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The effect of using scrap tire powder in the perforated brick holes on thermal insulation

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ABSTRACT

In this study, old scrap tire powder was used with building materials commonly used in Iraq, where it was used in some brick holes in the form of powder 0-1 mm (crumb rubber without fabric and metal), and this case, it was called scrap tire powder in bricks [STP-I]. It was compared with the traditional wall that does not contain scrap tires, called [No STs]. A test room has been build prepared for this purpose and a heating source for 8 hours applied on each wall. The comparison was by measuring the temperatures on the inner and the outer surfaces as well as the center of the wall, and comparing the thermal resistance and the heat transferred. The results noted that the addition of this material might be reducing the internal surface temperature by 2.56℃, which is a good incentive for this material's role as a thermal insulator.

1. Introduction

Scrap tires (STs) represent environmental contamination and a public health concern because they can easily become mosquito-breeding sites or can harbor other disease-borne pests Mohammed et al. [1]. Iraq seeks to recycle millions of tires, unrecognized waste disposal in general increases health risks, and lack of economic benefits. Iraq imports 10 million tires from various countries annually according to the statistics of the Iraqi Ministry of planning to supply more than 6 million cars Iraq CSO [2].
In Iraq, the residential sector accounts for over 46% of total energy consumption Mohamed et al. [3] and most of this energy is consumed by air conditioning. The use of thermal insulation to reduce energy consumption in residential buildings is not a common practice. When insulation is used, traditional materials with low thermal conductivity, such as polystyrene, are common Jelle [4]. The development of new insulation materials is an opportunity, as there are several disadvantages associated with the use of polystyrenes, such as poor mechanical resistance, solar degradation, and high cost.

There are two indirect problems; high-energy consumption due to poor insulation of buildings and misuse of land for ST landfills. These problems can be resolved at the same time if the number of STs disposed of is reduced by using them as insulation material in residential buildings and other applications.
Building sustainability is the main goal that researchers look for in their research, many research had dealt with this topic to achieve the necessary recommendations that would raise the level of practical reality in building design Qusay [5]. It was found that the process of sustainability in buildings is achieved by many mechanisms, foremost of which is reducing the cost of electrical energy by reducing the electrical energy spent in the building. The reduction of the cooling and heating in electric power leads to saving money, which is often very expensive, as well as the process of reducing energy consumption, which in turn leads to a reduction in gas emissions from power plants Dawood, M.S [6]. Some applications of ST have been previously reported.

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Nomenclature

C	*Thermal Conductance (W m^{-2} K^{-1})*
k	*thermal conductivity (W m^{-1} K^{-1})*
$q_{cond.}$	*Heat conduction (W m-2)*
R	*thermal resistance (m^2 k /W)*
$R_{(No\ STs)}$	*thermal resistance of wall without scrap tire powder (m^2 k /W)*
$R_{(STP-I)}$	*thermal resistance of wall with scrap tire powder (m^2 K /W)*
T-M	*temperature of the middle wall*
T-L	*temperature of laboratory(℃)*
T-Z	*temperature of test zone(℃)*
T-E	*temperature of the external surface(℃)*
T-I	*temperature of the internal surface(℃)*
$(T-I)^{Max}$	*Max. temperature of the internal surface(℃)*
$(T-I)^{Min}$	*Min. temperature of the internal surface(℃)*
$(T-E)^{Max}$	*Max. temperature of the external surface(℃)*
$(T-E)^{Min}$	*Min. temperature of the external surface(℃)*
Ø	*air volume fraction*

For instance, Yesilata et al. [7], reported that ST scrap tires may be mixed with concrete for use as construction material in exterior walls in order to increase thermal protection. The use of scrap rubber tires (STs) as insulation gives additional features, such as reducing storage space in landfills, in addition to reducing environmental damage and the risk of combustion. Ashraf Fadiel et al. [8] showed that with the increase in the volume of added rubber, the thermal conductivity decreases, as the rubber mortar that contains 40% rubber the thermal conductivity equal to 0.492 [W/m. k], which meaning there is a decrease of 28% for conventional mortar. M. Romero et al. [9] studied experimentally the thermal performance of scrap tire blocks as roof insulators in residential building roofs. They used rubber blocks with dimensions of 30×30×2.54 cm^3 and in both white and black colors. They were placed both on the roof of concrete buildings and studied the thermal performance and the effect of their presence on the temperature inside the room.

In addition to studying the surface without block, but in white color from the facing side to the source of manufactured radiation, which simulates solar radiation. The results showed that scrap tire blocks (STBs) had thermal conductivity more than polystyrene but, the ability of STBs to maintain the interior temperature was nearly similar because of the conduction–convection heat transfer mechanism inside STBs. Also, they showed that STBs-white was performed better as insulating material. (STBs had Rapid loss of heat gain as well as slow gain of thermal energy). This is a good indication of the role of scrap tire blocks in thermal insulation.

Researchers' recommendations included several opinions on reducing energy consumption, the most important of which was the use of insulators in the outer walls, which would create a comfortable environment for occupants while reducing energy bills. In addition, the STs presented certain positive characteristics, such as moisture resistance, mildew, heat, humidity, ultraviolet rays (from the sun), acids, and other chemicals. In addition, STs show a delay in the development of bacteria.

In this study, the focus will be on the efficiency of using scrip tire rubber produced by the tire factory in Al-Diwaniyah (powder 0-1mm) and recycled from used tires in the holes of the brick units used in the construction of the walls and its effect on the thermal insulation in the building.

2.Materials and methods

1.1. Materials

Building materials available in the Iraqi market, perforated bricks with dimensions of 8×12 ×24 cm^3, cement, and sand. The rubber (powder 0-1mm) made from old tire scrap and prepared in Al Diwaniyah Tire Factory /ABRAJ Al KUT Company. Powder rubber tire scrap was used in perforated brick holes and a certificate of examination of conformity to the European standard EN1177 and as well as perforated bricks and mortar.

For two models, the temperature readings for each model are taken by placing the temperature sensors on the outer and inner side of the wall and in the middle of the wall, and by completing the readings, a comparison was made with the results achieved to find out the effect of using scrap tire powder in brick holes.

1.2. Thermal conductivity measurements

1.2.1. Thermal conductivity for structural materials

In this study, Thermal conductivity and some other characteristics of structural materials used in building walls, such as perforated bricks and mortar, are according to the details in the **Table 1.**

Table 1. Thermo-physical characteristics of the layers of the wall[10][11]

material	Thickness (m)	Density (kg/ m3)	C (W/m. k)	K (W/ m. k)
External cement mortar	0.02	2050	-	1.08
Perforated bricks[24mm]	0.24	1880	1.37	0.66
Perforated bricks[12mm]	0.12	1880	2.78	0.66
Internal cement mortar	0.02	2050	-	1.08

2.2.2.Thermal conductivity for scrap tire powder

To calculate the thermal conductivity of scrap tire powder, the properties of this material must be known In **Table 2** some properties of scrap tires are shown, which are the result of several previous researches.

Table 2. properties of scrap tires [12, 13]

No	Size in (mm)	Absorption (%)	Specific gravity	Density ton/m^3
1	0-5	-	-	0.40-.46
2	5-10	5.30-8.9	1.1	0.45
3	10-20	0.8-1.3	1.1	0.48

Tire scrap powder takes the shape of the space it contains, when it is placed inside the perforated bricks, it takes the cylindrical shape that contains between its particles the air as shown in **Fig. (1B).**

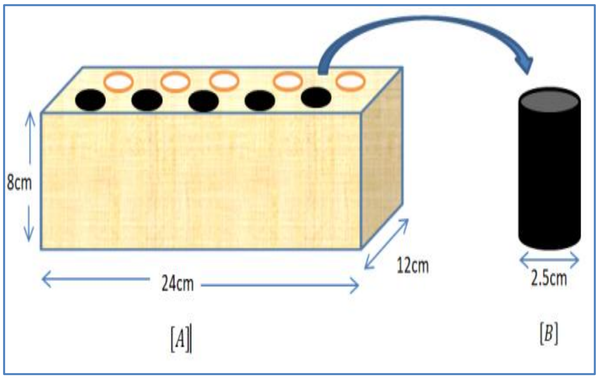

Figure 1. Shows bricks with scrap tire powder.

Therefore, the calculation of the thermal conductivity of scrap tire powder with air in a cylindrical form first, and rubber and air cylinders with bricks second we use the equations listed below to calculate the conductivity of the scrap tire powder;[5]:

$$K=k_1(1-\emptyset)+k_2(\emptyset) \qquad (1)$$

Where k_1 is the estimated thermal conductivity for bricks and k_2 the thermal conductivities of scrap tires powder (STP) with air in a cylindrical shape, respectively, and $\emptyset$ porosity to powder cylinder scrap tire.

To find $\emptyset$:

We measured the weight of the rubber placed in a cylindrical shape, which is equal to 15 grams and the density of 430 kg/m^3 [14]. to find the volume of rubber in the hole:

$$v_{rubber}=\frac{m_{rubber}}{\rho_{rubber}} \qquad (2)$$

The volume of air in a single hole in the brick is equal to the volume of one hole minus the volume of rubber in one hole.

$$v_{air}=v_{hole}-v_{rubber} \qquad (3)$$

$$\phi = v\_air/v\_hole \qquad (4)$$

We substitute the porosity value $\emptyset$ into equation (1) to find the thermal conductivity value of the rubber cylinder and the air

$$k_{rubber\ and\ air}=k_{rubber}(1-\emptyset)+k_{air}.\emptyset \qquad (5)$$

In addition, when putting rubber in the holes of the bricks, it is necessary to find the thermal conductivity of this brick that contains rubber and air cylinders in its holes Therefore, equation (1) is reused. However, the value of $\emptyset$ is found by considering the five holes filled with rubber and air being the porous part of the brick, and finding the size of one hole multiplied by five is the number of holes.

$$V_{(rubber\ and\ air)}=\left[\frac{\pi}{4}D^4\times L\right]\times 5 \qquad (6)$$

$$V_{brick}=L\times D\times H \qquad (7)$$

To find new $\emptyset$:

$$\emptyset=\frac{V_{(rubber\ and\ air)}}{V_{Brick}} \qquad (8)$$

To find the thermal conductivity of the perforated bricks containing the rubber and air cylinders, by substitute the value of $\emptyset$ from equation (8) into equation (1), taking the value k_1 of the perforated bricks is equal 0.66(w/m.℃), [10] the value of k_2 calculated from equation (5)and shows in **Table 2**.

$$K_{\substack{STP\ with\ Air\\ in\ brick}}=k_{bricks}(1-\emptyset)+k_{STP\&\ air}.\emptyset \qquad (9)$$

Table 3. shows steps to measure the thermal conductivity of scrap tires powder in perforated bricks.

	TYPE	K_1(W/m.℃)	K_2(W/m.℃)	$\emptyset$	K_{type}(W/m.℃)
1	Cylinder STP with Air	K_{STP} = 0.19[7]	K_{air} = 0.024 [6]	$\emptyset$=0.112 from eq. (4)	$K_{STP\ \&\ Air}$ = 0.145 from eq. (5)
2	STP with Air in 5 holes of brick	$K_{brick12cm}$ = 0.66	$K_{STP\ \&\ Air}$ = 0.145	$\emptyset$=0.08522 from eq.(8)	$K_{\substack{STP\ Air\\ in\ brick}}$ = 0.616 from eq.(9)

2.2.3.The experimental model and heat source

2.2.3.1.The experimental model

The experimental model involves two parts, a small room (cubic box) to compare two environments (inside and outside the box zone). This because there was a need for a small room inside the laboratory to compare its temperature with the laboratory temperature. The room was created with dimensions 110 cm×110 cm ×110 cm of sandwiched material with 5 cm in thickness. The wall samples that were used for comparison were fitted in square-shaped open created in one of its walls with dimensions of 60 cm ×60 cm. A wooden frame is installed inside that hole with identical dimensions and 5 cm in thickness as shown in **Fig .2.**

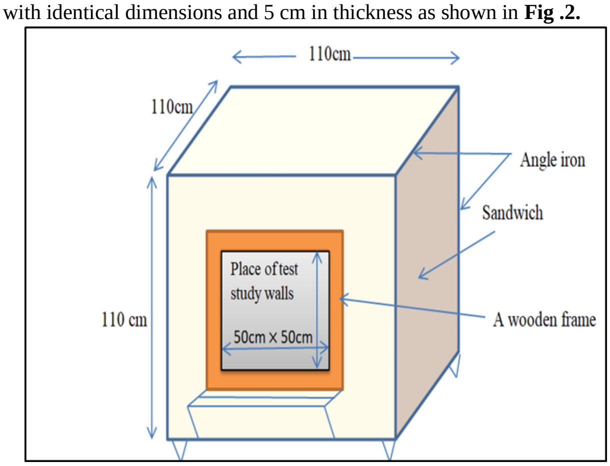

Figure 2. A 3D view for the experimental room (adiabatic box).

2.2.3.2.Heat source

To simulate solar radiation inside the laboratory, an iron structure was created to carry lamps that highlight the sample under study, which we called a solar simulator. It consisted of the following:

•The structure made of iron is a rectangular section 2.5 cm×10 cm and with dimensions of inside 50 cm×50 cm. This frame is attached to a steel pole ended with a circular base.

•The heat generated with four lamps with a capacity of each lamp is 1000 watts, the dimensions of 25 cm×15 cm. These lamps are fixed inside the iron structure, as shown in **Fig .3**.

•An electrical board that contains a circuit breaker to separate and connect each lamp from the lighting lamps, 4 circuit breakers, each with a capacity of 10 amperes. This board is installed on the side of the iron frame.

•A voltage regulator is worked to control the intensity of the incident lighting from the lamps by increasing and decreasing the voltage. The capacity of this regulator is about 10000 watts.

Figure 3. Heat source or solar simulator

2.3. Preparing test walls samples

Test models were built inside the wooden frame with dimensions of 50 cm * 50 cm, consisting of building materials available in the Iraqi market, perforated bricks with dimensions of 8 cm * 12 cm * 24 cm, cement, and sand. The rubber powder is made from old tire scrap and prepared in Al Diwaniyah Tire Factory /ABRAJ Al KUT company. Powder rubber tire scrap was used in perforated brick holes, it represents the last model. **Fig .4** shows the experimental setup for each test wall.

1- The first model included a conventional wall without scrap tire powder(No STs)

2- The second model a conventional wall containing scrap tire powder(STP-I) in the outer perforations line from the wall facing to the heating source as shows in **Fig .4**.

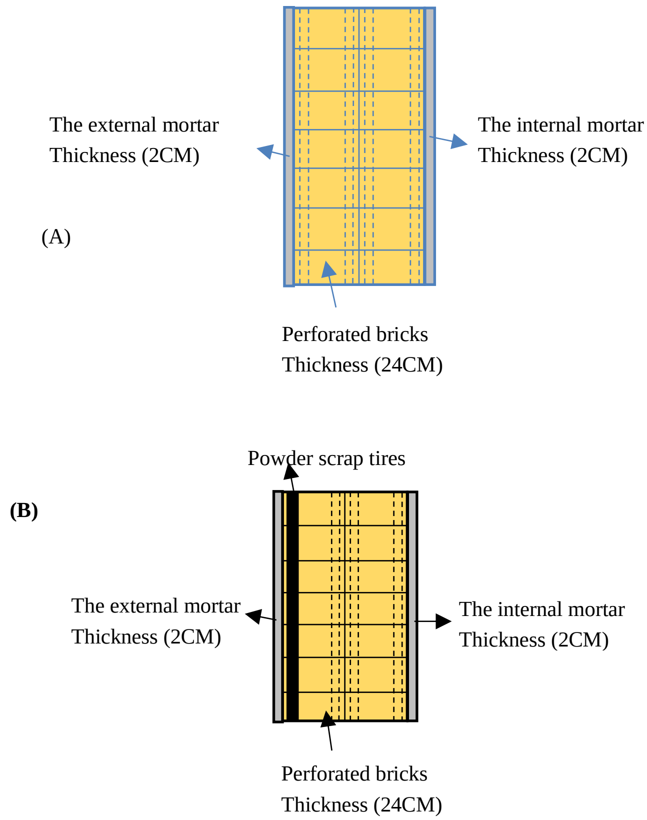

Figure 4. (A)The first model shows a conventional wall[28mm] without scrap tire powder(No STs), and(B) the second model shows a conventional wall[28mm] that contains scrap tire powder(STP-I) in the front holes facing the heating source.

For the test models, after the heat source was turned on for 8 hours on the external surfaces, the temperature readings were taken by placing the temperature sensors type (K) on the outer and inner side of the wall and in the middle of the wall. The readings data was recorded by using a data logger (AT4516) and these results are compared with the results achieved from the traditional wall.

1-For first model

Building a model number one with dimensions of 50 cm * 50 cm * 28 cm inside the wood frame using perforated bricks, sand, cement, and coating from the inside and outside as shown in **Fig .5**. After the wall becomes completely dry, the temperature sensors are installed on the front side of the wall outside the small room and the backside of the wall inside the small room and in the middle of the wall as well, and a sensor is also placed in the middle of the small room to measure the temperature change in it, and then heat is projected by the lighting on it from the solar simulator. as shown in **Figs 6 & 7**.

The mechanism referred to earlier in this chapter, which is placed 50 cm from the front of the wall, and the solar simulator is run for eight hours, and the intensity of the incident light is read in units of watts of square meters on the front wall every hour using the solar radiation meter. The multi-channel thermometer measures the temperatures in each sensor in addition to measuring the laboratory temperature during the heating period of the wall using solar simulation. All recorded data are saved in the Excel program and shows in **Fig .8**.

Figure 5. steps of build model NO. 1

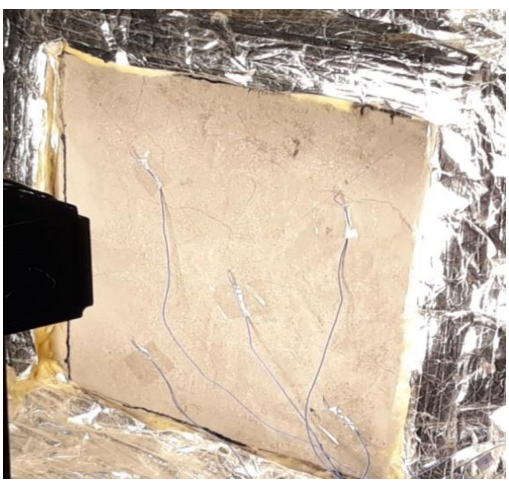

Figure 6. Install sensors on both sides of the wall and in the middle of the room

Figure 7. Apply heat source about 1200 w/m^2 and measurement of temperatures by data logger AT4516

2-For second modelWe follow the same steps as in the first model, but by using scrap tires powder in the holes in the bricks (15g/hole), as shown in **Figs 8,9,** and **10**.

Figure 8. Put 15g of scrap tire powder into one hole

Figure 9. Put the tire scrap power in the line of the outer holes during construction

Figure 10. Apply heat source and measurement of temperatures in model No.2

2. Parameters used in this study

The range (R): is the difference between the maximum and minimum temperatures (Eq. (1)), calculated as follows [5]:

$$R = T_{max-}T_{min} \qquad (10)$$

Decrement factor: is an important factor in building energy consumption calculations, which is the ratio between an amplitude of the internal wall temperatures to an amplitude of the exterior wall temperatures and symbolized by the symbol (f)[15]. (Eq.(2))

$$f = \frac{A_i}{A_E} = \frac{(T-I)Max-(T-I)^{Min}}{(T-E)^{Max}-(T-E)^{Min}} \qquad (11)$$

Heat conduction through materials is governed by Fourier's law, which is based on an observation made based on experimental evidence. Fourier's law states that heat rate (Q_{cond}) is equal to the temperature gradient[**4**]:

$$Q_{cond} = -KA\frac{\Delta T}{x} \qquad (12)$$

The thermal resistance of both the traditional first wall and the second wall containing the scrap tire powder in equations 4 and 5 respectively according to the thermal insulation code[11]

$$R_{(NoSTs)} = \left(\frac{l}{k}\right)_{cement.p} + \left[\frac{1}{c_{bricks24}}\right] + \left(\frac{l}{k}\right)_{cement.p} \qquad (13)$$

$$R_{(STP-I)} = \left(\frac{l}{k}\right)_{cement.p} + \frac{l}{k_{STP\ with\ Air\ in\ brick}} + \left[\frac{1}{c_{bricks12}}\right] + \left(\frac{l}{k}\right)_{cement.p} \qquad (14)$$

3. Results and discussion

1- From **Fig .11**, the temperature on the outer surface increased from 25.04℃ to 88.74℃ when the heating source was turned on, due to the heat absorbed at the outer surface. Because of the thermal diffusivity, the absorbed heat transferred inside the wall, where the temperature in the middle of the wall increased from 25.1 ℃ to 53.4 ℃ . The inner surface reaches a temperature of 22.06℃ to 31.74℃ after 8 hours from the heating process take off.

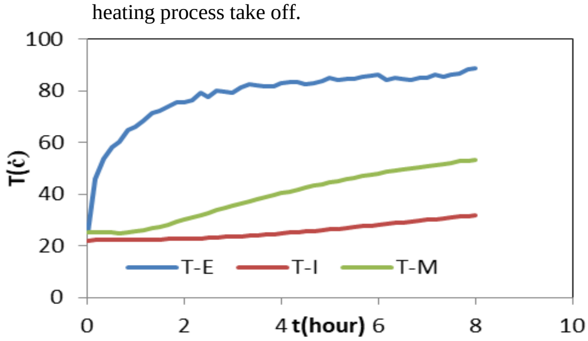

Figure 11. temperatures in external surface T-E, internal surface T-I, and middle of wall T-M in the traditional wall without scrap tires powder (No STs).

2-From **Fig .12**, it finds that the laboratory temperature T-L ranges between 18.1℃-22.3℃, while the temperature of the test zone T-Z rose from 18.9 to 29.1 due to convection and radiation from the inner wall. With a difference of 6.8℃ between them, after 8 hours of heating.

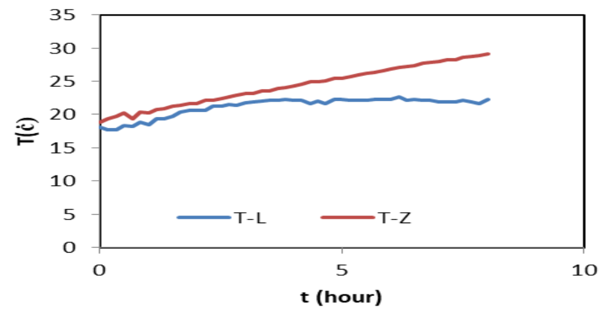

Figure 12. shows temperatures in laboratory T-L and test zone T-Z in No STs

3-From **Fig .13**, for case (STP-I) it can be noticed that the temperature on the outer surface increased from 20.24℃ to 89.36℃ when the heating source was turned on, and thus due to the absorption of the outer surface. As shown in case 2, the absorbed heat transferred inside, the temperature in the middle of the wall increased from 24℃ to 48.6℃ and the inner surface reaches a temperature of 20.52℃ to 29.18℃.

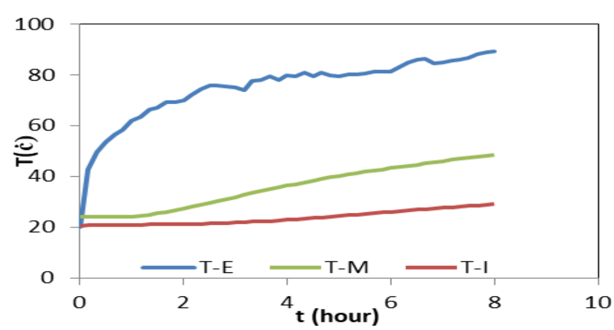

Figure 13. temperatures in external surface T-E, internal surface T-I, and the middle of wall T-M in the traditional wall with scrap tires powder (STP-I).

4-From **Fig .14**, the laboratory temperature T-L ranges between 17.3℃-21.9℃, while the temperature of the test zone T-Z rose from 18.4℃ to 27.1℃ with a maximum difference reach 5.8 oC at the end of the heating process.

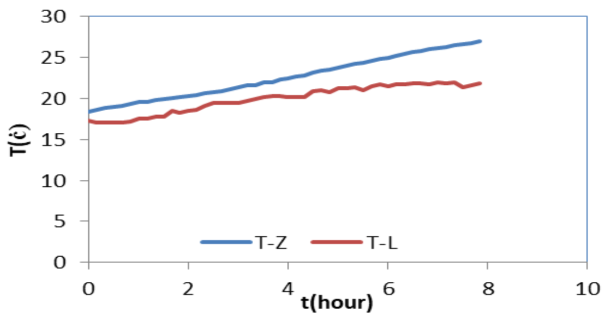

Figure 14. shows temperatures in laboratory T-L and test zone T-Z in STP-I

From **Fig.** 1**5** and at a time of 8 hours, we clearly notice the decrease in temperature along the wall in the case of STP-I compared to the traditional wall due to the presence of rubber in the holes, which affected the increase of the thermal resistance of the wall.

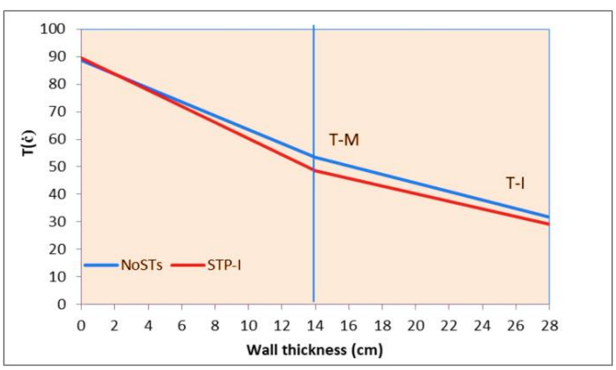

Figure 15 .shows temperatures along the wall in both cases. (**NoSTs) and (STP-I)**

Table 4, summarizes the maximum and minimum temperatures on the interior and exterior surfaces, in addition to the temperature in the middle of the wall for the beginning and end of the 8-hour heating period. The initial and final conditions for both the laboratory and the test room are all explained in the table below.

Table 3. shows temperatures in the external, internal & middle of the wall as well as test zone & laboratory.

Section	No STs		STP-I	
	Max (℃)	Min(℃)	Max(℃)	Min(℃)
T-E	88.74	25.04	89.36	20.24
T-M	53.4	25.1	48.6	24
T-I	31.74	22.06	29.18	20.52
T-Z	29.1	18.9	27.1	18.4
T-L	22.3	18.1	21.9	17.3

From the above table, it was found that the temperature of the laboratory T-L changed about 4 ℃ in the time of operation of the heat source due to the coldness of the atmosphere outside the laboratory, where the walls were tested during the winter season, which increased the transfer of heat by conduction through the laboratory walls to the outside compared to the heat transferred by convection from heat source.

5-From the data in **Tables 1, 2,** and 3 the thermal insulation parameters range on external, internal surfaces, decrement factor (f), and heat conduction, are summarized as shown in **Table 4** below.

Table 4. shows the range on external & internal surfaces, decrement factor (f), and heat conduction for both cases (No STs) & (STP-I)

Section	R-E (℃)	R-I (℃)	f	q (W m^{-2})
No STs	63.7	9.68	0.15	96.33
STP-I	69.12	8.66	0.125	78.41

From the above results, it can be concluded that the amount of heat transferred through the second wall decreased to 78.41(W/m^2) due to the presence of scrap powder in the holes of the bricks, and this is a good and encouraging indicator in the role of this material ST in thermal insulation. Also, the inner surface temperature decreased by 2.56℃. The decrement factor also slows down from 0.15 to 0.125, indicating an increase in the wall's ability when adding scrap tire powder to reduce the amplitude of the temperature on the outer surface to that which is on the inner surface.

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