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EXPERIMENTAL EVALUATING OF THERMAL RESISTANCE PERFORMANCE FOR DIFFERENT TYPES OF THERMAL INSULATORS FOR MOUNTED ROOF WATER STORAGE TANKS

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ABSTRACT

Fluctuating the temperature of water stored in a mounted roof tank in summer and winter has become an issue for domestic uses in developing countries. This study focused to keep the temperature of the stored water low in summer to use it comfortably and relatively high in winter to save energy. Nine water containers were insulated with different types of thermal insulators. The insulators used in this study were: aluminum foil (AF) sheet, Air gap + AF, dry soil + AF, dry canes of arundo donax + AF, fiberglass + AF, polystyrene only, polystyrene + AF, polystyrene + mirror and industrial sponge + AF. The effectiveness of thermal resistance for each individual insulator and for a reference unwrapped container was calculated depending on temperature measurements recorded over 24 hours for both summer and winter cases. The results showed that AF has a significant effect to enhance the thermal insulation efficiency. Industrial sponge + AF provided the best value of thermal insulation effectiveness compared to the other insulators used in the current study. Air gap and arundo donax could be more suitable applications in winter to reduce heating energy consumption.

Keywords: water tanks; overhead water storage; thermal insulation; thermal resistance; radiant barriers.

1. INTRODUCTION

Intermittent water supply service to residential buildings in the developing countries has forced people to store water for later usage. In Iraq, for example, every home has to be provided with at least one water tank which is commonly made from plastic and usually installed on the roof to be the main water supplier for all a house's taps. Despite the city water is supplied with about 33°Cin summer and about 10 ℃ in winter, the temperature of the stored water inside a mounted roof tank increases to 50°Cor more in summer and decreases to 5 °Cor less in winter. According to the US Consumer Product Safety Commission, bathing water temperature should within a range of 21 to 38℃ [1]. Water with approximately a half of the boiling temperature is not just uncomfortable to use, but it also causes third-degree burns for five minutes exposure [2]. Even water with 43℃ could cause serious skin burns especially for elderly people and young children [3]. Also, the risk of cold water in winter is not less that of hot water in summer. The National Center for Cold Water Safety [4] reported risky for different ranges of cold water temperature. Water temperature of 25℃ and below makes breathing difficult, so swimming pools in the Olympic Games are recommended to be in temperature between (25 and 28) ℃. The difficulty in breathing becomes worse and heartbeats boost when a temperature of water in the range of (21-15) ℃. Cold water (15-10) ℃ becomes dangerous and life-threatening. The unsafe cold water that its temperature below 5℃ which is an instantaneous life-threatening and causes a feeling of burning. Moreover, the energy used to heat cold water is another big issue. Statistics Finland [5] reported that the second largest part of the total energy usage is used for water heating purposes.

Thus, integrating a mounted roof water tank with a suitable thermal insulator could help to avoid all the above-mentioned issues.

Fouli [6] investigated the efficiency of insulation for four types of insulators made from natural materials. In his study, two layers of fronds surrounded air gap, two layers of fronds separated by an air gap, palm leaves and two layers of fronds composted with palm leaves were used. The results showed that frond-leaves provided higher thermal resistance compared with other used insulators. In the other study, Fouli *et al.* [7] focused on comfortable levels of domestic water temperature during summer and energy saving to warm up water during winter by using palm-based insulator for water storage tank. Clayton [8] investigated the effect of the color of storage water tank and shade intensity on the temperature of the stored water. He found that a light color and intensive shade helped to keep stored water temperature relatively low in hot seasons.

In the current study, investigation of nine types of natural and industrial materials used to insulate water plastic containers was conducted experimentally. The study aimed to keep the temperature of stored water low in summer and not too cold in winter under Iraqi climate.

2. METHODOLOGY

2.1 Experimental setup

Ten plastic containers were used in the present study. The length and mean diameter of the container were 25cm and 22cm, respectively as shown in Figure-1. This size of containers was used to handle the setup easily.

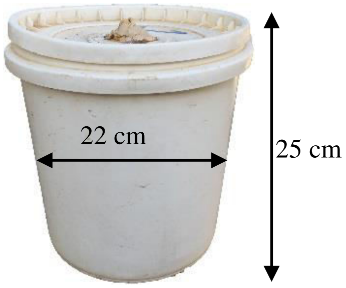

Figure-1. Dimensions of the water container used in the present study.

The containers were mounted on a roof of a house located in Kerbala City (Latitude: 32°36' and Longitude: 44°01'). The containers were separated in a circle pattern with a suitable distance to avoid shads effects of one container to the others as shown in Figure-2. One container was left always unwrapped to be a reference for comparison purposes with other insulated ones. The other containers were insulated with different material to investigate their effectiveness of thermal insulation in a hot and cold environment. All containers were filled with tap water, and a thermocouple prop K-type with an uncertainty of ± 1.1 °Cwas inserted inside each container. All wires of the thermocouples were connected to 12 channels temperature recorder model: BTM-4208SD to record the temperature of the stored water as well as the temperature of ambient air over 24 hours. Two tests were conducted in the present study: one in summer and the other in winter.

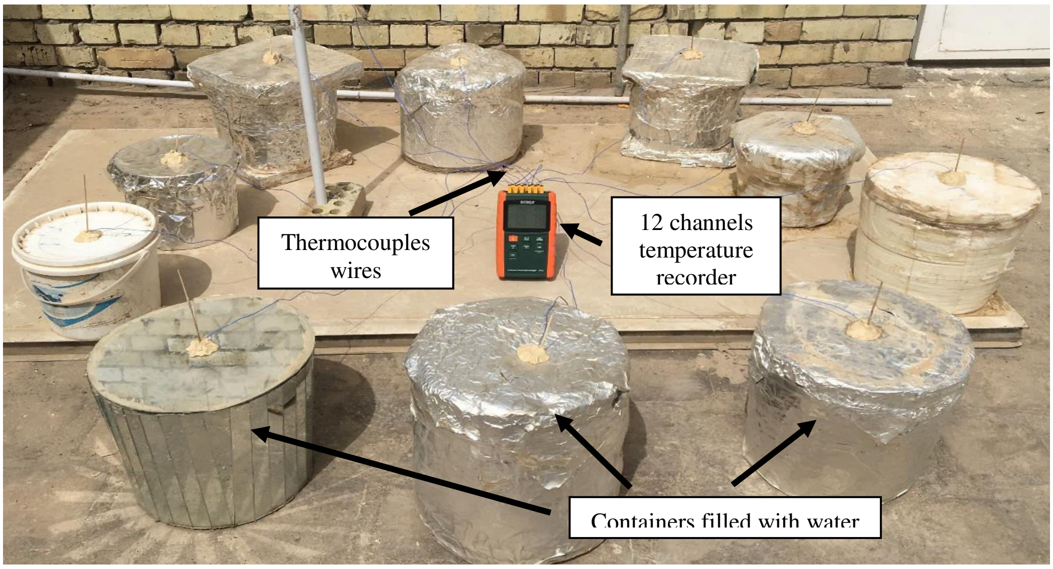

Figure-2. Photo of the experimental setup.

Figure-3 shows photos of thermal insulators used in the current study. A reference container was always kept without insulation as shown in Figure-3.a. Next to it, container (b) was warped with only aluminum foil (AF) sheet. Air gap was also used to insulate container seen in Figure-3.c. The air gap was created by using multiple air-filled juice cartons, each one dimensioned (15×5×3) cm, glued side by side and warped around the container. Dry soil with a thickness of about 3 cm was used to insulate the container shown in Figure-3.d. Another natural material used in this study was dry canes of arundo donax which is planted neutrally and widely in the south and middle of Iraq. The dry canes of arundo donax were cut to the desired length and warped to create two layers around the container as declared in Figure-3.e. The container shown in Figure-3.f was warped with a layer of industrial fiberglass. Containers seen in Figure-3.g-i were insulated with two layers of polystyrene by cutting sheet with a thickness of 1.5 cm into desired pieces and warped around the containers by adhesive tape. Finally, the container shown in Figure-3.j was warped by a layer of industrial sponge with a thickness of about 3 cm. In addition to the thermal insulators, all containers covered by the radiant barrier except the reference container. Aluminum foil (AF) was used as a radiant barrier for all insulated containers except container shown in Figure-3.g which covered by mirrors.

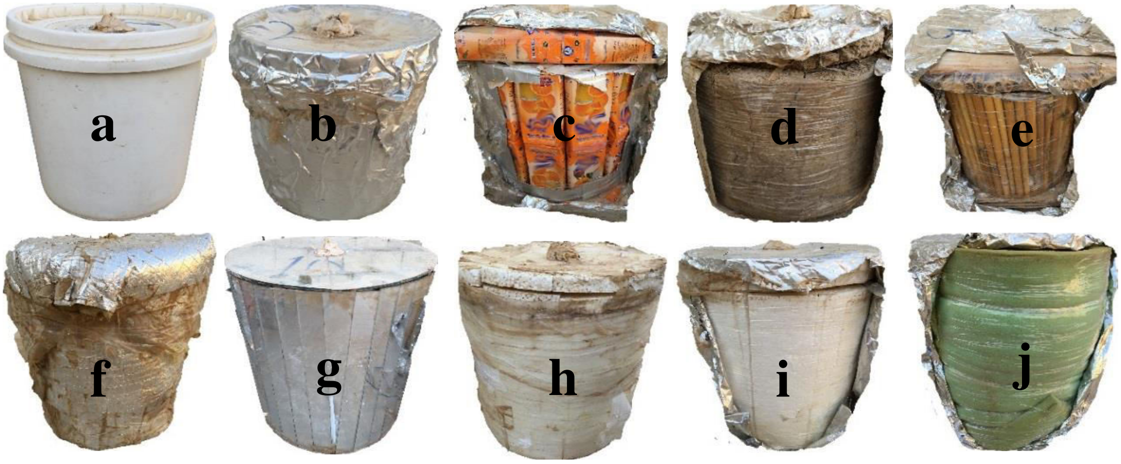

Figure-3. Photos of insulators used in the present study: (a) reference container (no insulation), (b) aluminum foil (AF) sheet only, (c) air-filled juice cartons + AF, (d) dry soil + AF, (e) dry canes of arundo donax + AF, (f) fiberglass + AF, (g) polystyrene + mirror, (h) polystyrene only (i) polystyrene + AF and industrial sponge + AF.

2.2 Experimental procedures

Two tastes were conducted in the current study: one in summer and the other in winter. In August 2017, summer test was done by filling the containers with tap water supplied from city water with temperature about 33°C. After that, the temperature of the stored water inside the containers ware recorded over 24 hours by using thermocouple props K-type connected to the data logger as shown in Figure-2. The same scenario was repeated in January 2018 to do the winter test in which city water temperature was about 10 °C.

3 RESULTS AND DISCUSSIONS

3.1 Results of summer case

Figure-4 shows different fluctuations of water temperature trends according to the type of insulation due to the changing of the ambient air temperature. Water temperature in the reference container increased significantly along with ambient air temperature and hit peak temperature at around 4 PM. Then, it kept being higher than ambient air temperature until the end of the test period used in this study. That happened due to water's thermal storage characteristics. Covering the water container with only aluminum foil (AF) helped to keep the water temperature low during the peak hours. However, it caused to keep it higher than that in the reference container during the night. Dry soil and fiberglass covered by AF sheet had relatively the same thermal insulation performance which kept the temperature lower than that in the reference container during peak time. The rest types of insulations, such as air gap + AF, polystyrene + mirror, arundo donax + AF, polystyrene only, polystyrene + AF and industrial sponge + AF provided good results regarding to keep stored water temperature low during a summer day. In the present study, the best thermal insulator was industrial sponge + AF in which minimized the increase of temperature to just about 4 °C. That provided water with a temperature about 37 °Cthroughout a summer day, which is in range of comfort temperature [1].

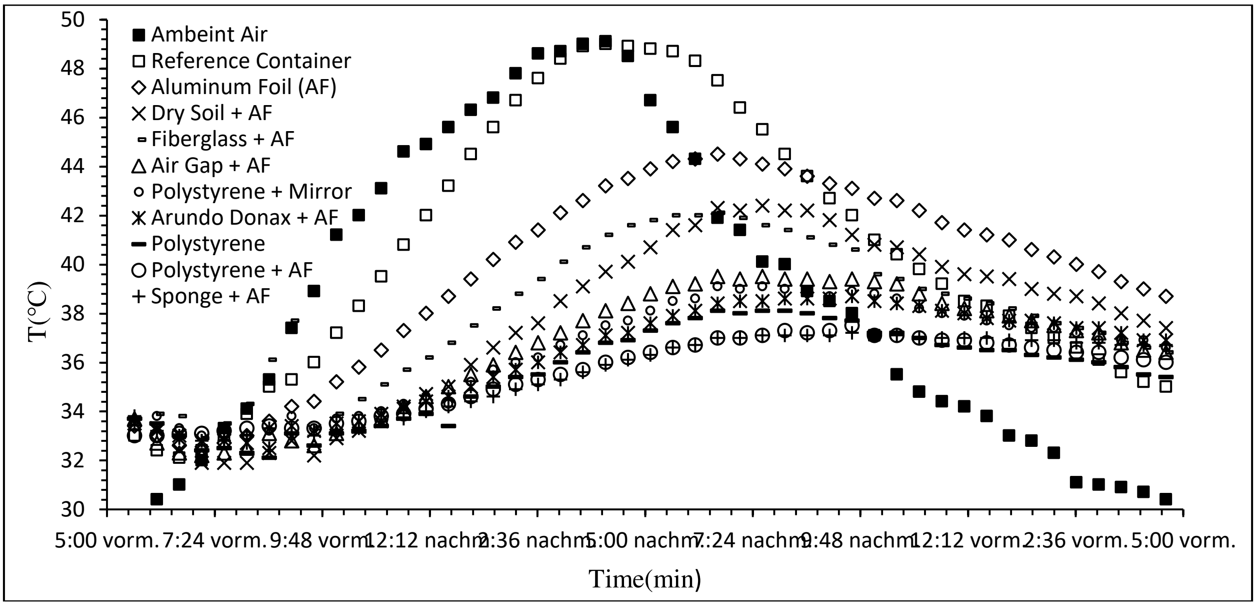

Figure-4. Fluctuating temperature of the water inside containers and ambient air during a summer time.

3.1.1 Thermal insulation effectiveness (ε)

The thermal insulation effectiveness was calculated by equation (1) depending on the peak temperature of both ambient air and stored water as well as the initial state of water.

$$\varepsilon = \frac{T_{a,max} - T_{w,max}}{T_{a,max} - T_{w,in}} \times 100\% \quad (1)$$

Where $T_{a,max}$ is the maximum ambient air temperature(°C), and $T_{w,in}$ and $T_{w,max}$ are the initial and maximum water temperature(°C), respectively. From the results presented in Figure-4, $T_{a,max}$was always greater than T_w.

Figure-5 shows the thermal insulation effectiveness of each type of thermal insulation used in the current study. The reference container provided the lowest thermal resistance. Aluminum foil (AF) boosted the effectiveness of thermal insulation about 28 times as compared with reference container. Dray soil and fiberglass gave almost the same results regarding the thermal efficiency of about 44%. Air gap + AF, polystyrene + mirror and arundo donax + AF provided about 64% in average of thermal efficiency. The highest thermal efficiency of 76% obtained in this study was by using industrial sponge + AF which was higher than those provided by polystyrene only or polystyrene + AF. The effect of sunlight barriers used in the present study (e.g. mirror and AF) seen in the Figure-5. AF was better than mirror from point of radiant reflectivity because it increased the thermal effectiveness.

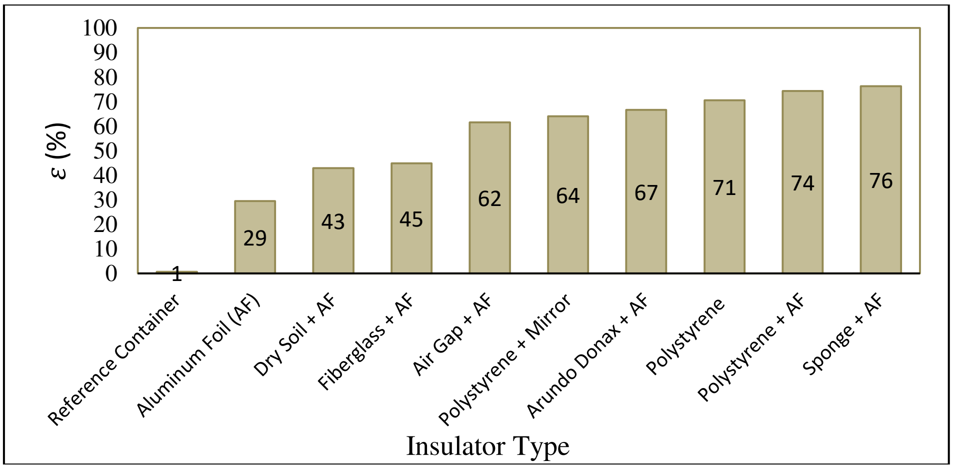

Figure-5. Thermal insulation effectiveness of insulators used in the current study, summer case.

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3.2 Results of winter case

Figure-6 shows the fluctuating temperature of the water stored inside the containers according to the ambient air temperature during a winter time. Unlike the summer case, fewer temperatures fluctuating seen in Figure-6. Almost all temperature measurements were relatively equal for the early night. The lowest ambient air temperature hit about 5.5 ℃ in the early morning for test time used in the present study. The temperature of water stored in the reference container and other containers which insulating with AF only, dry soil + AF or fiberglass + AF fluctuated up and down due to the change of ambient air temperature. The rest types of insulation used in this study performed very well to keep water temperature relatively stable during night time. Polystyrene and sponge were the best in point of thermal insulation. However, in cold weather, it is good to take advantages of sunlight during daytime to preheat water before using an electrical heater. Thus, the insulators of the air gap or arundo donax could be suitable in winter because they provided relatively stable temperature during night time and high temperature during daytime.

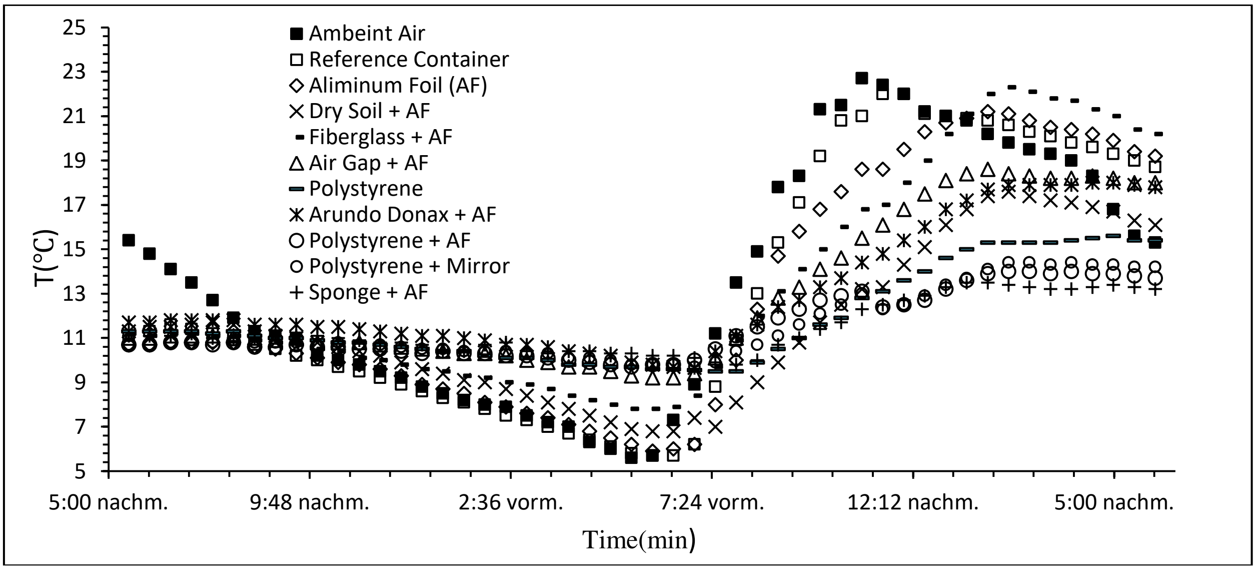

Figure-6. Fluctuating temperature of the water inside containers and ambient air during a winter time.

3.2.1 Thermal insulation effectiveness (ε)

For winter case, the objective is to make water temperature high as much as possible to save heating process energy. Thus, the thermal insulation effectiveness was calculated by equation (2) depending on the lowest temperature recorded for both ambient air and stored water as well as the initial state of water.

$$\varepsilon = \frac{T_{w,min} - T_{a,min}}{T_{w,in} - T_{a,min}} \times 100\% \quad (2)$$

Where $T_{a,min}$ is the minimum ambient air temperature(℃), and $T_{w,in}$ and $T_{w,min}$ are the initial and maximum water temperature(℃), respectively. From the results presented in Figure-6, $T_{a,min}$ was always less than T_w.

Figure-7 shows the thermal insulation effectiveness of each type of thermal insulation used in the current study under cold conditions. Again, the reference container provided the lowest thermal resistance. Aluminum foil (AF) sheet increased the thermal effectiveness about 4 times as compared to that in the reference container. Dray soil and fiberglass gave low values of thermal efficiency, 24% and 43%, respectively. The other types of thermal insulation, such as Air gap + AF, polystyrene only, arundo donax + AF, polystyrene + AF, polystyrene + mirror, and sponge + AF provided better thermal efficiency compared to the reference container or the other thermal insulators used in this study.

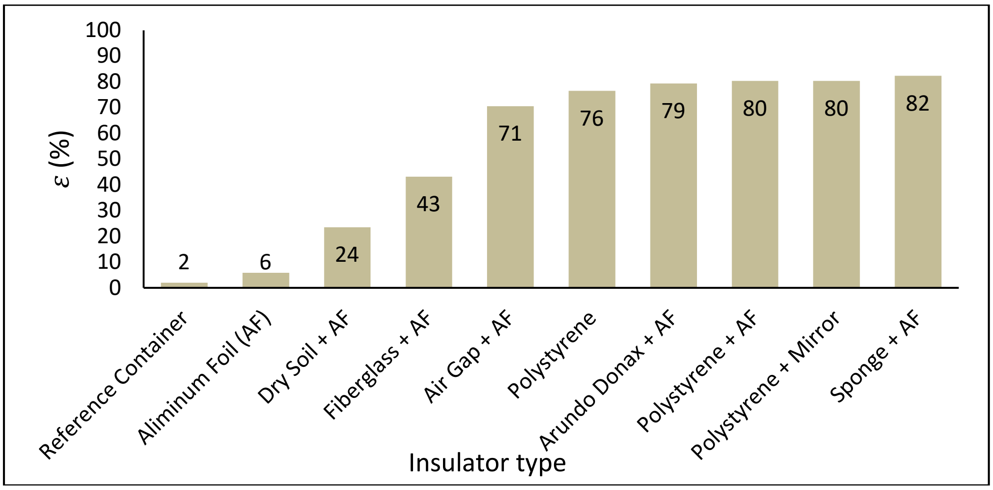

Figure-7. Thermal insulation effectiveness of insulators used in the current study, winter case.

CONCLUSIONS

Nine types of thermal insulation were examined experimentally in the present study to keep water inside mounted roof tanks cool during summer for comfortable usage and relatively high in winter to save heating energy. One reference container was always left without insulation and other nine containers wrapped with different types of thermal insulation, such as aluminum foil (AF) sheet, dry soil + AF, fiberglass + AF, air gap + AF, dry canes of arundo donax + AF, polystyrene only, polystyrene + AF, polystyrene + mirror or industrial sponge + AF. Two tests were conducted in the current study: one in August 2017 and the second in January 2018. The tests were done by filling all containers with tap water and monitoring its temperature along with ambient air over 24 hours for both testes individually. The main conclusions obtained from the present study could be summarized as follow:

a) Overhead water tanks should be wrapped by both thermal and radiant insulator.

b) Radiant insulator (e.g. aluminum foil) not just increases the thermal efficiency resistant but also could keep materials of thermal insulation for longer time.

c) Reflectivity and installation process of aluminum foil sheet was better and easier than those of mirrors.

d) Industrial sponge + AF provided the best thermal insulation efficiency and an easy installation.

e) Air gap + AF and dry canes of arundo donax + AF could be suitable to be used in winter because they provided relatively stable temperature during night time and high temperature during daytime in which heating energy consumption could be reduced.

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