EFFECTIVENESS OF SOME METHODS USED TO REDUCE WATER TEMPERATURE FROM RESIDENTIAL WATER TANKS UNDER HOT AND HUMID CLIMATIC CONDITIONS

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ABSTRACT

During summer months, hot water coming from residential water tanks represent a serious problem for residential and agricultural buildings in the Kingdom of Saudi Arabia (KSA) where water temperature may exceeds 50ºC. Based on that, numerous methods and practices were utilized to reduce the outlet water temperature of incoming from the tanks, the effectiveness of these methods is varying from one to another, so that the decision to choose the appropriate method mainly depends upon the information available from manufacturers. In addition, scientific publication about this problem is relatively scarce. Therefore, in this study, a field and laboratory tests were conducted to determine the effect available various practices (e.g. insulation materials, color, orientation, shading, and cooling techniques) on the thermal performance of the water tanks reaching to the best practice to be adapted to thermally protect water inside the tanks from the harsh external environment (intensity of solar radiation, ambient air temperature, and air relative humidity).

Keywords: Water *tank, Polycon, Fiberglass, Thermal Conductivity.*

INTRODUCTION

The need for a water tank is as old as civilized human, providing storage of water for human drinking water, irrigation of plants, fire suppression, drinking of poultry and livestock, chemical manufacturing, food preparation and many other applications. Water tank parameters include the general design of the tank, and choice of construction materials. Various materials are mainly used for manufacturing a water tank; plastics (polyethylene, polypropylene), fiberglass, concrete, stone, and steel either welded or bolted, carbon or stainless (**Wikipedia, 2014**).

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Householders in Saudi Arabia namely install water tanks for water storage on the roof of buildings in order to provide adequate hydrostatic pressure of supplied water. Furthermore, similar practice was done in the industrial and agricultural activities. Based on the health regulations for drinking water tanks adapted by the ministry of municipal and rural affairs, KSA **(MOMRA, 2013)**; residential water tanks as a place where drinking water collection and storage and preservation of natural and chemical properties, reducing any pollution, reservoir should be in conformity with the technical specifications. Water tanks are classified into several types according to their location and the nature of manufacturing materials for using, and its physical location, as follows:

1- Depending on the location of the water tank includes; underground tank and upper building
2- Depending on materials water tank made of; reinforced concrete, fiberglass, galvanized steel, and polycon (polyethylene).
3- Depending on the nature of use: Special water tanks (include; house water tanks and tanks for complexes or condominiums); and General tanks (include; Schools, mosques, hospitals, prisons, government agencies, emergency, etc., food and water desalination plants, and main tanks for towns and villages

Nowadays, in Saudi Arabia polycon of water tanks are the most popular type used in different shapes and applications. It has a smooth inner layer which helps guard against bacteria, fungus and algae and it has high environmental stress resistance, and can withstand high-pressure impacts, poor temperature conditions and prevents water from ultra-violet radiations, rust and leakage. Polycon water tanks are adaptable to a variety of applications in household, water supply schemes, agricultural farms, chemical plants, defense, hospital, office, schools and colleges (**Polycon Gulf Ltd, 2014)**. Physical properties of polycon water tanks are important to determine the durability of water tanks. As example, thermal protection of the water storage tank is critical **(Tripanagnostopoulos, 2004)**. During summer, hot water coming from water tanks considered as a serious problem especially in residential buildings in Saudi Arabia where water temperature may exceeds 50ºC, as consequence, efforts made to protect water tanks from being heated by solar radiation or by ambient air temperature. Methods and practices were used in order to cool down the water coming from tanks at homes. The effectiveness of these methods are vary and the decision of adopting suitable methods are depending only upon the available information from the manufacturers. The physical properties of polycon water tanks are summarized and listed in **Table (1)**.

Table (1): Some physical properties of polycon water tanks according to the Polycon Gulf co., (2014).

Property	Values
Melt index	5.0 g/10 min
Vicat softening	115.0°C
Density	0.935 g/cm^3
Bulk density	0.420 g/cm^3
Tensile strength at yield	2600.0 Psi
Tensile elongation yield at break	700.00%
Flexural strength	2800.00 Psi
Flexural modulus	105000 Psi
Environmental stress-crack resistance	F 50-300 Hr
Toxicity Free from	Toxic
Water absorption	0.20%

The main objective of this research work is to investigate, test and examine the affecting factors and practices that may be used to control the water temperature inside the residential water tanks.

This project is covered; (1) effect of water tank characteristics included: used material, thermal insulation material, and color; and (2) effectiveness of water thanks cooling methods including: orientation, shading and cooling techniques. This research project was dependent upon realistic and field tests to avoid the theoretical assumptions during this study and realistic results were extended over a complete year to test all the macroclimatic variables.

MATERIALS AND METHODS

A series of experiments were performed during summer and winter seasons using six different horizontal water tanks; four of polyethylene material, one of fiberglass material, and one of steel material. These water tanks were tested and examine during June of 2014 at the Agricultural and Veterinary training and Research Station of King Faisal University, Saudi Arabia (Latitude angle 25.3ºN, longitude angle 49.5ºE, and mean altitude above sea level 172 m) as shown in **Fig. (1)**. The first and second polycon water tanks are of four layers with white color, the third one is of four layers with yellow color, and the last one is of three layers (without insulator) with white color. The fifth water tank is of one layer fiberglass with white color. The sixth water tank is of steel with gray color. The geometric characteristics of six water tanks are listed in **Table (2).**

Fig. (1): Four water storage tanks used during the experimental work.

Table (2): Geometric characteristics for the six different water tanks (experimental setup)

Tank	Material	Color	No of layers	Insulation	Capacity, L	Dimension, cm		
						L	D or W	H
1	Polyethylene	White	4	Foam layer	400	117	73	87
2	Polyethylene	White	4	Foam layer	400	117	73	87
3	Polyethylene	Yellow	4	Foam layer	400	117	73	87
4	Polyethylene	White	3	Non	400	117	73	87
5	Fiberglass	White	1	Non	350			
6	Steel	Gray	1	Fiberglass	350			

Polycon water tanks are usually made of four layers and each layer giving a different advantage for the tank **(Polycon Gulf Ltd, 2014)** as revealed in **Fig. (2)**. First layer (external): preventing dust absorption and resistance to the rays passage, comes in various colors. Second layer (black): blocking all types of radiation, including ultraviolet radiation, thus preventing any type of algae inside the tank. Third layer (polyethylene foam): isolating the outside temperature and prevent it from penetrating the wall of the tank to keep the water temperature is ideal during times of summer. Fourth floor (smooth): a layer of soft snow-white to prevent any accumulation of impurities may cause the bacteria to breed in the inner wall of the tank it is also resistant to corrosion that can occur, which keep water healthy and pure.

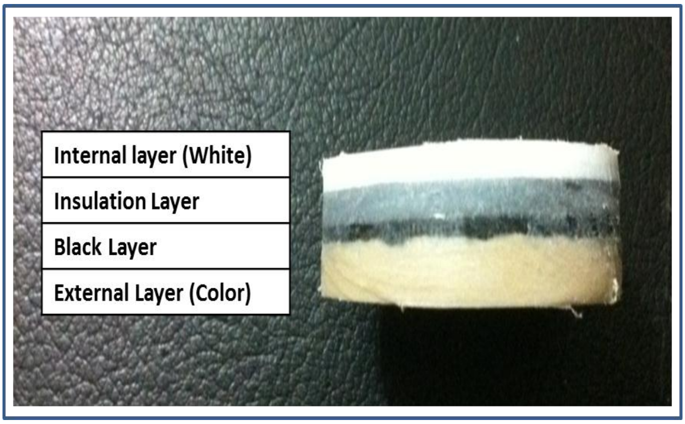

Fig. (2): Polyethylene tanks with different of layers (yellow and white tanks).

To study and examine the effect of insulation layer on the water temperature inside the storage tank, two polyethylene tanks of the same color and two different insultion layers (3 and 4 layers) were functioned during the experimental period as shown in **Fig. (3)**. Two different colors of water storage tank (yellow and white colors) having the same capacity (400 liters) and four layers thick were employed to study the effect of storage tank color on the water temperature as revealed in **Fig. (3)**. To test the effect of orientation on the water temperature inside the storage tank, two different directions (horizontal and vertical directions) having the same capacity (400 liters) and white color with four layers thick were used as illustrated in **Fig. (3)**. To investigate the effect of shading on the water temperature inside the storage tank, two storage tanks of the same capacity (400 liters) of polyethylene material and white color, one water tank was located unerneth a shed of balck net screens and the other situated under normal environmental conditions as demenstrated in **Fig. (3)**. To examine the effect of the external cooling operation on the water temperature inside the storage tank, two water tanks having the same capacity (400 liters) and white color with four layers thick were used, one was equipped with electerical fan and the other tank without cooling fan as shown in as illustrated in **Fig. (3)**. Two water storage tanks of different materials (fiberglass and polyethylene materials) were functioned to study the effect of material on the water temperature as revealed in **Fig. (3)**.

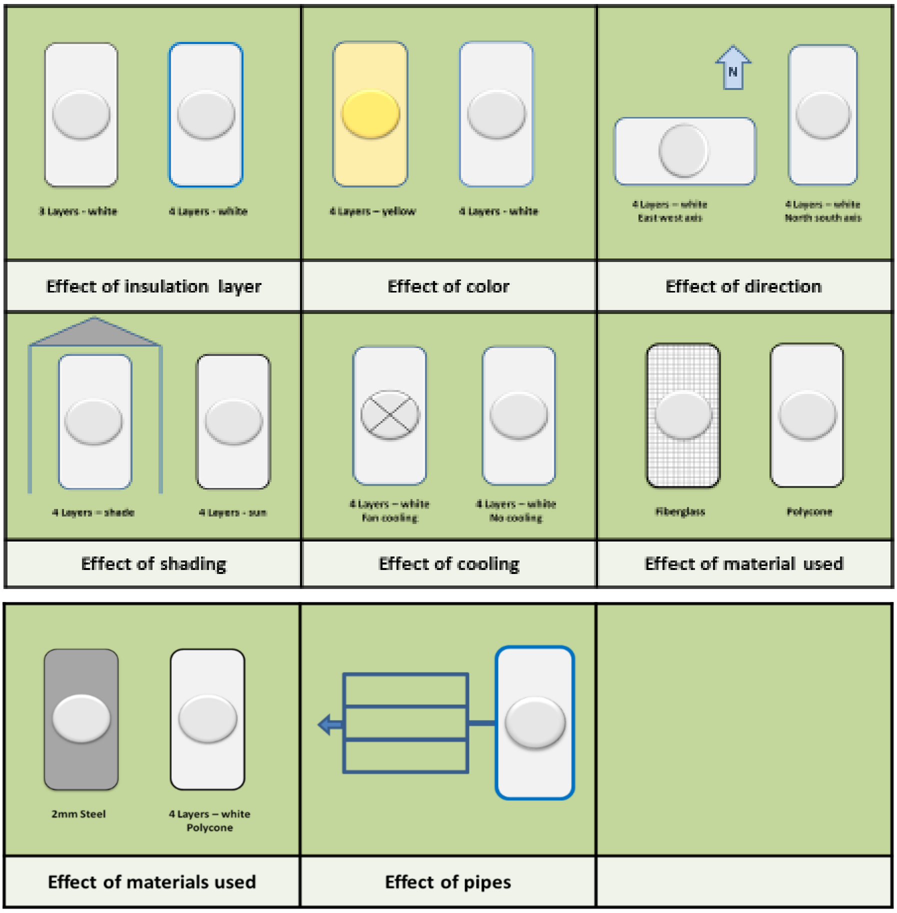

Fig. (3): Schematic diagram of the experimental treatments during this study.

Effect of insulation material:

Thermal conductivity tests:

In the polyethylene tanks, the third layer is namely adding as an insulation layer and functioned to reduce the heat transfer from the surroundings environment to the water inside the storage tank. This layer also increases the strength of the water tank. Samples from different tanks brands were acquired and tested. Heat transfer within the tank walls were measured based on based on ASTM C177-04 standard (Test Method for Steady-State Heat Flux Measurements and Thermal Transmission Properties by Means of the Guarded-Hot-Plate Apparatus) using hot box apparatus. The thermal conductivity was calculated using Fourier's law **(Holman, 2010; Fadiel et al., 2014)** as follows:

$$Q = -k \frac{\Delta T}{L}, \quad W\,m^{-2} \tag{1}$$

Where, Q, is the heat flux in Wm^{-2}, k, is the thermal conductivity of the tank material in $W\,m^{-1}\,{}^{o}K^{-1}$, ΔT, is the temperature potential difference across material section in K and, L, is the thickness of tank material in m.

THERMAL CONDUCTIVITY MEASUREMENT

A specially designed thermal conductivity measurements apparatus were constructed and used based on hot box principle. The principle of measurement is to place the specimen between two boundaries held at constant temperatures. One side was heated by a heat source and the other side kept at room temperature. The box was constructed from homogeneous materials that have stable thermal properties and have high thermal resistance and good mechanical properties. The gross dimensions of the box are113.03 cm high, 40.64 cm wide and 40.64 cm deep (44.5 x 16 x 16 inches) as shown in **Fig. (4)**. The thickness of the surrounding chamber was 5.08 cm (2-in.). In order to minimize the heat losses to its surroundings, the chamber was constructed of Extruded Polystyrene (XPS) layer placed between two layers of Maple plywood with a thickness of 6.35 mm (¼ in.). The three layers were assembled using a heavy duty construction adhesive **(Fadiel et al., 2014)**. The apparatus was calibrated by conducting the test on materials with known thermal conductivities. The reciprocal of thermal conductivity is the thermal resistance, usually expressed in Kelvin meters per Watt ($K\ m\ W^{-1}$). For a given thickness of material, that particular construction's thermal resistance and the reciprocal property, thermal conductance can be determined. For general scientific use, thermal conductance is the quantity of heat that passes in unit time through a plate of particular area and thickness when its opposite faces differ in temperature by one Kelvin. For a plate of thermal conductivity, k, area, A, and thickness, L, the conductance calculated is $k\ A/L$, measured in $W\ K^{-1}$. The thermal conductance of that particular construction is the inverse of the thermal resistance. There is also a measure known as heat transfer coefficient: the quantity of heat that passes in unit time through a *unit area* of a plate of particular thickness when its opposite faces differ in temperature by one Kelvin. The reciprocal is the thermal insulate. Therefore, the following area is very important for this research work: Thermal conductance = $k\ A/L$, in $W\ K^{-1}$, thermal resistance = $L/(kA)$, in KW^{-1}, heat transfer coefficient = k/L, in $WK^{-1}\ m^{-2}$, and thermal insulate = L/k, in $Km^2\ W^{-1}$.

Fig. (4): Apparatus of the hot box.

To measure the heat flux, a device was equipped with HFP01 heat flux sensors as revealed in **Fig. (5).** The body of HFP01 was composed of ceramics-plastic and a thermopile embedded in the plastic ceramic composite (thermopile is a set of connected thermocouples that can measure a small quantity of heat flux). To collect the data from HFP01, an accurate voltmeter that has milli-volt range was used. HFP01 sensor was calibrated using a guarded hot plate according to ASTM C 177. It has sensitivity (E) of 61.37 $\mu V\ W^{-1}\ m^{-2}$. After the voltage output was collected, the heat flux was calculated based on the following formula:

$$Q = V / E \qquad (2)$$

Where, Q, is the heat flux in Wm^{-2}, V, is the measured voltage in volt and, E, is the sensor sensitivity (61.37 µV W – 1 m $^{-2}$).


(a) (b)

Fig. (5): (a) HFP01 heat flux sensor, (b) HOBO data logger

To measure the temperature difference across the specimen, three temperature data loggers are placed from each side of the specimen. HOBO data logger type H08007-02 and Box-Car 3.7 software was used to measure the temperature as illustrated in Fig. (5b). The data logger has two internal temperature sensors and two external sensors. Furthermore, the data logger is programmable in term of time increment and the start and end time as recommended by **Fadiel et al. (2014)**.

Calibration of the Measurement Device

The device was calibrated by testing materials with known thermal conductivity. Four different construction materials were tested for the thermal conductivity. The dimensions of the tested samples were 30.48 cm × 30.48 cm × 2.54 cm (12-in. × 12-in. × 1 in.). The tested samples included: Gypsum board (drywall) with 1.27cm (½ in.) thick, Oriented Strand Board (OSB) with 1.27cm (½ in.) thick, Plywood with 1.27cm (½ in.) thick; Mortar with 2.54 cm (1 in.) thick.

Test Setup

A schematic diagram of thermal conductivity test setup is shown in **Fig. (6)**. The following testing steps were executed for each test: (a) Specimen was mounted and sealed from all sides; (b) The heat flux sensor was attached to the surface of the specimen with the red side facing the heat source as revealed in **Fig. (7)** and heat flux was recorded when it reached steady state; (c) Three temperature loggers were mounted to each side of the specimen using double sided tape. The temperature logger was placed in such way that there was a temperature logger placed across from it on the other side; (d) the door of the box was tightly closed and sealed to ensure no heat loss through the edges of the door, (e) The heat source switched ON till reached the steady state heat flow. The test was run for 90 minutes, and (f) at the end of the test, the data were collected and the thermal conductivity was calculated using Fourier's law as follows:

$$Q = -k\frac{\Delta T}{L}, \qquad W\,m^{-2} \qquad (3)$$

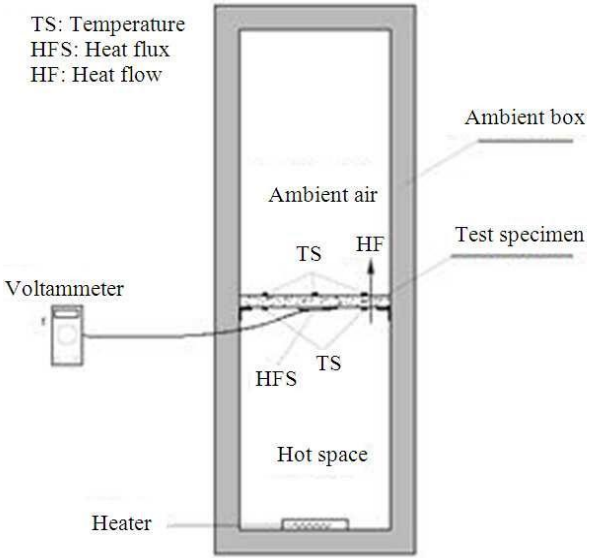

Fig. (6): Schematic diagram of the test set-up

Fig. (7): Heat flux and temperature loggers attached to the specimen

The device was calibrated by conducting the test on materials with known thermal conductivities. The data of these reference materials were obtained from online sources (**www.engineeringtoolbox.comandwww.bca.gov.sg**) and from engineering handbooks. The thermal conductivity of the reference materials and the obtained results are listed in **Table (3)**. The reference values of thermal conductivity (k_{ref}) for different materials were examined against the measured values (K_{exp}) during the experimental period. Regression analysis revealed a highly significant linear relationship ($r = 0.9975$; $P > 0.001$) between these parameters. The regression equation for the best fit was:

$$K_m = 0.011 + 0.964\, k_{exp.} \qquad (4)$$

The statistical analysis also gave a coefficient of determination (R^2) value of 0.995 which indicated a strong relation between the reference and experimental values.

Table (3): Reference and test values of thermal conductivity for different materials

Sample designation	Conductivity (W/ m K)	
	Reference values	Test values
Gypsum board, ½ in thick	0.170	0.1760
Gypsum board, ½ in. thick	0.170	0.1720
Gypsum board, ½ in. thick	0.170	0.1790
Oriented strand board, ½ in.	0.130	0.1495
Plywood with ½ in. thick	0.138	0.1304
Mortar, 2.54 cm (1 in.) thick	0.710	0.6820
Mortar, 2.54 cm (1 in.) thick	0.710	0.6720
Mortar, 2.54 cm (1 in.) thick	0.710	0.7340

Field tests of insulation layer:

Water storage tanks manufacturers claim that the insulation layer added to the tank will greatly improve the insulation capabilities of tanks and will efficiently reduce the heat transfer within the tank wall. In this study, a comparison between four-layer tank (with insulation) and three-layer tank (without insulation) and their effect on the tank thermal performance were carried out.

Effect of tank color:

Light colors (white and yellow) usually used for upper part of tanks, whereas, dark colors used for underground tanks. In this study, the effect of color on the water tanks thermal performance were investigated using two identical polycon water tanks with common used colors (white and yellow).

Effect of tank direction:

Effect of water tank direction and its effect on the exposure area to the sun rays was studied and examined. Therefore, a comparison study between two different directions (east-west and south-north) was investigated using two identical white polycon water tanks (This test will not be applicable for round tanks).

Effect of tank material:

Two commonly used materials (Polycon and Fiberglas) for manufacturing water tanks were tested, a comparison between the thermal performances of each material were investigated and the relation between the thermal performance of polycon and fibreglass tanks was obtained.

Effect of tank shading:

Effect of protecting the water tank from the intensity of solar radiation (shading) and therefore the heating effect were evaluated using two identical white polyethylene water tanks, one underneath the black net shading screen and the other without shading.

Effect of tank cooling techniques:

When a hot water tank without external flow is subjected to the ambient air temperature, a thermal stratification of water is formed in the course of the cooling process. The cold water accumulates at the bottom while hot water ascends to the top of the tank. This phenomenon occurs even if all the water inside the tank is initially at a uniform temperature. Part of this heat is then transferred by diffusion towards the core of the tank. The water of the vertical layer becomes denser than its surrounding and then slips towards the bottom of the tank creating the stratification **(Khalifa et al., 2011)**. Effect of water tank cooling techniques such as; adding cooling fan on the top of the tank, adding cooling fan on the top of the tank and spraying nozzle inside the tank, and connecting the water tank to a mechanical cooling system using heat exchanger on the thermal performances were studied and tested. Power consumption for each technique was evaluated. The cooling fan system consists of the following components as shown in **Fig. (8)**: (1) axial fan (0.31 m diameter, 30 m^3/min capacity, pressure of 13 mm mercury, model Windy DVN-121, Seoul, Korea), (2) cover-chamber, and (3) air-inlet filter. The cross-section area of outlet air and inlet air, respectively, was 0.16 m^2 and 0.11 m^2.

Effect of pipes connected to tank:

Effect of pipes connected to the water storage tank were measured using two identical white polyethylene water tanks, one as standalone and the other was connected to certain length of pipes exposed to sun rays. Amount of heating effect for each unit of pipe length were obtained.

Monitoring of meteorological conditions and data analysis:

Meteorological data, including the intensity of solar radiation flux incident on a horizontal surface, the air temperature and the relative humidity, wind speed and its direction were measured by a meteorological station situated at same test location. Measurements of water temperature inside the water storage tanks and internal and external walls of the tanks were also measured using thermocouple (type K). The temperature sensors were connected to a data-logger system. Heat transfer within the tank wall was measured based on hot box apparatus and based on ASTM C177-04 standard (Test Method for Steady-State Heat Flux Measurements and Thermal Transmission Properties by Means of the Guarded-Hot-Plate Apparatus).

The obtained data from laboratory and field tests were statistically analyzed using PROC GLM of SAS **(Version 9.1, SAS Institute, Inc., Cary, N.C., 2001)**. Treatment means were compared using t test at a significance level of 5%. **Table (4)** shows a comparison of treatment using *t* test.

RESULTS AND DISCUSSION

During the experimental period (June, 2014), the following parameters that affecting the water temperature inside the water storage tank were studied, examined, and tested:

Effect of insulation material

Thermal conductivity (*k*) measurement was determined using the above mentioned designed device. The *k* value was obtained by taking the averages of heat flux passing through the thank walls at steady state condition and temperature difference across the tank walls (specimen) concurrently. These values were used in the Fourier's law (Eq. 3) to calculate the k-values. The results were then modified using Equation 4 which was established by comparing the k-value of known materials by *k*-values obtained for the same materials using the designed apparatus.

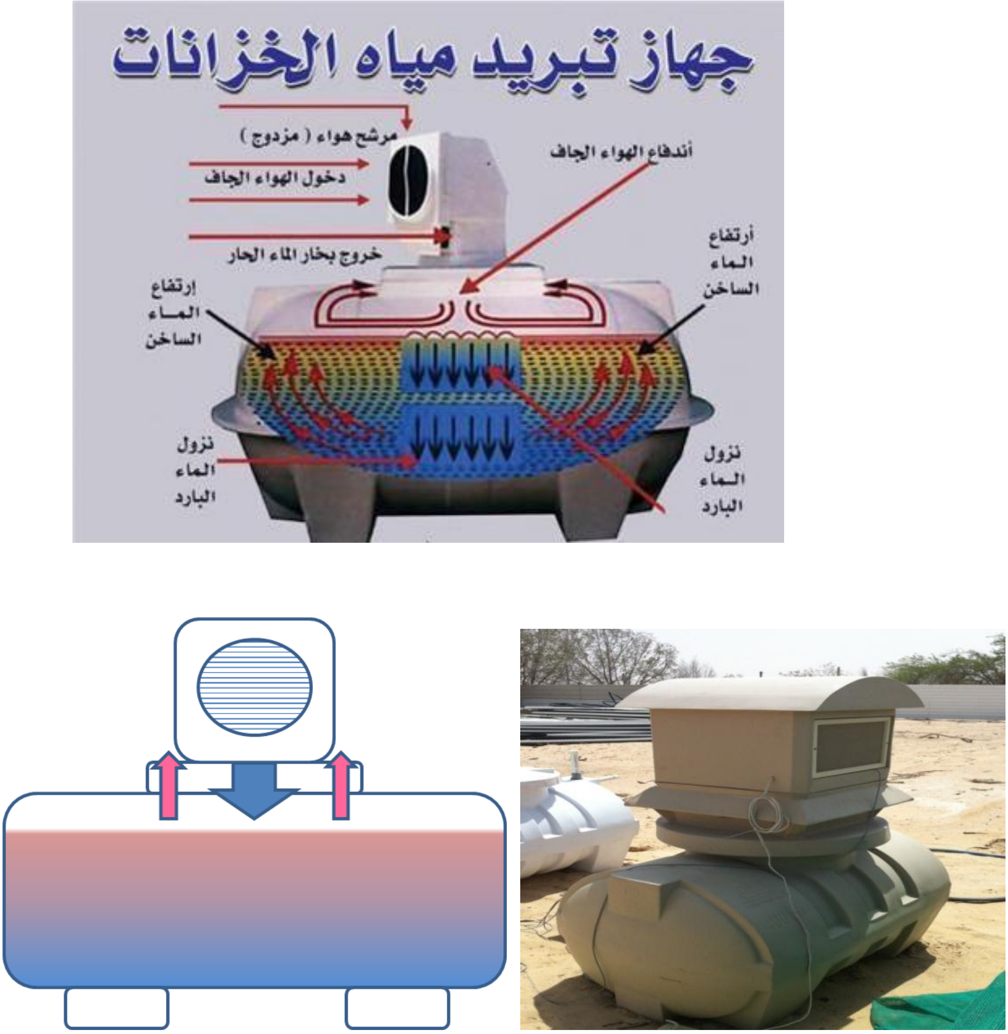

Fig. (8): Polyethylene water tank equipped with cooling fan

Table (4): comparison of treatment using *t* test:

Treatment 1	vs.	Treatment 2	Variable
Reference tank *	×	3 layers tank	Insulation material
Reference tank *	×	Yellow tank	Tank color
Reference tank *	×	south-north	Tank direction
Reference tank *	×	Fibreglass tank	Tank material
Reference tank *	×	Tank with shading	Tank shading
Reference tank *	×	Tank with fan	Tank cooling
Reference tank *	×	Tank connected to pipes	Pipes connected to tank
Reference tank *	×	Steel tank	Tank material
* Reference tank: Polycon – White; 4-layer - no shading – East-west direction - not connected to pipes			

Thermal Conductivity of tank wall:

The obtained results of the thermal conductivity (k) for the tank walls are summarized and listed in Table (3). The thermal conductivity values (k) decrease when the thickness of insulation materials increases regardless of the size of the tank. It was found that the k-value of tank wall varied between 0.593 W/m K to 0.492 W/m K compared to 0.682 W/m K for tank walls without insulation material. This is about 13 to 28% increase in the thermal conductivity. For different types of tank walls, the decrease in thermal conductivity varied based on the availability and size of insulation material. When the thickness of the insulation material increased from 30% to 40%, the reduction in the thermal conductivity was about 2-5%. The results also indicated that the type of material is mainly affected the thermal conductivity.

Field tests:

The maximum, minimum, mean, and standard division of water temperatures inside the water storage tank, intensity of solar radiation and ambient air temperatures for three and four layers insulation materials during the experimental period are summarized and listed in **Table (5)**. The water temperatures inside the two different tanks (3 and 4-layer), intensity of solar radiation, and ambient air temperatures are plotted in **Fig. (9)**. It clearly revealed that, the water temperatures inside the two storage tanks varied from hour to hour day to another during the experimental period. The water temperatures of both tanks gradually increased after 6 am from 33.7 and 34.2°C, respectively, until reached the maximum values at 7 pm (42.5 and 43.0°C, respectively). It also showed that, the mean difference between the water temperature inside the water storage tank of 4-layer tank and 3-layer tank was not significant at ($P<0.05$).

Table (5): Maximum, minimum, mean, and standard division of water temperatures inside the water storage tank, intensity of solar radiation and ambient air temperatures for three and four layers insulation materials during the experimental period

Parameter	3-Layer	4-Layer	Solar radiation, W/m²	Ambient air temperature, °C
Maximum	42.5	43.0	1000.6	48.7
Minimum	33.7	34.2	160.0	25.4
Mean[a]	38.0^a	38.5^a	692.6	36.8
SD	±2.27	±2.27	±290.4	±6.60

[a] Column means followed by the same letter are not significantly different at 95% level of confidence.

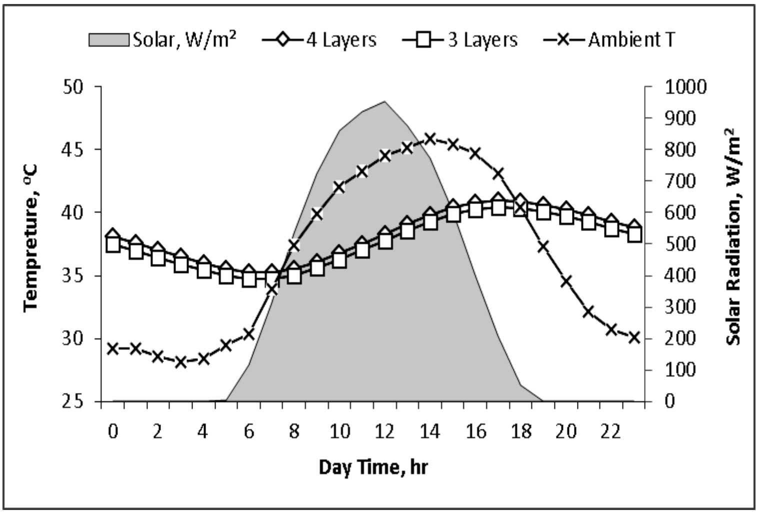

Fig. (9): Hourly average temperatures (3-layer and 4-layer tanks, and ambient air) and solar radiation intensity during the experimental period.

Effect of tank color (white and yellow colors):

The maximum, minimum, mean, and standard division of water temperatures inside the water storage tank, intensity of solar radiation and ambient air temperatures for white and yellow colors of storage tanks during the experimental period are summarized and listed in **Table (6)**.

The water temperatures inside the two different colors of storage tanks (white and yellow colors), intensity of solar radiation, and ambient air temperatures are plotted in **Fig. (10)**. It clearly showed that, the water temperatures inside the two storage tanks varied from hour to hour and day to another during the experimental period. The water temperatures of both tanks gradually increased after 6 am from 36.4 and 38.0ºC, respectively, till reached the maximum values at 7 pm (42.1 and 43.9ºC, respectively). The water temperatures inside the storage tank of white color were always lower than that of yellow color during the experimental period. It also showed that, the mean difference between the water temperature inside the water storage tank of white and yellow colors was not significant at ($P<0.05$).

Table (6): Maximum, minimum, mean, and standard division of water temperatures inside the water storage tank, intensity of solar radiation and ambient air temperatures for white and yellow colors during the experimental period

Parameter	White tank	Yellow tank	Ambient Air, ºC	Solar radiation
Maximum	42.1	43.9	47.6	939.2
Minimum	36.4	38.0	30.2	0.6
Mean[a]	39.3^a	41^b	37.9	497.3
SD	±2.0	±2.1	±6.6	±259.8

[a] Column means followed by the same letter are not significantly different at 95% level of confidence

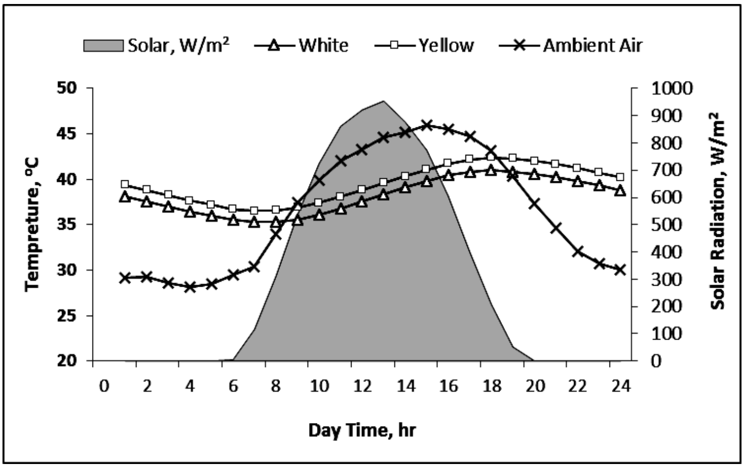

Fig. (10): Hourly average temperatures (white and yellow colors, and ambient air) and solar radiation intensity during the experimental period.

Effect of tank direction (North-South and East-West directions):

The maximum, minimum, mean, and standard division of water temperatures inside the water storage tank, intensity of solar radiation and ambient air temperatures for north-south and east-west directions of storage tanks during the experimental period are summarized and listed in **Table (7)**. The water temperatures inside the two different directions of storage tanks (north-south and east-west directions), intensity of solar radiation, and ambient air temperatures are plotted in **Fig. (11)**. It clearly indicated that, the water temperatures inside the two storage tanks varied from hour to hour and day to another during the experimental period. The water temperatures of both tanks gradually increased after 6 am from 34.9 and 34.2°C, respectively, till reached the maximum values at 7 pm (42.4 and 42.1°C, respectively). The water temperatures inside the storage tank of east-west directions were always lower than that of south-north directions during the experimental period. It also showed that, the mean difference between the water temperature inside the water storage tank of north-south and east-west directions of storage tanks was not significant at ($P<0.05$).

Table (7): Maximum, minimum, mean, and standard division of water temperatures inside the water storage tank, intensity of solar radiation and ambient air temperatures for north-south and east-west directions during the experimental period

Parameter	North-South direction	East-West direction	Solar radiation, W/m²	Ambient air temperature, °C
Maximum	42.4	42.1	981.9	48.2
Minimum	34.9	34.2	186.3	25.1
Mean[a]	38.7^{a}	38.2^{a}	515.4	36.6
SD	±2.0	±2.1	±169.2	±7.4

[a] Column means followed by the same letter are not significantly different at 95% level of confidence.

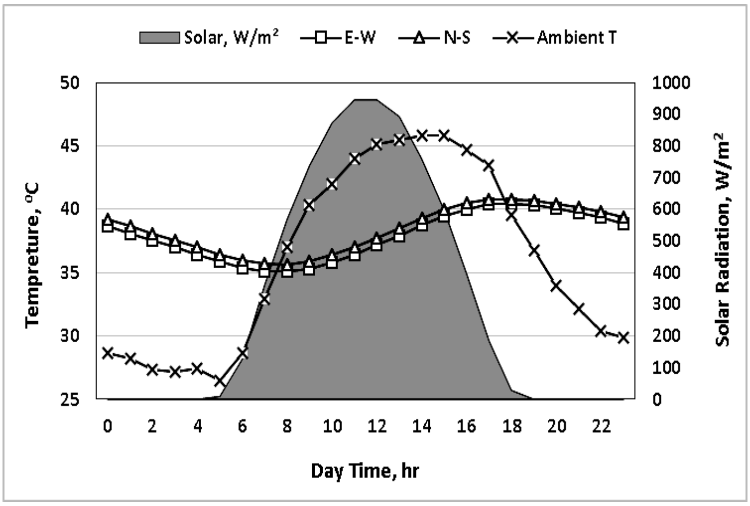

Fig. (11): Hourly average temperatures (north-south and east-west directions, and ambient air) and solar radiation intensity during the experimental period.

Effect of tank material (polycon and insulated steel storage tanks):

Two water storage tanks of two different materials (polycon and insulated steel tanks) were functioned during the experimental period to study and examined the effect of tank material on water temperature as shown in **Fig. (12)**. The obtained date include; the maximum, minimum, mean, and standard division of water temperatures inside the water storage tank, intensity of solar radiation and ambient air temperatures for polyethylene and insulated steel storage tanks during the experimental period are summarized and listed in **Table (8)**. The water temperatures inside the two different materials of storage tanks (polyethylene and insulated steel tanks), and ambient air temperatures are plotted in **Fig. (13)**. It clearly revealed that, the water temperatures inside the two storage tanks varied from hour to hour and day to another during the experimental period. The water temperatures of both tanks gradually increased after 6 am from 35.6 and 38.6°C, respectively, till reached the maximum values at 7 pm (41.4 and 41.4°C, respectively). The water temperatures inside the storage tank of polyethylene were always lower than that of insulated steel tank during the majority of day-time except only from 4.0 to 8.0 pm when the same temperatures were observed. It also showed that, the mean difference between the water temperature inside the water storage tank of polyethylene and insulated steel storage tanks was not significant at ($P<0.05$).

Fig. (12): Two water storage tanks of two different materials (polycon and insulated steel tanks)

Table (8): Maximum, minimum, mean, and standard division of water temperatures inside the water storage tank, intensity of solar radiation and ambient air temperatures for polycon and insulated steel tanks during the experimental period

Parameter	Polycon storage tank	Insulated steel storage tank	Solar radiation, W/m²	Ambient air temperature, ⁰C
Maximum	41.4	41.4	954.8	46.4
Minimum	35.6	38.6	220.4	29.7
Mean[a]	38.5^{a}	40.0^{b}	528.6	37.0
SD	±2.03	±1.01	±149.5	±6.45

[a] Column means followed by the same letter are not significantly different at 95% level of confidence.

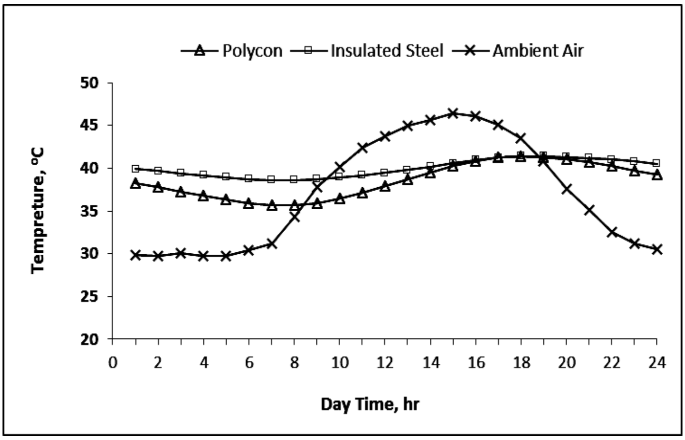

Fig. (13): Hourly average temperatures (polycon and insulated steel tanks, and ambient air) during the experimental period.

Effect of tank material (polycon and fiberglass storage tanks):

Two similar water storage tanks of two different materials (polyethylene and fiberglass tanks) were used during the experimental period to study and tested the effect of storage tank material on water temperature of the two tanks during the experimental period. The obtained date include; the maximum, minimum, mean, and standard division of water temperatures inside the water storage tank, intensity of solar radiation and ambient air temperatures for polyethylene and fiberglass storage tanks during the experimental period are listed in **Table (9)**.

Table (9): Maximum, minimum, mean, and standard division of water temperatures inside the water storage tank, intensity of solar radiation and ambient air temperatures for polyethylene and fiberglass materials during the experimental period

Parameter	Polycon storage tank	Fiberglass storage tank	Solar radiation, W/m²	Ambient air temperature, °C
Maximum	43.4	41.5	989.4	45.8
Minimum	34.1	33.0	160.6	22.8
Mean[a]	38.7^a	37.4^a	604.7	35.6
SD	±2.6	±2.4	±158.5	±6.5

[a] Column means followed by the same letter are not significantly different at 95% level of confidence.

The water temperatures inside the two different materials of storage tanks (polyethylene and fiberglass storage tanks), and ambient air temperatures are plotted in **Fig. (14)**. It clearly showed that, the water temperatures inside the two storage tanks varied from hour to hour and day to another during the experimental period. The water temperatures of both tanks gradually increased after 6 am from 34.1 and 33.0°C, respectively, till reached the maximum values at 7 pm (43.4 and 41.5°C, respectively). The water temperatures inside the storage tank of fiberglass material were always lower than that of insulated steel tank during the majority of daylight-time except only at nighttime 7.0 pm to 3.0 am when the same temperatures were observed. It also showed that, the mean difference between the water temperature inside the water storage tank of polyethylene and fiberglass storage tanks was not significant at ($P<0.05$).

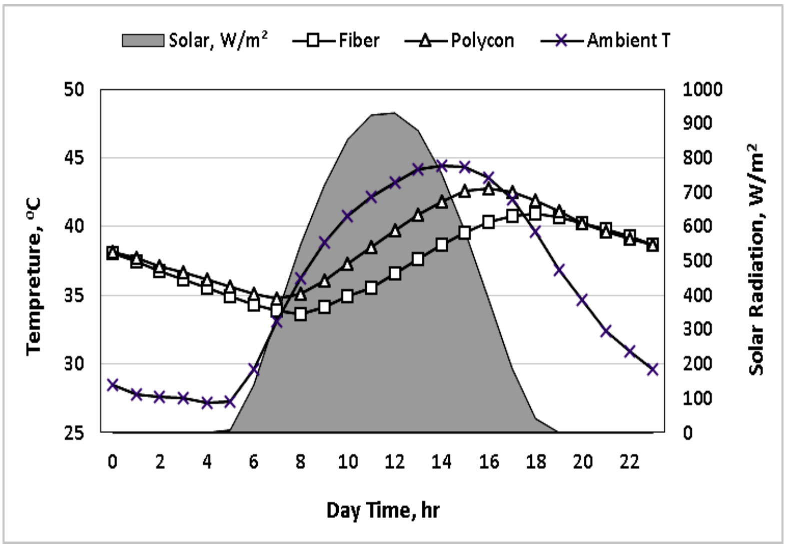

Fig. (14): Hourly average temperatures (polyethylene and fibreglass storage tanks, and ambient air) and solar radiation intensity during the experimental period.

Effect of shading on water temperature:

To study and examine the effect of shading on the water temperature of the storage tank, two identical water storage tanks were functioned; one was located underneath black screens (shaded tank) and the other without shading. The maximum, minimum, mean, and standard division of water temperatures inside the water storage tank, intensity of solar radiation and ambient air temperatures for shaded and not shaded storage tanks during the experimental period are summarized and listed in **Table (10)**. The water temperatures inside the two different conditions of storage tanks (with shading and without shading), intensity of solar radiation, and ambient air temperatures are plotted in **Fig. (15)**. It clearly showed that, the water temperatures inside the two storage tanks varied from hour to hour and day to another during the experimental period. The water temperatures of both tanks gradually increased after 6 am from 36.3 and 36.0°C, respectively, until reached the maximum values at 5 pm (41.6 and 44.8°C, respectively). The water temperatures inside the storage tank underneath a black screen were always lower than that of the storage tank without shading particularly during the daylight-time. However, the mean difference between the water temperature inside the water storage tank of shaded and not shaded storage tank was not significant at $(P<0.05)$.

Table (10): Maximum, minimum, mean, and standard division of water temperatures inside the water storage tank, intensity of solar radiation and ambient air temperatures for shaded and not shaded storage tanks during the experimental period

Parameters	Storage tank with shading	Storage tank without shading	Solar radiation, W/m²	Ambient air temperature, ºC
Maximum	41.6	44.8	945.1	45.4
Minimum	36.3	36.0	146.8	32.5
Mean[a]	38.9^b	40.2^a	590.1	38.4
SD	±1.8	±2.9	±159.6	±4.7

[a] Column means followed by the same letter are not significantly different at 95% level of confidence

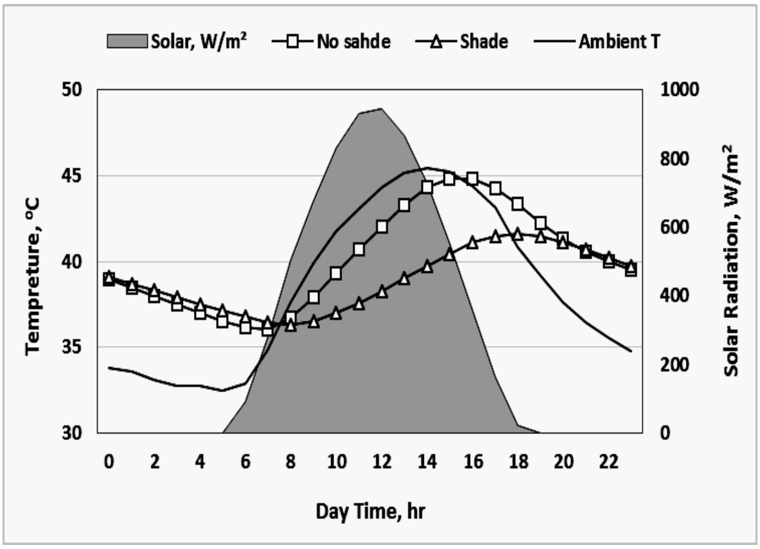

Fig. (15): Hourly average temperatures (with shading screen and without shading storage tanks, and ambient air) and solar radiation intensity during the experimental period.

Effect of cooling technique (with shading screen and without fan):

Two identical water storage tanks, one was equipped with air-fan and the other without fan were functioned during the experimental period to study and examined the effect of cooling technique on water temperature as shown in **Fig. (16)**. The obtained date include; the maximum, minimum, mean, and standard division of water temperatures inside the water storage tank, intensity of solar radiation and ambient air temperatures for storage tank with fan and storage tank without fan during the experimental period are summarized and listed in **Table (11)**. The water temperatures inside the two different conditions of storage tanks (with fan and without fan), intensity of solar radiation, and ambient air temperatures are plotted in **Fig. (17)**. It clearly revealed that, the water temperatures inside the two storage tanks varied from hour to hour and day to another during the experimental period. The water temperatures of both tanks gradually increased after 6 am from 20.3 and 33.8°C, respectively, until reached the maximum values at 5 pm (30.5 and 44.6°C, respectively). The water temperatures inside the storage tank equipped with electric fan were always lower than that of the storage tank without fan throughout the day-time (during daylight and at night). The mean difference between the water temperature inside the water storage tank equipped with electric fan as compared with the storage tank without fan was highly significant at ($P<0.05$).

Fig. (16): Two identical water storage tanks; one equipped with fan and the other without fan.

Table (11): Maximum, minimum, mean, and standard division of water temperatures inside the water storage tank, intensity of solar radiation and ambient air temperatures for storage tank with fan and storage tank without fan during the experimental period

Parameters	Storage tank with fan	Storage tank without fan	Solar radiation, W/m²	Ambient air temperature, °C
Maximum	30.5	44.6	989.4	49.1
Minimum	20.3	33.8	170.6	26.4
Mean[a]	25.6^b	38.4^a	302.4	35.4
SD	±2.6	±2.4	±148.7	±6.4

[a] Column means followed by the same letter are not significantly different at 95% level of confidence

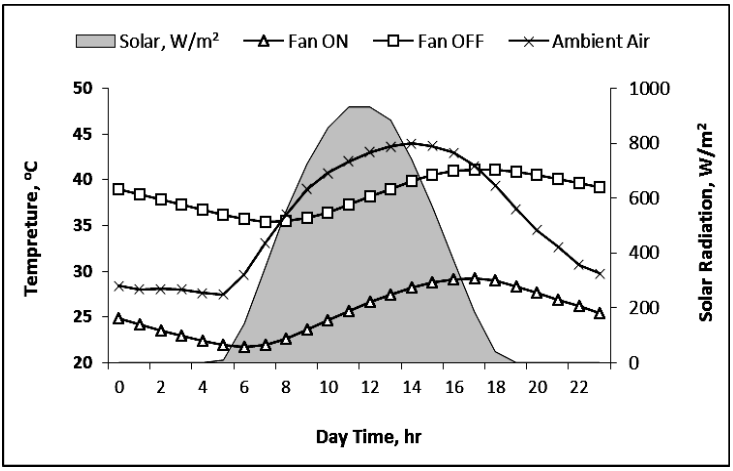

Fig. (17): Hourly average temperatures (with electric fan and without fan storage tanks, and ambient air) and solar radiation intensity during the experimental period.

Effect of pipes connected to the storage tank (with pipes and without pipes connections)

Two identical water storage tanks, one was equipped with water net work of pipes and the other without pipes were used during the experimental period to study and examined the effect of water network pipes on water temperature. The obtained date include; the maximum, minimum, mean, and standard division of water temperatures inside the water storage tank, intensity of solar radiation and ambient air temperatures for storage tank with water network pipes and storage tank without pipes during the experimental period are summarized and listed in **Table (12)**. The water temperatures inside the two different storage tanks (with water network pipes and without pipes), intensity of solar radiation, and ambient air temperatures are plotted in **Fig. (18)**. It clearly indicated that, the water temperatures inside the two storage tanks varied from hour to hour and day to another during the experimental period.

Table (12): Maximum, minimum, mean, and standard division of water temperatures inside the water storage tank, intensity of solar radiation and ambient air temperatures for storage tank with fan and storage tank without fan during the experimental period

Parameters	Storage tank with pipes	Storage tank without pipes	Solar radiation, W/m²	Ambient air temperature, °C
Maximum	42.1	40.2	980.6	47.3
Minimum	31.9	30.9	157.9	23.0
Mean[a]	37.0^{b}	35.6^{a}	602.1	34.8
SD	±2.53	±2.25	±160.9	±6.4

[a] Column means followed by the same letter are not significantly different at 95% level of confidence

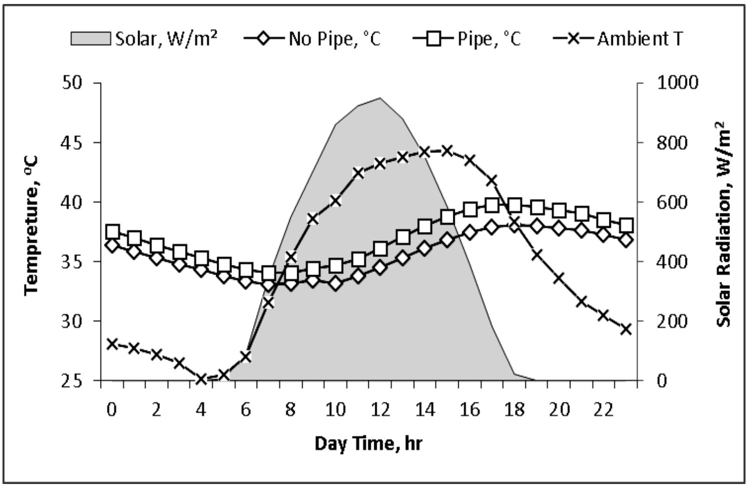

Fig. (17): Hourly average temperatures (with electric fan and without fan storage tanks, and ambient air) and solar radiation intensity during the experimental period.

The water temperatures of both tanks gradually increased after 6 am from 31.9 and 30.9°C, respectively, until reached the maximum values at 5 pm (42.1 and 40.2°C, respectively). The water temperatures inside the storage tank equipped with water network pipes were always higher than that of the storage tank without pipes particularly during the daylight-time. However, the mean difference between the water temperature inside the water storage tank with network pipes and without pipes storage tank was not significant at ($P<0.05$).

The water temperature just leaving the storage increased during passing through the pipes network of 10 m long and 2.54 (1 inch) diameter from 37.2ºC to 53.5ºC as revealed in **Fig. (18)**. Due to the pipes network length (10 m) and commonly exposed to the macroclimatic conditions including the intensity of solar radiation and ambient air which usually very high (674.4 W/m^2 and 41.9ºC), the water temperature just draining from the pipes network was increased. The hourly average water temperature just leaving the storage tank, water temperature just draining from the pipes network, solar radiation intensity, and ambient air temperature are and listed in **Table (13)**.

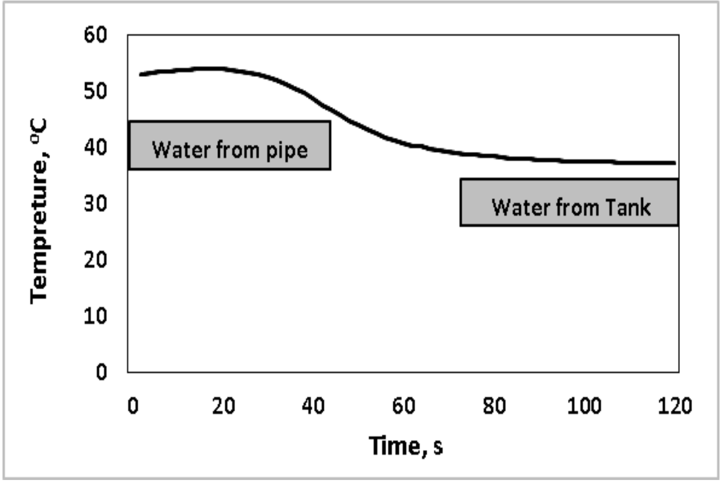

Fig. (18): Hourly average water temperatures just leaving the storage tank and draining from the pipes network.

Table (13): Hourly average water temperatures just leaving the storage tank and draining from the pipes net work

Parameter	Water temperature of storage tank, ºC	Water temperature of pipe, ºC	Solar radiation, W/m²	Ambient air temperature, ºC
Mean[a]	37.2	53.5	674.4	41.9
SD	±0.11	±0.35	±140.5	±7.3

[a]Column means followed by the same letter are not significantly different at 95% level of confidence.

For the duration of the experimental period, the water temperatures in house pipes, storage tank, water electric heater, pipes network, and ambient air are listed in **Table (14)** and plotted in **Fig. (19)**. The water temperature in the pipe of house was allows lower (29.8°C) than that in the storage water tank (38.0°C), electric water heater (42.0°C), water draining from the pipes (47.7°C), and ambient air temperature (48.6°C).

Table (14): Hourly average water temperatures coming from different sources

Parameter	In house pipe, °C	Storage tank, °C	Water heater, °C	Draining from pipes, °C	Ambient air temperature, °C
Mean[a]	29.8	38.0	42.0	47.7	48.6
SD	0.05	0.16	0.02	0.08	0.06

[a] Column means followed by the same letter are not significantly different at 95% level of confidence.

Different forms of water storage tanks which practically functioned to provide fresh water for human residential and offices in the Kingdom of Saudi Arabia included; (a) directly exposed to the solar radiation, (b) underneath shading ((concrete, umbrella or galvanized sheet cover), (c) warped with insulation, cooled by electric fan, and cooled by AC are plotted in **Fig. (20)**.

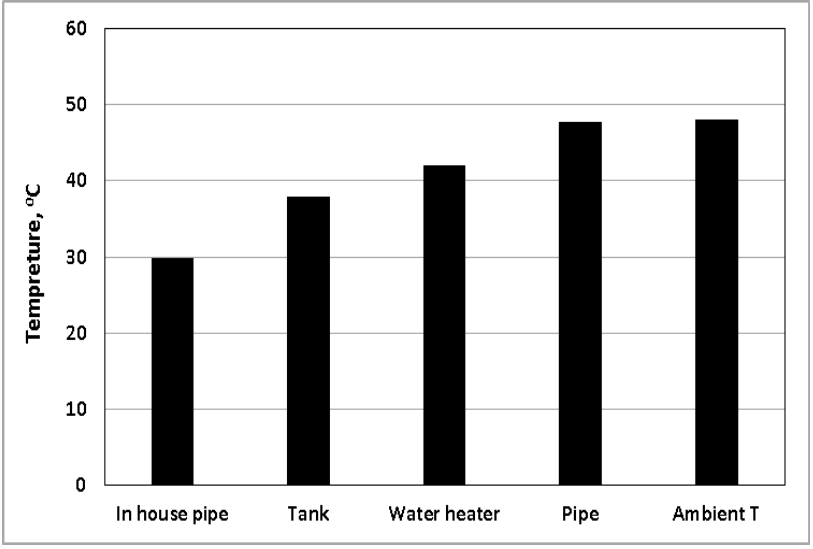

Fig. (19): Hourly average water temperatures coming from different sources (house pipe, storage tank, water electric heater, water drains from pipes network and ambient air temperature).

Fig. (20): Some Different forms of water storage tanks under different conditions.

CONCLUSION

This research work investigated the effect of some physical and engineering parameters that affecting the water temperature inside the water storage tanks commonly used in the Kingdome of Saudi Arabia (under hot and humid climatic conditions). A field and laboratory tests were conducted to determine the effect available various practices (e.g. insulation materials, color, orientation, shading, and cooling techniques) on the thermal performance of the water tanks reaching to the best practice to be adapted to thermally protect water inside the tanks from the harsh external environment (intensity of solar radiation, ambient air temperature, and air relative humidity).The obtained results revealed that, the best type of water storage tank is white color, made of fiberglass material (has a thermal conductivity of 0.492 W m^{-1} K^{-1}), located underneath a shading material and consequently out of exposing the high intensity of solar radiation, and cooling using electric fan.

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الملخص العربي

فاعلية بعض الطرق المستخدمة فى خفض درجة حرارة الماء فى خزانات ماء المساكن تحت الظروف المناخية الحارة والرطبة

عماد على المهنا*

تمثل درجة حرارة الماء القادم من خزانات مياه المساكن والمبانى الزراعية أثناء موسم الصيف أخطر مشكلة فى المملكة العربية السعودية حيث ترتفع درجة حرارة الماء داخل هذه الخزانات إلى أعلى من 50°C لذا فإن العديد من الطرق والممارسات تستخدم لتقليل درجة حرارة الماء القادم من هذه الخزانات حيث تختلف فاعلية هذه الطرق من منطقة إلى أخرى، لذا فإن إختيار الطريقة المناسبة تعتمد أساساً على المعلومات المتاحة من صناع الخزانات بالإضافة إلى أن النشر العلمى حول هذه المشكلة يعتبر قليل نسبياً.

***أستاذ مشارك بقسم هندسة النظم الزراعية – كلية الزراعة وعلوم الأغذية – جامعة الملك فيصل – المملكة العربية السعودية.**

لذلك فإن هذه الدراسة تهدف إلى إجراء إختبارات معملية وحقلية لتحديد تآثير فاعلية الطرق والممارسات المختلفة مثل مواد العزل – اللون - التوجيه – التظليل – تقنيات التبريد على الأداء الحرارى لخزانات الماء وصولاً إلى أفضل ممارسة وطريقة لخفض درجة حرارة الماء داخل الخزانات خاصة أثناء موسم الصيف الحار والرطب.

تم إستخدام ستة خزانات مختلفة من حيث السمك واللون ومادة التصنيع لتحديد أفضل مادة تحت ظروف مختلفة من حيث التظليل والتوجيه وتقنيات التبريد المختلفة. أوضحت النتائج المتحصل عليها من هذا العمل البحثى أن أفضل خزان يمكن إستخدامه يكون مصنع من مادة الفيبرجلاس ذو معامل توصيل حرارى مقداره $0.492\ \mathrm{W\ m^{-1}\ K^{-1}}$ يوضع تحت مادة تظليل وبالتالى يكون بعيداً عن شدة الإشعاع الشمسى العالية مع التبريد الخارجى بإستخدام مروحة هواء كهربية.