibit limited mechanical properties, increased gas permeability, reduced dimensional stability, and higher extensibility [1-3], these characteristics can be significantly improved through crystallization and orientation .Adjusting the degree of crystallinity and orientation allows for the enhancement of PET's properties. [2,3]

Plastic, which was introduced in the past as a petrochemical derivative, has revolutionized various industries. It is composed of synthetic or semisynthetic organic compounds with a high molecular mass, derived from natural materials such as cellulose, coal, natural gas, salt, crude oil, minerals, and plants. [4]. Plastic's versatility, lightweight nature, durability, flexibility, variety, and cost have provided significant advantages over other materials like wood, natural fibers, rubber, and paper. [5] However, improper plastic waste management has contributed to a global waste challenge. [6, 7]

Annually, more than 380 million tons of plastic are produced worldwide, with polyethylene resins alone accounting for 34% of the total plastics market [8]. Despite recycling efforts, only a small portion of plastic waste is recycled [9], while a significant amount ends up in landfills, incineration, or improper disposal. The increasing production of plastic waste poses a serious environmental threat, affecting air, water, and land quality [10]. Plastic pollution has far-reaching consequences, including marine ecosystem degradation, compromised food safety, coastal tourism decline, and climate change [11]. Incinerating plastic waste contributes to carbon emissions and visually detracts from tourist attractions [12], resulting in economic losses associated with cleaning and maintenance [13].

Global plastic production is projected to reach approximately 619 million tons per year by 2030 [14]. There is a growing interest in recycling post-consumer PET products due to their recycling potential [15] and the environmental concerns associated with their pollution and slow degradation. Reducing the demand for single-use plastics could significantly decrease plastic consumption by 2030. Developing sustainable recycling solutions for PET waste is crucial to mitigate the environmental impact caused by its non-biodegradable nature [16, 17].

2. Materials and methods

2.1.Raw materials used

2.1.1 Kaolin and grog

Kaolin clay was obtained from the Kalabsha area in southern Aswan, Egypt. The clay was pulverized in a laboratory ball mill to achieve a particle size smaller than 417 µm. A portion of the clay was heated to 1100 degrees Celsius for six hours to produce grog, while another portion was ground to pass through 147 µm screens to enhance plasticity.

Characterization of kaolin

The chemical analysis of kaolin was assessed using XRF which are shown in the followed table

Table 1: Chemical analysis of kaolin

Oxide	SiO_2	Al_2O_3	Fe_2O_3	CaO	Na_2O	K_2O	TiO_2	other	LOI
Weight %	49.24	33.1	0.33	2.68	0.12	0.08	1.45	1.51	11.35

Figure 1 illustrates the XRD pattern of the utilized clay. Consistently, the pattern reveals distinct peaks corresponding to kaolinite ($Al_2O_3.2SiO_2.2H_2O$) and quartz (SiO_2). The presence of free silica in conjunction with kaolin accounts for the observed peaks attributed to quartz. Although no peaks associated with calcium compounds were observed, likely indicating their minimal presence in the clay sample

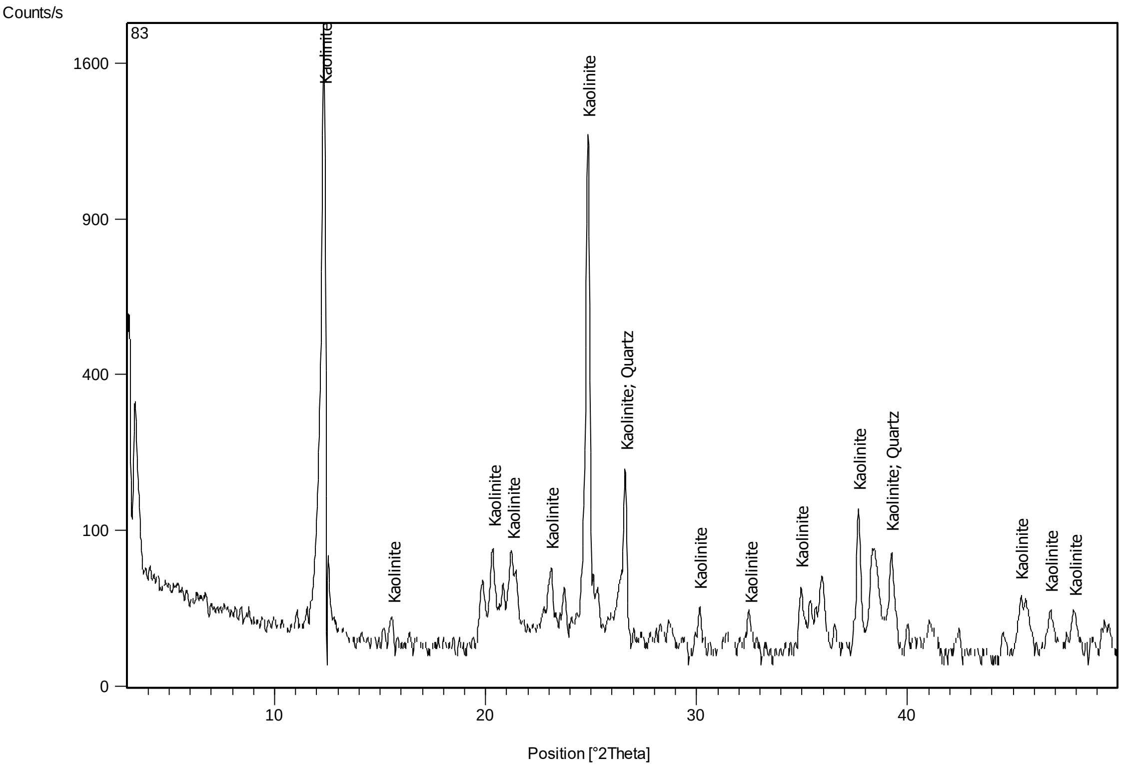

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Fig.1: XRD pattern of clay

2.1.2 Polyethylene Terephthalate (PET)

The plastic used in the brick composition was sourced from drinking water bottles. The bottles were thoroughly cleaned, dried, and cut into small pieces. These pieces were further reduced in size until they could pass through a 2-millimeter sieve.

The thermal analysis of pet has been proved that the heat capacity of PET at 25 ^{o}C is dependent on the degree of crystallinity, varying between 1.103 J/g oC for crystalline and1.146 J/g ^{o}C for amorphous PET. The value found for post-consumer PET was 1.144 J/g ^{o}C. [18]

Thermo gravimetric analysis of (PET)

Figure 2 presents the corresponding thermal gravimetric (TG) analysis conducted on PET samples using a heating rate of 10°C.min-1. Notably, a significant decline in weight is observed commencing at 460°C. The TGA curves of PET exhibit four distinct stages of thermal degradation, which are likely indicative of various compound fragments within the polymer structure as it undergoes thermal decomposition. This finding aligns with previous research [19]. During the initial stages, the weight loss can be attributed to CO_2 and CO liberation, followed by the release of $C_2H_6O_2$ and C_2H_4O in the second stage, C_4O_2 in the third stage, and RCO-OR in the final stage.

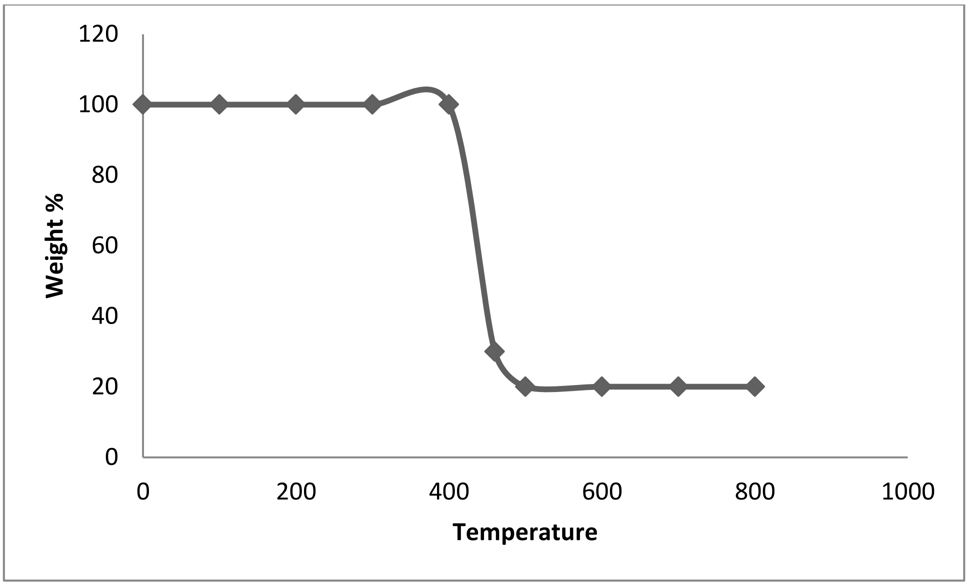

Fig. 2: TGA curves of the PET

2.2.Preparation of samples

The required quantity of raw materials was weighed and dry mixed for ½ hour in a laboratory ball mill. Subsequently, water was added, and wet mixing was carried out in a mechanical mixer with a capacity of two liters and adjustable rotating speeds for duration of 5 to 7 minutes. The specific compositions of the mixed batches can be observed in the provided Table 2.

Table 2: Sample compositions

Mass in g	(0% PET)	(5% PET)	(10% PET)	(15% PET)	(20% PET)	(25% PET)
Clay	340	320	300	280	260	240
Grog	60	60	60	60	60	60
PET	0	20	40	60	80	100

2.3.Drying and firing

After molding the mixes in (6*6*6 cm^3) steel molds, they were allowed to dry for one day. The samples were then taken out of the molds and dried overnight in an oven at 110°C. Firing was performed in a muffle kiln at 1250°C for 12 hours.

3. Characteristics of fired bricks containing PET

3.1. Water absorption

The percentage of water absorption (% WA) was determined for samples containing varying percentages of PET. The results are presented in Figure 3, which demonstrates a consistent increase in water absorption with the addition of PET. The relationship between the percentage of water absorption and PET addition can be described by the following linear equation:

$$\%WA = 212.66\ \%\ PET + 19.286 \qquad (R^2 = 0.9974) \qquad (1)$$

This equation clearly indicates a strong dependence on PET levels, as evidenced by the respective coefficients in the equation. The increase in water absorption percentage following the addition of PET is significant, with values rising from 18% at 0% PET to 71% at a 25% addition.

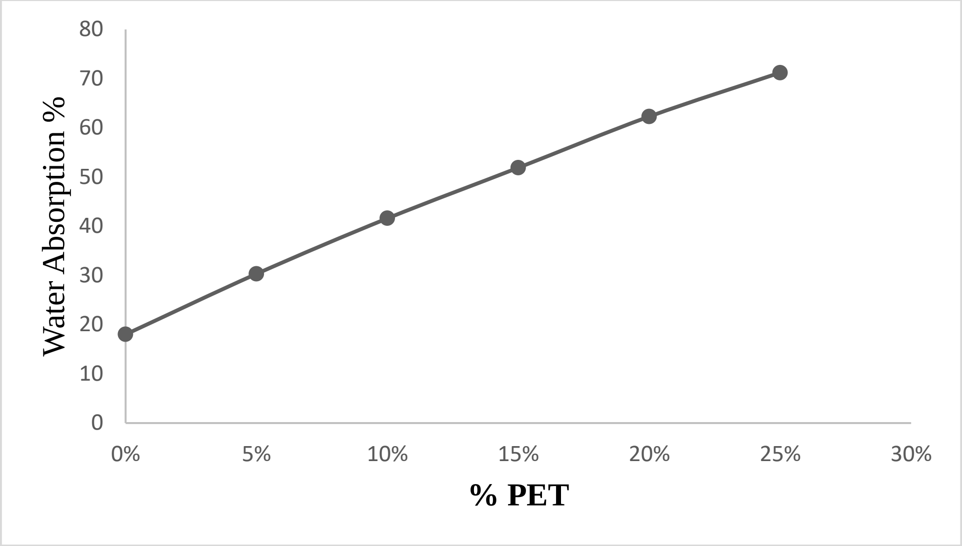

Fig. 3: Effect of percent PET addition to percent water absorption

3.2. Apparent Porosity

As expected, the inclusion of PET significantly increases the porosity level in the bricks. Figure 4 illustrates the combined effect of adding PET to the bricks. The porosity values start at 31% for plain bricks with no addition and reach nearly 62% at the maximum addition of 25% PET. A linear regression equation was derived to describe the relationship between the percentage of porosity and the addition of PET. The equation is as follows:

$$\% P = 120.87\ \%\ \mathrm{PET} + 36.046 \qquad (R^2 = 0.9303) \qquad (2)$$

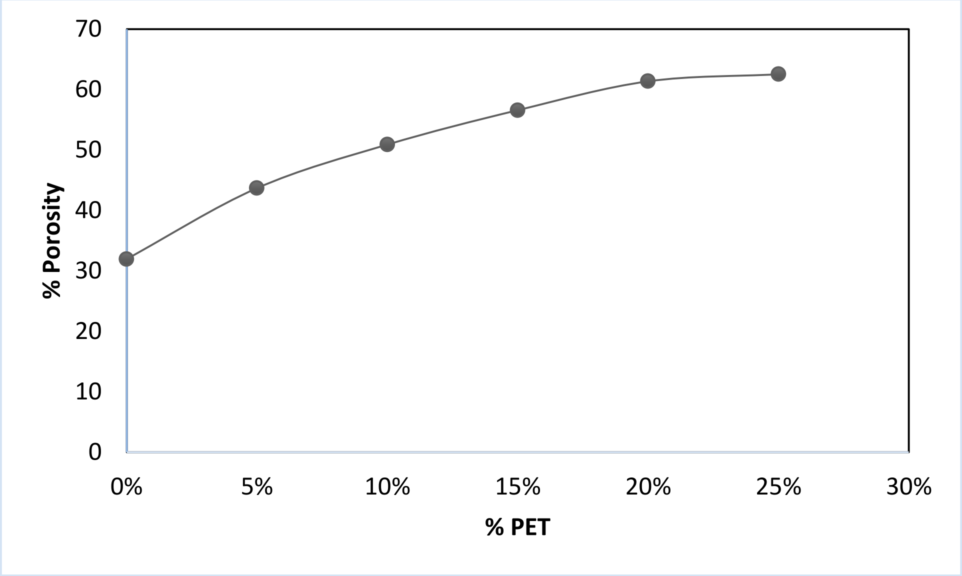

Fig. 4: Effect of percent PET addition to percent porosity

3.3. Bulk density

Bulk density is a crucial characteristic of insulating refractory bricks. According to ASTM C155-97 specifications, this type of bricks typically has a bulk density of 1.03 g/cm³. Figure 5 demonstrates the impact of PET addition on bulk density, showing a decrease in density with the addition.

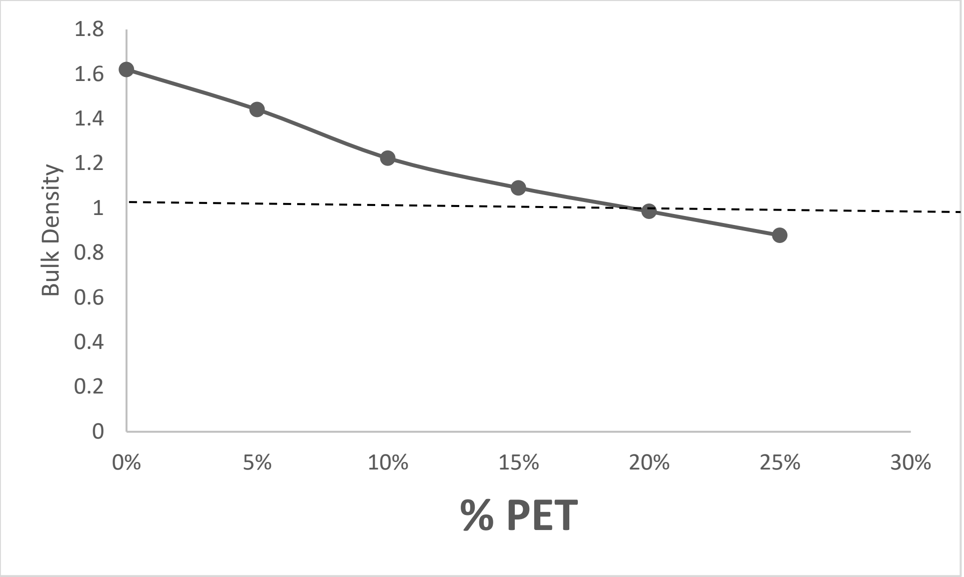

Fig. 5: Effect of percent PET addition to bulk density

However, it requires approximately 20% PET addition to achieve a brick density lower than 1.03 g/cm³. A linear correlation between bulk density and the level of PET addition can be described by the following equation:

$$\rho_B = -2.9774\ \%\ PET + 1.5786 \qquad (R^2 = 0.9779) \qquad (3)$$

3.4. Cold crushing strength (CCS) of WS based bricks

An increase in porosity is expected to negatively affect the mechanical strength of the bricks. Consequently, a consistent decrease in cold crushing strength (CCS) was observed as the addition level increased. However, the decrease is not linear, unlike the sintering properties. Figure 6 emphasizes these findings, indicating that the CCS values decrease from 4.3 MPa for plain bricks to less than 1.2 MPa at the maximum addition level of 25% PET. According to ASTM standards, the minimum CCS value for this type of bricks is 1 MPa, which is achieved when the percentage of PET does not exceed 20%.

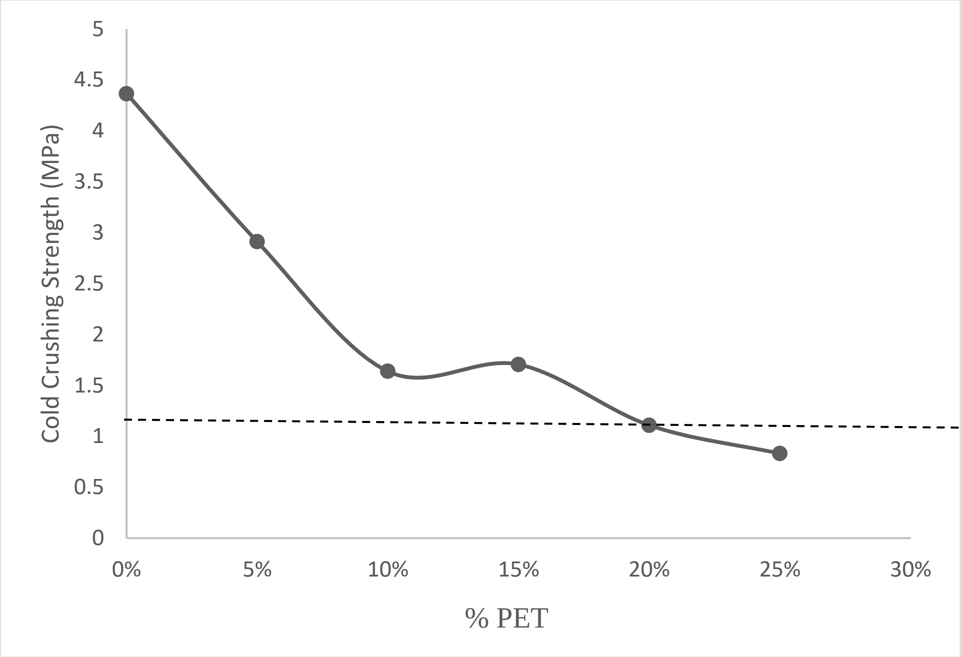

Fig. 6: Effect of PET addition with respect to cold crushing strength

An empirical correlation between CCS and the percentage of PET addition can be expressed by the following equation:

$$CCS = -13.149\ \%\ PET + 3.7352 \qquad (R^2 = 0.8644) \qquad (4)$$

3.5. Thermal conductivity of PET based bricks

3.5.1. Thermal conductivity at 400 °C

The thermal conductivity of insulating bricks samples was determined at 400°C as function of addition level of PET. As can be seen from Figure 7, all compositions tested yielded thermal conductivities less than the maximum allowed value of 0.4 W.K^{-1}.m^{-1}.

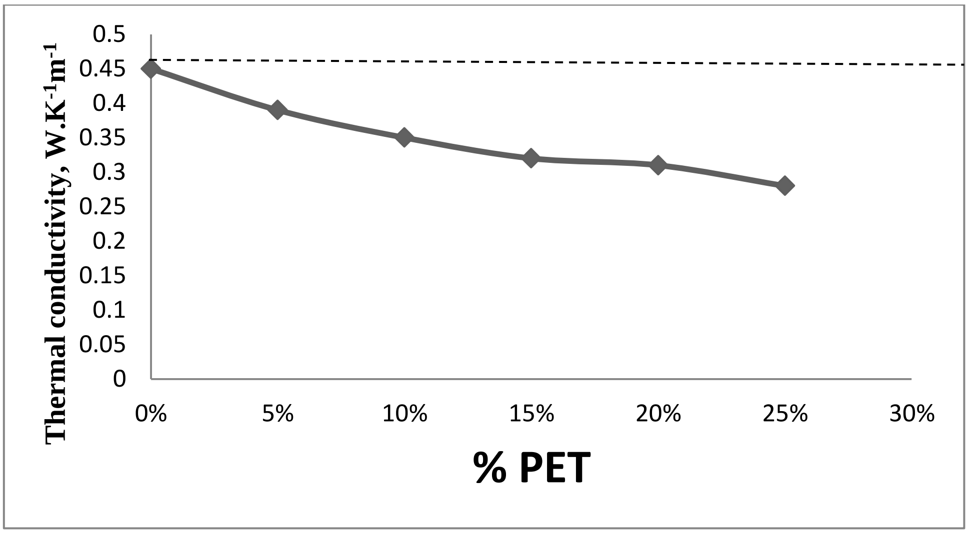

Fig. 7: Effect of percent PET addition on thermal conductivity at 400°C

3.5.2. Thermal conductivity at 600 °C

Figure 8 show an increase in the value of thermal conductivity presumably because of pore radiation ,also shows that all investigated compositions produce insulating bodies having a thermal conductivity <0.43 W.K^{-1}.m^{-1} which is the allowable value at 600 °C for insulating fire bricks.

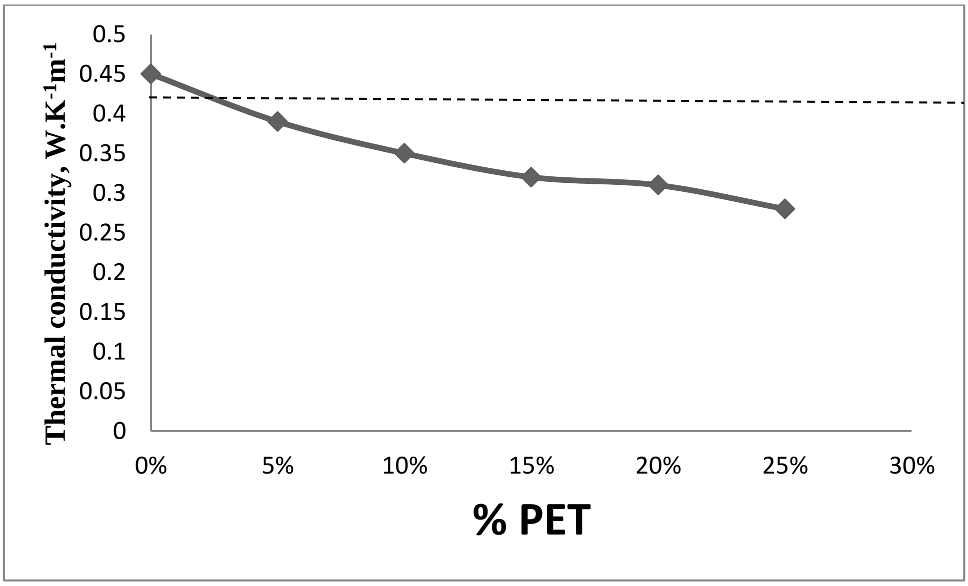

Fig. 8: Effect of percent PET addition on thermal conductivity at 600°C

4. Conclusion

Insulating fire bricks were prepared by the addition of PET, used water bottles after collecting, grinding and mixing together with local Egyptian clay. Shaped cubic samples of bricks (60×60×60 mm^3) were prepared, dried overnight then fired at 1250°C for 12 hours. The effect of varying PET content on the fired bricks was investigated.

Addition of either material had for effect to increase water absorption and decrease bulk density and compressive strength. On the other hand the effect of this addition was more comparable in decreasing thermal conductivity at different temperatures.

A brick containing 20% PET was found to abide by recommended values for insulating refractory bricks, thus utilizing a waste and therefore decreasing the production cost.

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