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Incorporating of landfill leachate in fired-clay bricks manufacturing: An experimental study

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ABSTRACT

Fired clay- brick industry consumes around 386 liters of water per 1000 bricks. Landfill leachate is considered an environmental burden. Therefore, this study aimed to use untreated landfill leachate instead of water in fired clay-brick to save water consumption and eradicate landfill leachate problems. Two types of landfill leachate were used instead of water, old and fresh leachate. They were characterized before use. Their water content was 90.9 and 95.8, respectively. Green brick was successfully manufactured without any deformation, cracking, or failure during brick molding, drying or burning. The produced fired clay- brick met the Egyptian standard requirements in terms of compression strength, water absorption, and efflorescence. It also met the environmental protection and consequently public health concerns in terms of heavy metal leaching. Recourses conservation, environmental pollution control, cost-saving, and production of standard products are the main benefits of this research work.

1. Introduction

The generation of solid waste, when improperly managed, may cause adverse impacts related to public health and the environment (Ziraba et al., 2016). In developing countries placing waste in landfills or open dumps is considered one of the methods used for municipal solid waste final disposal (Torretta et al., 2016). Landfill generates a liquid as a by-product that holds excessive quantities of pollutants, this liquid is known as landfill leachate (Al-Wasify et al., 2018). The characteristics of the landfill leachate differ regarding the age of the landfill and the type of waste it contains (Pavithra et al., 2020).

Landfill leachate is a dark-colored liquid, with a strong bad smell, that contains a high organic and inorganic load. It usually contains four main groups: dissolved organic matter, inorganic compound, xenobiotic organic compounds resulting from the chemical and domestic deposit with low concentration, and microorganisms like predominantly total and thermotolerant coliform (Peng, 2017).

Different technologies, including biological treatments, chemical treatments, and physicochemical treatments have been studied for the treatment of landfill leachate. However, a compromise is required between treatment performance and the cost associated with these techniques (Teng et al., 2021). The incorporation of such waste without treatment into construction materials is a feasible solution to the pollution problem.

Burnt bricks have been used as a construction material for the development of homes for many years across the world (Akinyele et al., 2020). The usual fired-clay brick manufacturing process is by mixing the raw materials (water, clay, hay, and sand), molding the bricks, drying, and finally firing them till they acquire the required level of strength (Al-Fakih et al., 2019).

The fired-clay bricks manufacturing process is considered a water-consuming industry that needs an integrated water management plan to lessen the dependence on freshwater consumption. Green bricks contains about 25–30% water; This means that the 1000 bricks contain from 350 to 450 kg of water which means from 350 liters to 450 liters of water (Akinyele et al., 2020). According to the Egyptian code for design and building construction, the most common fired clay- brick weight is ranged from 1.4 kg to 1.5 kg (ASTM, 2012; Ministry of Housing, 2005).

Substitution of water by landfill leachate in the fired-clay brick manufacturing will save water and consume the landfill leachate

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without treatment. However, in this attempt producing standard fired clay- brick is a must. This research paper aimed at using landfill leachate in the manufacturing process instead of water without any problems in brick making, drying, burning, and finally, the product must comply with Egyptian codes and standards.

2. Materials and methods

2.1. Study setting

The study was conducted in a fired clay- brick factory in El-Amreyya district, Alexandria, Egypt, and the laboratories of the High Institute of Public Health, Faculty of Engineering and Graduate Research Institute, Alexandria University Egypt.

2.2. Landfill Leachate

The used leachate was brought from leachate ponds of Alexandria municipal solid waste landfill locates at El-Hammam district, Matrouh Governorate. Two types of leachate were used in brick manufacturing instead of water, old leachate, concentrated, and fresh leachate. Grab samples were collected from each type of leachate (1.5 m^3 each). The water content, the total solids, and pH were measured and calculated according to the standard methods for the examination of water and wastewater (Bird, 2017).

2.3. Water demand in brick making

The water demand (W_d) "which could be replaced by landfill leachate" in fired clay- brick making equals the difference between the weight of water contained in green brick (W_c) and water evaporation (We) during clay wetting as follow:

$$W_d = W_c - W_e$$

The weight of water contained (W_c) in the green brick was calculated through measuring of the mean weigh of the green brick (W_g) and the mean weight of fired brick (W_f) then the following equation was used to calculate the water content (ASTM International, 1990; Reddy, 2002).

$$W_c = W_g - W_f$$

The water content ratio was calculated using the following equation (ASTM International, 1990; Reddy, 2002):

$$W_{cr} = \frac{W_g - W_f}{W_g} \times 100$$

The weight of the evaporated water (W_e) during the clay wetting period was calculated using the following equation (Academy, 2005):

$$W_e = A \times T \times E \times S_g$$

Where, (A) is the total evaporation surface area of wetting clay cuboid, in m^2. It.

equals the lateral side area plus the upper surface area of the wetting clay cuboid. The lateral side area equals 4 times the length multiplied by the height of the cuboid. While the upper surface area equals length of the cuboid power two $(L)^2$. And (T) wetting time in days, (E) is the evaporation rate in m/day and S_g is the specific gravity of water in t/m^3 (1 t/m^3) The dimensions of the wetting clay cuboid were determined using measuring tape and the operator was asked about the wetting time while the evaporation rate was determined from other research papers and the specific gravity of water is 1 k/l or 1 t/m^3 (Abd-Elhamid et al., 2021; Said and Hussein, 2013).

2.4. Fired- clay brick manufacturing incorporating leachate

The selected factory uses clay, sand, and water in brick manufacturing. The water was replaced with leachate (old and fresh). Clay, sand, and leachate were mechanically mixed to produce a mixed paste and then compressed in a mold to make green brick. The green brick was transferred and stacked in piles under a shed using the stacking method that allows good natural aeration for green brick to get dry. It was left under the shed for around two weeks. The dried green bricks were fired for around 18 h using fuel oil and blew air. The burned bricks were left in the kiln for 6 h for gradually cooling (Fig. 1).

Around 12000 green bricks were made (4000 using water, 4000 using old leachate, and the last 4000 using fresh leachate). This number of samples were to assure that there is no failure or collapse to happen during the burning step. To make sure that the samples were correctly collected; the first 1000 green bricks from each batch were excluded from sampling. Then 30 bricks were systematically selected from 3000 bricks, one from every 100 Brick. In addition, 30 bricks were collected from the factory brick, which was made from clay, sand and water, to be used as control and to be compared with the bricks made from clay, sand, and leachate. The collected samples were used to be tested for compression strength, water absorption and efflorescence, and heavy metals leaching. According to the Egyptian standard method for brick testing the required sample size is 5 bricks from each type (ASTM, 2012; Ministry of Housing, 2005). For each of the above-mentioned tests, 5 bricks were selected randomly from the collected 30 bricks.

2.5. Green and Fired- clay bricks testing

According to the Egyptian standard method for brick testing (ASTM, 2012; Ministry of Housing, 2005), no tests are required for green bricks. However, successful green brick making through using of leachate instead of water without failure, cracking, or deformations during the molding, drying, and burning processes were targets.

After burning and cooling three standard tests (compression strength, water absorption and efflorescence) are required (ASTM, 2012; Ministry of Housing, 2005). In compression strength the dimensions of each brick were measured, using Vernier Caliper, and the brick was centered and rested (on its wide side 16 ×8 cm) in the compression machine. Then the brick was gradually loaded till crushing. The fracture load was read from the machine monitor then the compression strength was calculated using the following equation:

$$C_s = \frac{C_l}{S_a} * 1000$$

C_s is the compression strength stress in N/mm^2.
C_l is the fracture load in KN and.
S_a is the loaded surface area in mm^2.

In the water absorption test, the brick samples were placed in the dry oven at 100 °C for 24 h till the weight of the brick became constant. Then the dried bricks were immersed in water for 24 h then the wet bricks were weighted. The water absorption was calculated using the following equation:

$$W_a = \frac{W_w - W_d}{W_d} \times 100$$

W_a is the water absorption percentage.
W_w is the weight of wet brick.
W_d is the weight of dried brick.

Efflorescence is the appearance of white powders on the surface of the dry-fired brick after due to subjected to wetting and drying(Nhabih et al., 2020). In this test, the dry bricks were immersed in water for 24 h and then left to be dried naturally. Then, efflorescence areas were measured, it has to be less than 50% of the total surface area of the brick. For environmental and public health considerations, the leaching of heavy metals from the fired bricks should be tested. In this test, the bricks were immersed in distilled water for 24 h the heavy metals were measured in the water using atomic absorption (Bird, 2017).

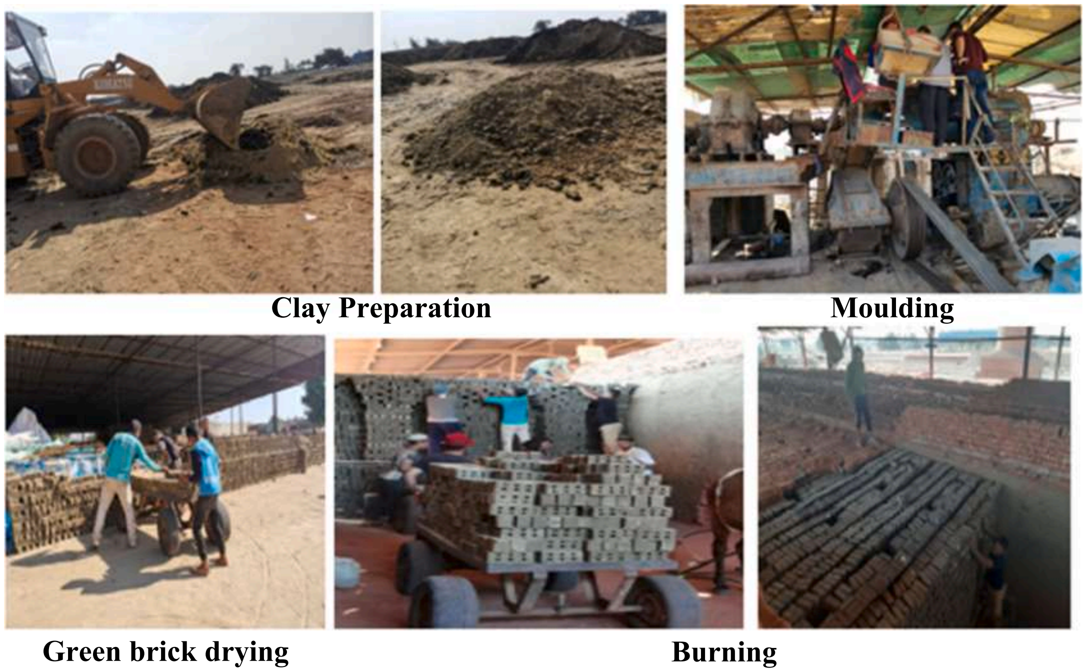

Fig. 1. Brick Manufacturing Incorporating Leachate.

2.6. Statistical Analysis

After which the data were updated, coded, and input into the statistical Programme SPSS version 16 (Nie et al., 2007). Descriptive statistics, such as the mean, standard deviation, and percentages were employed to describe scale data.

Data were analyzed using analysis-of-variance techniques to determine significant leachate types effects ($P \leq 0.05$) using Statistical Analysis System (SAS) (Stokes et al., 2012). The study was on three types of produced fired clay- bricks (original, using old leachate, and using fresh leachate) within five replicates for produced fired-clay brick tests in a randomized complete block design. The obtained data were statistically analyzed according to Snedecor and Cochran (Snedecor and Cochran, 1990), and produced fired-clay brick tests means were compared using least significant differences LSD at a probability level of 5%.

3. Results

3.1. Leachate characterization

The characteristics of two types of leachate samples (old and fresh samples) were analyzed for water content, pH, and total solids. The water content of old leachate was 90.9% with total solids 104143 mg/l and of fresh leachate was 95.8% with total solids 84667 mg/l. For pH, old leachate and fresh leachate had a pH 9 (Table 1).

3.2. Fired- clay brick manufacturing incorporating leachate

No deformations, cracking or failures were noticed during molding, draying, or burning of the three types of brick normal bricks, brick incorporating old leachate, and brick incorporating fresh leachate.

Visually, both green and fired bricks for normal bricks, brick incorporating old leachate, and fresh leachate were almost the same. The bricks incorporating leachate did not collapse after burning in the kiln.

Table 1
Characteristics of two types of leachate samples (old and fresh samples).

Parameters	Old leachate Sample	Fresh leachate Sample
Water content (%)	90.9	95.8
Total solids (mg/l)	104143	84667
pH	9	9

3.3. Water consumption

Water consumption in brick making could be calculated through estimation of the evaporated water during clay wetting period and calculation of green brick water content. The collected data from the brick making factory showed that around 64 m^2 (8 $\times$8 m) of the factory land is used for clay wetting and clay height of 3 m. The lateral side area= 96 m^2, and the upper surface area = 64 m^2, then the total evaporation surface area = 96 + 64 = 160 m^2. The wetting period ranged from 1 to 19 day depending on the water content of the used clay and the weather conditions with average wetting time 10 days. The amount of wetted clay in this area is enough for making 300000 green bricks.

The average rate of water evaporation is 1.3 cm/day in the south of Egypt (It ranges from 0.8 cm/day in winter to 1.8 cm/day in summer). While, in the north of Egypt, it is 0.42 cm/day (it ranges from 0.4 cm/day in winter to 0.44 cm/day in summer) (Abd-Elhamid et al., 2021; Said and Hussein, 2013). Based on this data, the average estimated amount of evaporated water in the selected brick making factory for this study for 160 m^2 total surface area for 10 days clay wetting period and 0.42 cm/day water evaporation rate is = $0.0042 \times 160 \times 10 = 6.72$ m^3 = 6720 liter = 6720÷300 = 22.4 liter/1000 brick.

The mean weight of green and fired brick was measure. They were 1510 and 1144 g respectively. The average water content was 24%. It means 366 g of water/brick or 366 ml of water/brick or 366 liter/1000 brick. The total water consumption = 366 + 22 = 388 liter/1000 brick. This study was carried out in a factory produces 100000 brick/day. This means that it consumes 38.8 m^3 /day (14162 m^3 /year). This amount of water consumption could be saved and replaced with landfill leachate.

3.4. Fired- clay brick testing

3.4.1. Brick dimensions

For the three types of bricks, the mean dimensions were almost identical. Lengths mean were 16.4800 ± 0.16432, 16.5000

± 0.12247and 16.4200 ± 0.04472 cm for normal bricks (N), brick incorporating old leachate (O), and brick incorporating fresh leachate (F), respectively. The width means of N, O and F bricks were 7.8800 ± 0.13038, 7.8200 ± 0.13038, and 7.8600 ± 0.08944 cm, respectively. Height means of normal, old, and fresh bricks were 5.6600 ± 0.08944, 5.6200 ± 0.08944and 5.6200 ± 0.10954 cm, respectively (Table 2). Shrinkage in brick dimensions due to drying and burning was a common notice in several studies (ILO, 1984).

3.4.2. Brick weight

For the three types of bricks, the weight mean was almost equal (means were 1.1618 ± 0.0399, 1.1592 ± 0.05356, 1.1124 ± 0.01926 kg, for normal, old, and fresh bricks, respectively) (Table 3).

3.4.3. Compression strength

Compression strength (N/mm2) was calculated from the correlation between fracture load, and brick area. For the three types of bricks, the fracture load means were 132.6 ± 26.1854, 122 ± 30.18485, and 127 ± 16.6111 KN, for normal, old, and fresh bricks, respectively. (Table 4). Therefore, the compression strengths (CS) of different types of bricks (N, O, and F) were different (means were 10.22, 9.44, and 9.85 N/mm^2 for normal, old, and new bricks, respectively).

3.4.4. Water absorption

The water absorption means were 7.48 ± 0.1641, 9.56 ± 1.4361, and 10.34 ± 1.2755%, for normal, old, and new bricks, respectively (Table 5).

On one hand, the analysis of variance (ANOVA) showed that there was no significant difference between the different types of bricks in the brick dimensions (P equal 0.6155, 0.2958, and 0.8701 for length, width, and height, respectively), the weight of different bricks (P equals 0.2581), fracture load and fracture stress of different bricks (P equal 0.2253 and 0.2857), and the water absorption of different bricks (P equals 0.0743), based on the *P-value* with ≥ 95% of confidence level between different types of bricks. Consequently, the LSD test made pairwise comparisons using a stepwise order of comparisons showing the best and the worst manufactured brick. The different types of bricks (N, O, and F) were all almost similar in the previous properties. On the other hand, with P value < 0.0001, the results of CS revealed that there was a statistically significant difference in the compressive strength values.

3.4.5. Brick efflorescence

Comparing normal bricks with bricks incorporated leachate, there was no effloresces in all types of bricks (Fig. 2).

3.4.6. Heavy metals

The heavy metal concentrations in both fresh leachate-bricks and old leachate-bricks in comparison with control bricks were substantially below the regulatory thresholds given; it is reasonable to assume that leachate-bricks are safe. Cd had low concentration (<0.004 mg/l) followed by Cr in both control and fresh leachate-bricks was the same as Cd (<0.004 mg/l) while in old leachate-bricks was slightly higher than them (0.007 mg/l). following that, Cu concentrations had no variation between control, fresh leachate-bricks, and old leachate-bricks (<0.006 mg/l). Finally, Zn concentration had the highest values in control, new leachate-bricks, and old leachate-bricks (0.18, 0.13, and 0.16 mg/l, respectively) (Table 6).

Their concentrations were minimal as compared to regulatory criteria for potable water, as shown by the results (Ministry of Health and Population, 2007). To assess the acceptability of the burnt clay bricks including leachate, the findings were compared to the solid industrial waste hazard classification issued by the EPA Victoria Industrial Waste Resource Guidelines (Victoria, 2009).

Table 2
Descriptive Statistics of Brick dimensions.

Bricks	Mean ± S. D	Min	Max
Length			
Normal	16.4800 ± 0.16432	16.20	16.60
Old	16.5000 ± 0.12247	16.30	16.60
Fresh	16.4200 ± 0.04472	16.40	16.50
Width			
Normal	7.8800 ± 0.13038	7.70	8.00
Old	7.8200 ± 0.13038	7.60	7.90
Fresh	7.8600 ± 0.08944	7.80	8.00
Height			
Normal	5.6600 ± 0.08944	5.60	5.80
Old	5.6200 ± 0.08944	5.50	5.70
Fresh	5.6200 ± 0.10954	5.50	5.80

Table 3
Descriptive Statistics of Brick Weight.

Bricks	Mean ± S. D	Min	Max
Normal	1.1618 ± 0.0399	1.098	1.194
Old	1.1592 ± 0.05356	1.072	1.196
Fresh	1.1124 ± 0.01926	1.082	1.131

Table 4
Descriptive Statistics of Brick Fracture load, and Compression strength.

Bricks	Mean ± S. D	Min	Max	Egyptian standards
Fracture load (KN)				
Normal	132.6 ± 26.1854	100	164	–
Old	122 ± 30.18485	77	154	
Fresh	127 ± 16.6111	99	137	
Compression Strength (N/mm^2)				
Normal	10.2184 ± 2.0106	7.845	12.847	**Not less than 4 N/mm^2 for skeleton frame stucture**
Old	9.4356 ± 2.3132	5.884	11.678	
Fresh	9.8458 ± 1.3016	7.649	10.689	

Table 5
Descriptive Statistics of Water absorption.

Bricks	Mean ± S. D	Min	Max
Normal	7.48 ± 0.1641	7.3	7.7
Old	9.56 ± 1.4361	7.7	11.3
Fresh	10.34 ± 1.2755	8.8	11.7

4. Discussion

4.1. Leachate characterization

In this study the water content for the leachate replaced water was about 90.9% for old leachate and 95.8% for the fresh one, while the water content of the clay used was 0.25%.

4.2. Water saving

There will be two great environmental benefits. They are water saving (resources conservation) and landfill leachate consumption without treatment (environmental pollution/prevention control). In addition, there will be two great financial benefits. They are the water cost saving and the leachate bonds construction and leachate treatment cost saving.

4.3. Fired- clay brick manufacturing incorporating leachate

The fired-clay bricks incorporated leachate were well manufactured. The surfaces of the bricks incorporating leachate (both old and new)

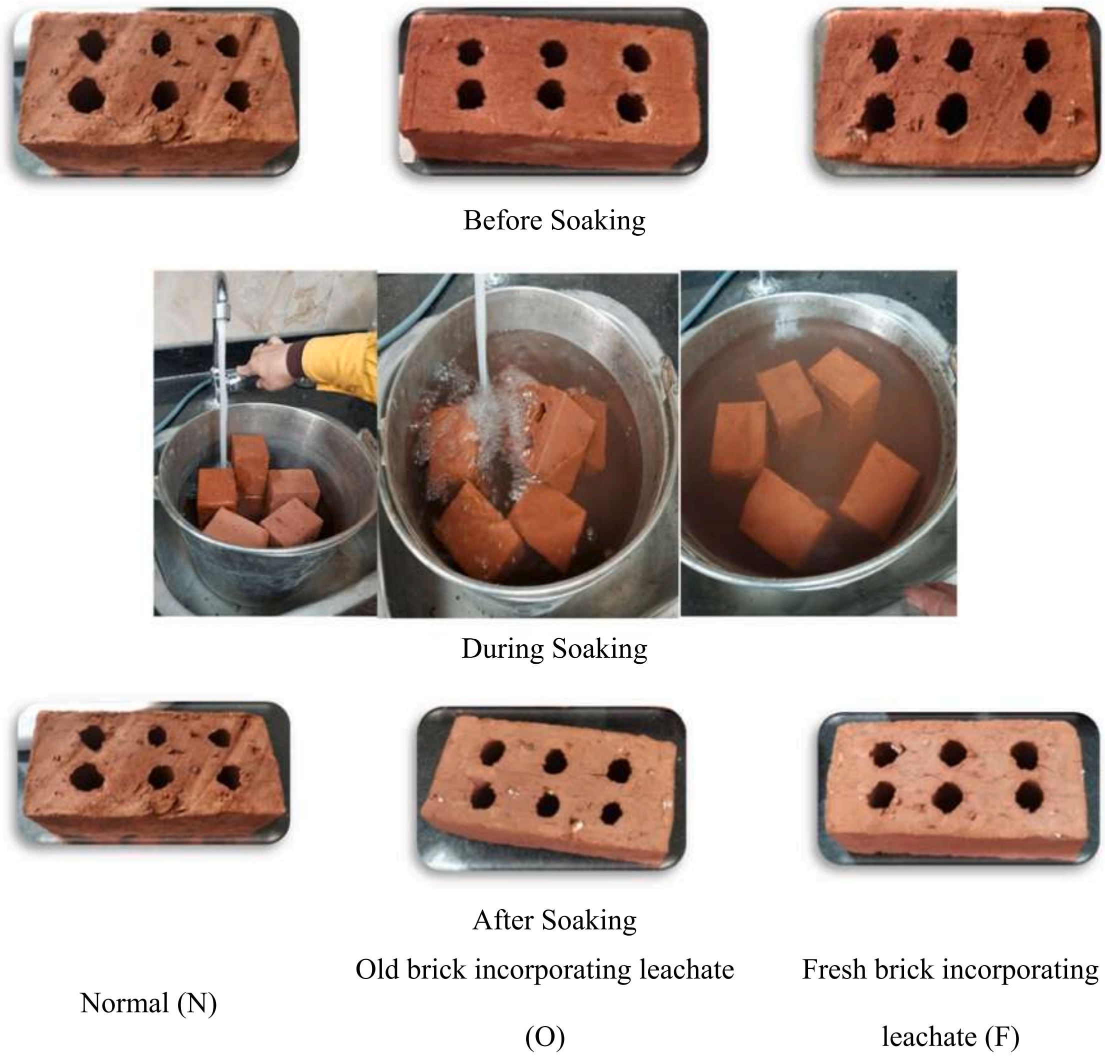

Fig. 2. Brick effloresces before, during, and after soaking.

Table 6
Heavy Metals Analysis in Control and Tested Leachate Bricks.

Heavy Metals	Concentration limit (mg/l)*	Upper Limit Concentration (mg/l)**	Detected concentration (mg/l)		
			Control Brick	Fresh Leachate- Brick	Old Leachate- Brick
Cd	0.005	3	< 0.004	< 0.004	< 0.004
Cu	1	100	< 0.006	< 0.006	< 0.006
Cr	0.05	1	< 0.004	< 0.004	0.007
Pb	0.05	300	< 0.028	< 0.028	< 0.028
Zn	5	200	0.18	0.13	0.16

* Limits for inorganic chemicals in potable water,
** Industrial Waste Resource Guideline

exhibited no obvious fractures. The shrinkage caused by variations in the drying process of the bricks finally leads to random cracking. These problems are largely the result of inadequate quality control mechanisms in place throughout the fired brick production process (Bendimerad et al., 2016). In this study, all bricks were exposed to the same condition of drying (open air) for 10–15 day which was sufficient for complete dryness before getting to burning process. Deformations, cracking, or failures in brick during molding, drying or burning may occur. Successful brick making using landfill leachate instead of water without deformations, cracking or failures showed that there will be no manufacturing problems when landfill leachate used instead of water in fired clay- brick making (ASTM, 2012).

4.4. *Fired- clay brick testing*

4.4.1. *Brick dimensions*

The fired brick dimensions were measured and compared to the normal brick dimension, as shown in the Table 2. This indicates that the fired bricks have a consistent shape. All the length, width, and height sides of the fired bricks were likewise found to be flat. The produced bricks were complied with Egyptian code as the only difference in normal brick manufacture is the leachate instead of the water. According to Danso and Akwaboah (Danso and Akwaboah, 2021), who had variation in sizes of bricks from the other three sites (Fum, Man, and Ada), was because the disproportion of the constituent of the soil used for preparing the bricks. Excessive shrinkage of the bricks during drying and burning might occur, especially when the clay concentration is high. Organic components and inorganic CaCO3 account for the majority of the weight loss during the ignition of bricks during the firing process (Mageed et al., 2011).

4.4.2. Brick weight

Changes in brick weight may be attributed to changes in the molding compression, changes in the constituent contents or changes in burning temperature. These items are not easy to be controlled 100% and consequently might affect the brick weight (Karaman et al., 2006).

4.4.3. Compression strength

The most significant test for ensuring the engineering quality of building materials is the compression test since it provides information on all of the brick's strength characteristics (Mageed et al., 2011). Based on average CS, bricks are divided into three classes. The average CS of five brick should not be less than 4 N/mm^2 for skeleton frame structure bricks according to Egyptian code (Ministry of Housing, 2005). High CS is frequently used to demonstrate the good and strong quality of an earthy material based on the degree of compaction, burning, and the lack of contaminants (Akinyele et al., 2020).

CS of skeleton frame structure bricks (FBB) incorporated leachate was 10.22, 9.44, and 9.85 N/mm^2 for normal, old, and fresh bricks, respectively. The highest among both leachate-based bricks was brick incorporated fresh leachate. CS of brick incorporated fresh leachate is slightly less than normal bricks otherwise it complied with the minimal value suggested by Egyptian code (Ministry of Housing, 2005).

A study by Kazmi et al. (2016) CS of 5.10–8.38 N/mm^2 was measured on burnt clay bricks. Another study on clayey materials, the highest CS for excellent burnt bricks was 5.2 N/mm^2 (Akintola et al., 2020). CS of burnt clay bricks with ash was found to be 8.4 N/mm^2, while the compressive strength of burnt bricks without ash was determined to be 8.4 N/mm^2. This indicates that the charred bricks' CS are enough for the current study (Kazmi et al., 2017).

It was noticed that the produced fired clay- brick using landfill leachate instead of water complies with the relevant required Egyptian standards (ASTM, 2012). Consumption of such environmentally and public health hazard material "leachate" in production of standard product and water saving could be considered a great success.

4.4.4. Water absorption

The water absorption of produced bricks values found in this investigation show general compliance with Egyptian code (Ministry of Housing, 2005), which stipulates that water absorption for fired bricks should not be greater than 20% for skeleton frame structure bricks. The water absorption of the bricks determines their long-term durability (Hegazy et al., 2012). The less water that gets into bricks, the more durable the brick will be and the more resistant it will be to the elements. As a result, the interior structure of the brick must be sufficiently dense to prevent water entry (Rouf and Hossain, 2003). Brick's Water percolates through a wall made of earth-based materials, according to studies, reducing its endurance (Alam et al., 2015).

The brick incorporated fresh leachate had the highest water absorption of 10.34%, followed by brick incorporated old leachate of 9.56%, and the least was 7.48% from the normal bricks. This suggests that the fresh leachate-infused bricks have a higher barrier to water absorption than the normal bricks. This study's water absorption result was almost similar to Akinyele et al.'s water absorption result of 10–16% (Akinyele et al., 2020), and slightly less than Akintola et al.'s water absorption result of 11–18% (Akintola et al., 2020).

4.4.5. Brick effloresces

The efflorescence of white salts brought to the surface by water and deposited by evaporation can occur on brickwork. These salts might come from the outside, such as water in the soil in touch with the brickwork, or they can come from the mortar. The salts, on the other hand, are frequently found in the bricks themselves. Even little amounts of salt can cause visible efflorescence. Although efflorescence is unsightly, it is usually harmless and dissipates within a few seasons. However, efflorescent salts can have a high sulphate content, which can trigger sulphate attack on cement mortar joints. (Hegazy et al., 2012). The findings of this study could be interpreted as a sign of the brick's extremely low soluble salts content. Also, there was no efflorescence on the produced bricks.

4.5. Heavy Metals

Environmental risk assessment is a vital issue when replacing water with leachate in fired clay- bricks manufacturing. This because leachate contain heavy metals that have negative impact on environment and human health (Paixão Filho, 2017). As a result, heavy metal analysis in burnt clay bricks containing leachate is critical for classifying and quantifying those hazardous elements (Kurmus and Mohajerani, 2020). It should be noted that some of the substances utilized may be hazardous. Leaching tests were performed in these circumstances (Faria et al., 2012)., and no health risks were discovered.

In a previous research, heavy metals concentrations of leachate samples were collected from sanitary landfills in Alexandria, Egypt. Leachate content of heavy metals can show significant variation where Cr had low concentration ranging from 0.029 to 0.094 mg/l. However, Pb shows a lower mean value of 0.019 mg/l. While Zn had high mean values of 0.749 mg/l (Abd El-Salam and G, 2015). The result of this study had no significant variation between heavy metals except Zn. High concentrations of Zn can be attributed to disposal of large quantities of industrial wastes within landfills (Abd El-Salam and G, 2015).

4.5.1. Feasibility of the study

To mitigate the negative effects of landfill sites such as bad odor, the Egyptian environmental law 4/1994 which was amended in law 9/2009 stated that the boundaries of landfill site have to be far 3 km from housing areas, water streams, water bodies, recreational areas, heritage, and coastal line (Ministry of State for Environmental Affairs, 1994). Therefore, the best practice for the use of landfill leachate instead of water in fired clay- brick manufacturing would be to build a fired clay-brick factory very closed to the landfill boundaries; within the 3 km surrounding the landfill site. This will ease the direct pumping of landfill leachate to the green brick making area in the brick making factory and will help to avoid transportation of landfill leachate to far existing brick making factories. This also will offer an excellent opportunity to utilize the landfill gas instead of heavy oil or natural gas in the burning of the green bricks.

The effects of bad odor on the workers of landfill and brick making could be mitigated by the using of Personal Protective Equipment PPE. In this study, the bad odor of leachate which was used in green brick making was significantly decreased with the natural drying process time (10–15 days) of the green brick and disappeared within few days (2–3 days). In addition, mechanical brick making reduced the number of workers in brick making industries.

Presence of high concentrations of organic substances in landfill leachate would reduce the fuel used in green brick burning as these organic substances has calorific value released in the burning process. Reduction of fuel use in brick burning could be considered an environmental benefit. The organic substances will be broken during burning process to ashes inorganic anions and CO_2. These inorganic anions will be converted to stable anionic compounds contained in the fired brick. The use of waste, leachate without treatment, instead of natural resources, water, are the great environmental and financial benefits in this study.

5. Conclusion

The possibility of integrating leachate into the raw material of fired-clay bricks was studied in this work. The chemical, physical, and mechanical qualities of bricks containing leachate samples originating from sanitary landfill, Alexandria, Egypt, were evaluated. As a result, the properties of the brunt bricks integrating leachate produced in the fired clay- brick factory in El-Amreya district are of acceptable grade, according to the study in comparison with Egyptian standards. Furthermore, incorporating leachate into bricks decreases the continuous and rising demand for vast volumes of water needed in the manufacturing process.

The novelty of this research work

Based on the literature review and to the best of our knowledge, the idea of this research paper is novel, and nobody undertakes research work based on this idea before the research team of this paper. The key advantages of this study activity are the preservation of resources, reduction of environmental pollution, cost savings, and production of standard products.

Ethics approval and consent to participate

This article does not contain any studies with human participants or animals performed by any of the authors.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Declaration of Competing Interest

The authors have no conflicts of interest relevant to the content of this article to disclose.

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