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Solar Radiation Impact on Interior Pressure and Temperature of LPG Storage Tank in Baghdad Provence

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Abstract

This work is related to reducing the impact of incident solar radiation on the internal thermal conditions of the LPG tank. An experimental study was carried out to test the effectiveness of using new thermal insulation layer for liquefied petroleum gas (LPG) tanks to reduce the absorbed heat during the summer season in Baghdad. Semi-spherical perlite particles of size (0.1861 to 1.604 mm) were mixed homogeneously with the resin coating is used as the heat insulating layer. Two identical thermally insulated and non-insulated LPG tanks are tested to indicate the effect of the adopted thermal insulation under different operating conditions. The two tanks were field tested with LPG volumetric filling ratio of (80%, 70%, 50%, 20%) and exposed to the same environmental conditions.

Experimental results indicated that the coating significantly reduced the increase in temperature and pressure in the tanks, thus ensuring effective protection for the tanks. Where the results showed that the approved thermal coating prevented an increase in temperature and pressure in the insulated tank by (18.6%, 25%), respectively, compared to the non-insulated tank in July 2022. The data obtained confirmed the improvement in the safety of LPG storage, meaning that the thermal coating It is an effective way to improve the storage and transportation of liquefied gas in hot summer days.

Keywords: LPG tank, outdoor test, temperature, pressure rise, thermal insulation.

تأثير الإشعاع الشمسي على الضغط الداخلي ودرجة حرارة خزان غاز البترول المسال في محافظة بغداد

الخلاصة:

يتعلق هذا العمل بتقليل تأثير الإشعاع الشمسي الساقط على الظروف الحرارية الداخلية لخزان غاز البترول المسال. تم انجاز دراسة تجريبية لاختبار فاعلية استخدام طبقة من العزل الحراري الجديد لخزانات غاز البترول المسال لتقليل الحرارة الممتصة خلال فصل الصيف في بغداد. تم خلط جسيمات البيرلايت شبه الكروية ذات قياس (0.1861 إلى 1.604 مم) بشكل متجانس مع طلاء الراتنج المستخدم كطلاء عازل للحرارة. تم اختبار خزانين متطابقين لغاز البترول المسال معزول و غير معزول حراريا

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للإشارة إلى تاثير العزل الحراري المعمد في العمل الحالي في ظل ظروف تشغيل مختلفة. اختبر الخزانين ميدانيا وبنسب تعبئة حجمية من غاز البترول المسال (80٪، 70٪، 50٪، 20٪) و معرضان الى نفس الإشعاع الشمسي المباشر.
أشارت النتائج التجريبية إلى أن الطلاء قلل بشكل كبير من الزيادة في درجات الحرارة والضغط في الخزانات مما يضمن الحماية الفعالة للخزانات. حيث اظهرت النتائج إلى أن الطلاء الحراري المعتمد منع ارتفاع درجة الحرارة والضغط في الخزان المعزول بنسبة (18.6٪، 25٪) على التوالي مقارنة بالخزان غير المعزول في تموز 2022. أكدت البيانات التي تم الحصول عليها تحسين سلامة تخزين غاز البترول المسال اي أن الطلاء الحراري هو وسيلة فعالة لتحسين تخزين ونقل الغاز المسال في أيام الصيف الحارة.

1. Introduction:

Liquefied petroleum gas (LPG) is a combination of butane (C4H10) and propane (C3H8), forms a flammable hydrocarbon gas casted for heating, cooking and energy sources in vehicles. In Europe, 7 million drive cars that run on liquefied petroleum gas therefore the widely most used compared alternative fuels for other fuels types. To provide an energy-economic environment, maintaining and optimizing the use of alternative fuels is the best option. LPG is considered economic and friendly environmentally, so it helps reduce environmentally pollution. LPG is transported and stored in insulated tanks in the liquid phase because of its ability to occupy a volume less than that which would occupy in the gas phase. When liquefied petroleum gas tanks are exposed to the external heat sources, where the process of evaporation for liquefied petroleum gas and thus turn into vapor. As LPG tank is subjected to any exterior heating sources such as a fire of sufficient intensity and duration, the tank pressure relief valves will vent LPG to the atmosphere or a flare stack. If this duration is sufficient to boil the liquid, then the vapor pressure is rises rapidly reaching th the explosion of the tank. This phenomenon is called a Boiling Liquid Expanding Vapor Explosion (BLEVE), some researchers studied the hazards of BLEVE. In Kanner, Kerala, India, an accident of a LPG tank was analyzed and simulated by [1]. The simulation was made possible by the Area Locations of Hazardous Atmospheres ALOHA and Processes Hazard Analysis PHAST Software tool. It is showed the jet fire scenario was very small impact compared to the radiation of the ball of fire, and the explosion of (BLEVE) is due to an increase in the pressure. A simplified mathematical model was used by [2], to represent the major physical phenomena that occur for an un-insulated and unprotected tank containing liquefied gas subjected to an external fire. Filling levels ranging from (22%, 36%, 58%, and 72%) of liquefied propane was used in this test. The study found that the received heat flux mainly affected the time of failure of the tank nonetheless, at both heat input and the initial storage temperature, while the opening time of (PRV) was very sensitive. Information of LPG tank subjected to an engulfed fire was provided through experiments carried out by [3], of different LPG tank sizes and filling-levels various. In the pool

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fires of kerosene, the experimental tests were performed on the behavior of a 5 ton of cylindrical horizontal LPG tank. The results showed that the pressure of the tank is steadily increased until the pressure relief valve (PRV) was opened from 5 to 7 minutes, after the ignition and the fire was extended from 12 to 30 minutes. One of the main effects of solar radiation during the summer is that the temperature of LPG in the storage tank reaches significantly higher temperatures throughout the day. This is typically a concern for large refineries and petrochemical plants that maintain very large containers. In the literature, this problem received some interest. The thermal insulation for (LPG) storage tank is designed and investigated by [4] to prevent its failure. The used thermal insulation was fibers of (mineral wool) sewed with steel wire it is named as (I-SOVER-MD2). The results showed that the non-protected tanks failed after exposed it to a period of burning between 7 to 12 minutes causing boiling of a liquefied gas then expanding vapor explosion because of the increased internal overpressure. The effect of the protective layer of PolyVinylChloride PVC resin on the LPG vessel is explored by [5]. It is reported that the failure time is increased rapidly, and the pressure rate is decreased significantly for insolated tanks with higher protective layer thickness. Layered Composite Insulation (LCI) system developed in the experiments is carried out by [6], for cryogenic tanks or liquefied natural gas (LNG) storage tanks. Results showed that the temperatures of about 4 K to 400 K were being suitable to the layered composite insulation system (LCX) system. A thermodynamic model of foam insulated was established to recognize the influence of the thickness of the insulation layer on the development of the liquefied thermal stratification of LPG pressurized tank [7]. Results showed that tanks with thinner insulation layer experiences pressure increase significantly, and an increase in stratified mass. [8] a studied thermal coatings efficiency to prevent hot (BLEVE) accidental scenarios. The thermal coating was selected of an epoxy intumescent material. The results showed that the thermal coating efficiency of swollen epoxy materials was studied to prevent accidentals scenarios of hot (BLEVE). The thermal coating efficiency of swollen epoxy materials was studied to prevent accidentals scenarios of hot (BLEVE). In fire suppression scenarios to understand the influence of coatings materials difference on LPG transport and storage reservoirs [9] developed a model of thermally and mechanically on LPG storage tanks. Cementitious inorganic material, fibrous mineral wool, vermiculite spray, and epoxy intumescent were used as coatings materials. Results showed that the last type of coatings materials gives lower heat transfer compared to other types due to its lower thermal conductivity. The passive fire protection is adopted by [10], to reduce LPG transportation riskiness. A reactive paint (rock wool and organic intumescing) which

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undulates up many times to its first thickness when exposed to high temperatures, like a fire is used. Tests presented after 20 minutes the non-insulated reservoirs is failed and the isolated reservoirs are collapsed after 100 minutes. The fire protection materials were reduced the risk ratio by 50 %. A new thermal insulation system was designed and discussed by [11], of the new independent type B CCS. The results showed that this type of insulation withstands loads at any filling level in the tank in case of shipping, and it is easy in inspection and repair. Experimentally Multilayer Insulation (MLI)/ Variable Density Multilayer Insulation (VDMLI) and the composite insulation system of Spray On Foam Insulation (SOFI) is studied experimentally and theoretically by Zheng et al. 2018. The results showed with 50 layers of reflector, heat leakage through VDMLI is lower than of MLI by 13.53%, and heat flux through VDMLI is lower than that of MLI by 17.49%.

All the studies reported the use of different types of thermal insulator, but so far no a new type of semi spherical particles have been used as insulation material. The main objective of this work is to find an economical and effective method to protect the gas storage tank from highly temperature increase in summer season.

2. Experimental Analysis

The experimental system consists of a horizontal cylindrical tank featuring liquefied petroleum gas (LPG) in the liquid and gas phases. It also consists of the temperature and pressure measurements devices, a multi-valve, and discharge valve. The system also consists of tank incubator which is placed as shown in the Figure (1).

2.1 Test tank

Two 40 liter LPG tanks of 315 mm diameter, and an overall length of 599 mm is tested in this work. Further engineering data of the experimental tank are given in Table (1) and in Figure (2). The tank is prepared according to Din En 1020 P (265 or 245) NB steel having a maximum ultimate of 30 bar, and 65˚C. The tank contains many holes designed for temperature and pressure measuring instruments. The tank contains six holes for temperature measurement and one hole for the pressure gauge. The tank includes six holes of ½ inch (12.7 mm) diameter at different locations as shown in Figure (3). Position of temperature gauges were set to measure the liquid and vapor phases of LPG at different filling level in this tests. Also, multi-valve is installed in the upper side of the tank. Socket of carbon steel type low carbon steel pipe fitting ASTM A234 WPB B16.9 of

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(½ inch, 12.7 mm) diameter is used to connect the tank with pressure and temperature instruments. This socket is welded to the tank using manual welding (manual electric arc welding).

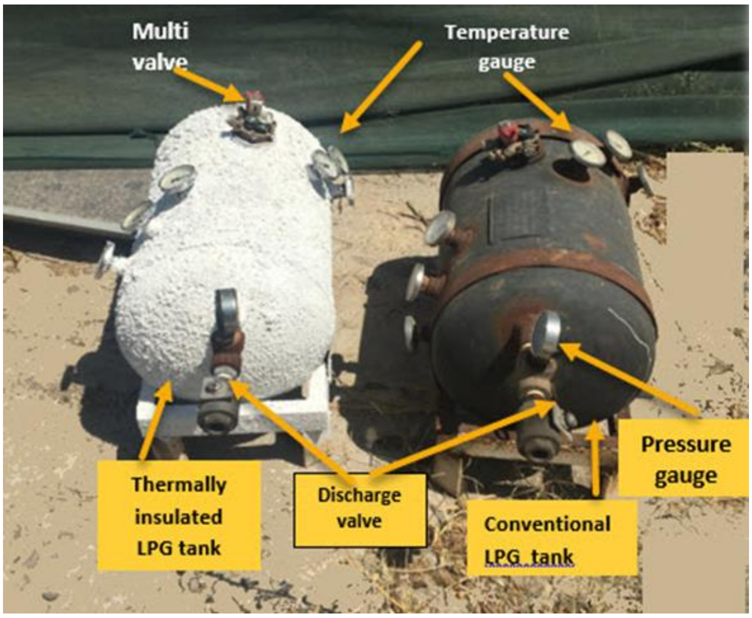

Fig. (1): The experimental test photograph.

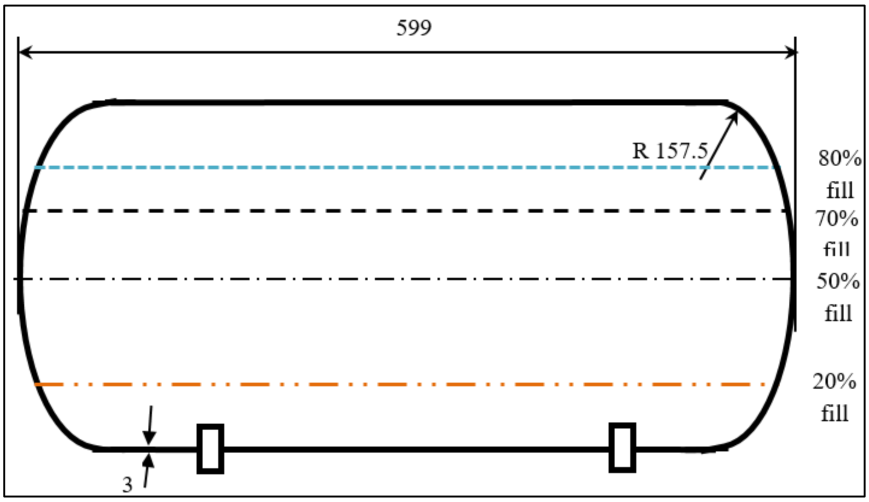

Fig. (2): Tested LPG tanks (all dimensions in mm).

2.2 Multi-valve (Safety valve)

The LPG multi-valve is a core component for the safety of LPG system. It is installed in the LPG tank and allowed the filling of fuel and delivery of fuel. Also, shows the LPG amount remaining in the tank. In this work, multi-valve was used made of (Hot forged brass – CNC Machined) of weight (0.9 – 1.1) kg, supports maximum pressure of 27 bar, filling flow rate is (17-18) 1/min at 10 bar.

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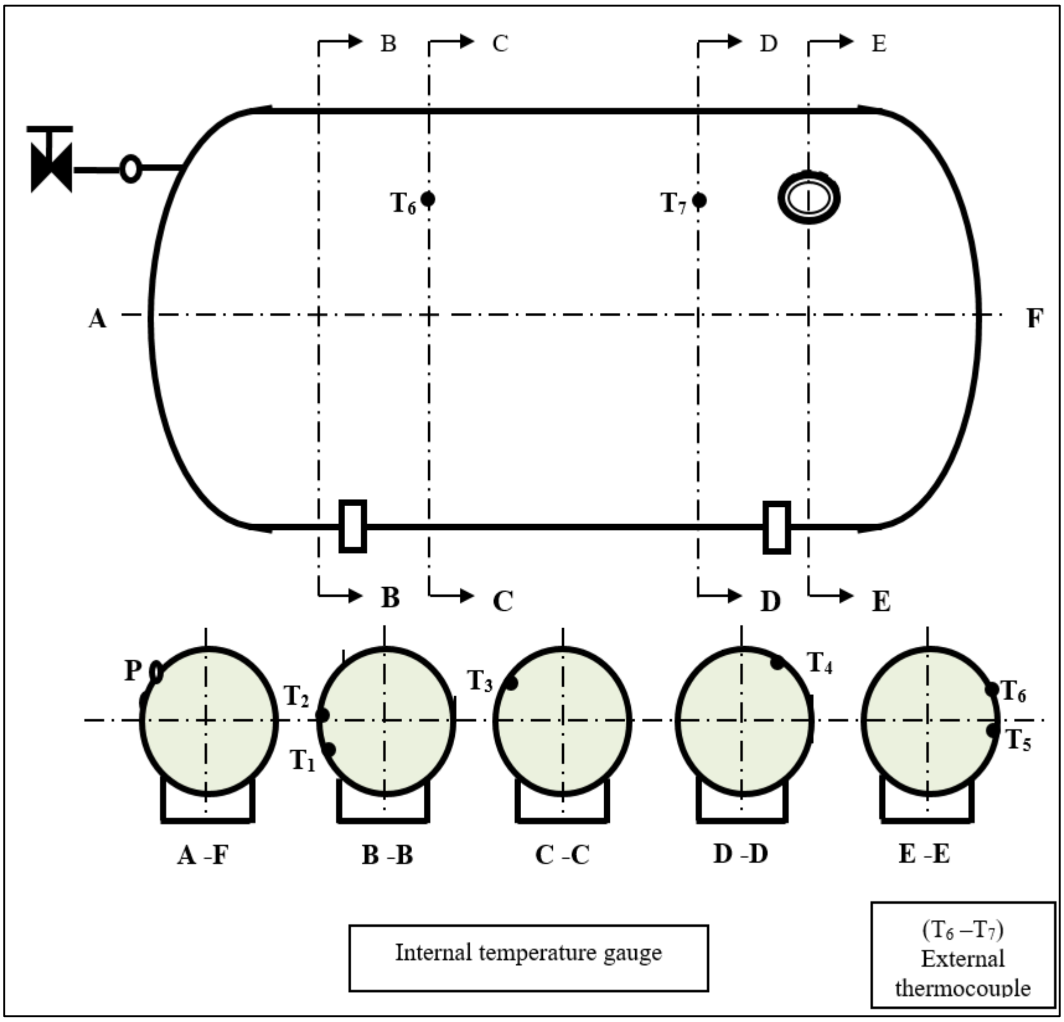

Fig. (3): Location of temperature and pressure measurements.

2.3 Discharge valve

Manual discharge valve was used to change the fill level inside the tank and in this way it was manually controlled.

2.4 The thermal insulating coating

Semi spherical Perlite expanded particles is used as a new thermal insulating coating material. The tested tank is coated by a granular insulating coating layer. Thermal granular coating is prepared in several stages, including first determining the particle size of the insulation material, which is found as diameter ranging (0.1861 to 1.604 mm). Second, formulate a homogeneous coating by mixing the insulation granules into a resin paint to obtain the insulation paste.

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3. Experimental procedure

Two liquefied petroleum gas tanks have been used the same specifications. One tank was insulated with insulating coating layer, and the other is uninsulated as shown in Figure (1). The tanks (insulated and uninsulated) are exposed to solar radiation. The readings have been taken for three months (June, July, and August) at different intervals time of the day. The external surface temperature of the LPG tanks and the internal content of the tanks were measured using two types of devices. Firstly, the test tanks were equipped with thermocouples of copper and chromium (type K) used to measure temperature of the outer tank wall and ensuring the reading of the average temperature with 0.1 $^{\circ}$C resolution. The readings were taken every twenty minutes. For each tank, Six of temperature gauge were placed on the tank with ensuring the reading of the average temperature with $\pm 1.20^{\circ}$C uncertainty between (0 to 120 $^{\circ}$C), in order to measure LPG liquid and vapor temperatures respectively. A simplified diagram of the temperature instruments measurements positions as shown in Figure (3). Before all tests, once all internal and external temperature instruments measurement had been checked and calibrated. Initially, the test tank was filled with (0.032 liter) of LPG (filling level 80%). Thereafter, the LPG level was reduced to the levels required for other tests by the discharge valve.

Table (1) Specifications of tested LPG tank

Item	Specification
Type	Cylinder tank
Version	S01
Usage	LPG
Material	Din En 1020 P (265 or 245) NB
Diameter (mm)	315
Length (mm)	599
Minimum wall thickness (mm)	3
Design pressure	30 bar
Working pressure	20 bar
Working temperature	-20 ^{o}C to 65^{o}C
Color code	RAL 9005

4. Results and Discussion

The experimental tests of various operating conditions of filled LPG tanks at levels (80%, 70%, 50%, 20%) (the fill is defined as the percentage of the tank volume occupied by liquid) were performed using identical tanks (0.04 m^3) with characteristics discussed in section 2, to assess the effect of thermal insulation on both pressure and temperature of liquid and vapor phase inside the

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tanks. The Figures (4, a, b, c, d) show the temporal variation of the external surface temperature of the insulated and non-insulated tanks. It turns out that the surface temperature gradually increases during daylight hours to reach the maximum temperature. Table (2) shows the percentage of surface temperature reduction during daylight hours.

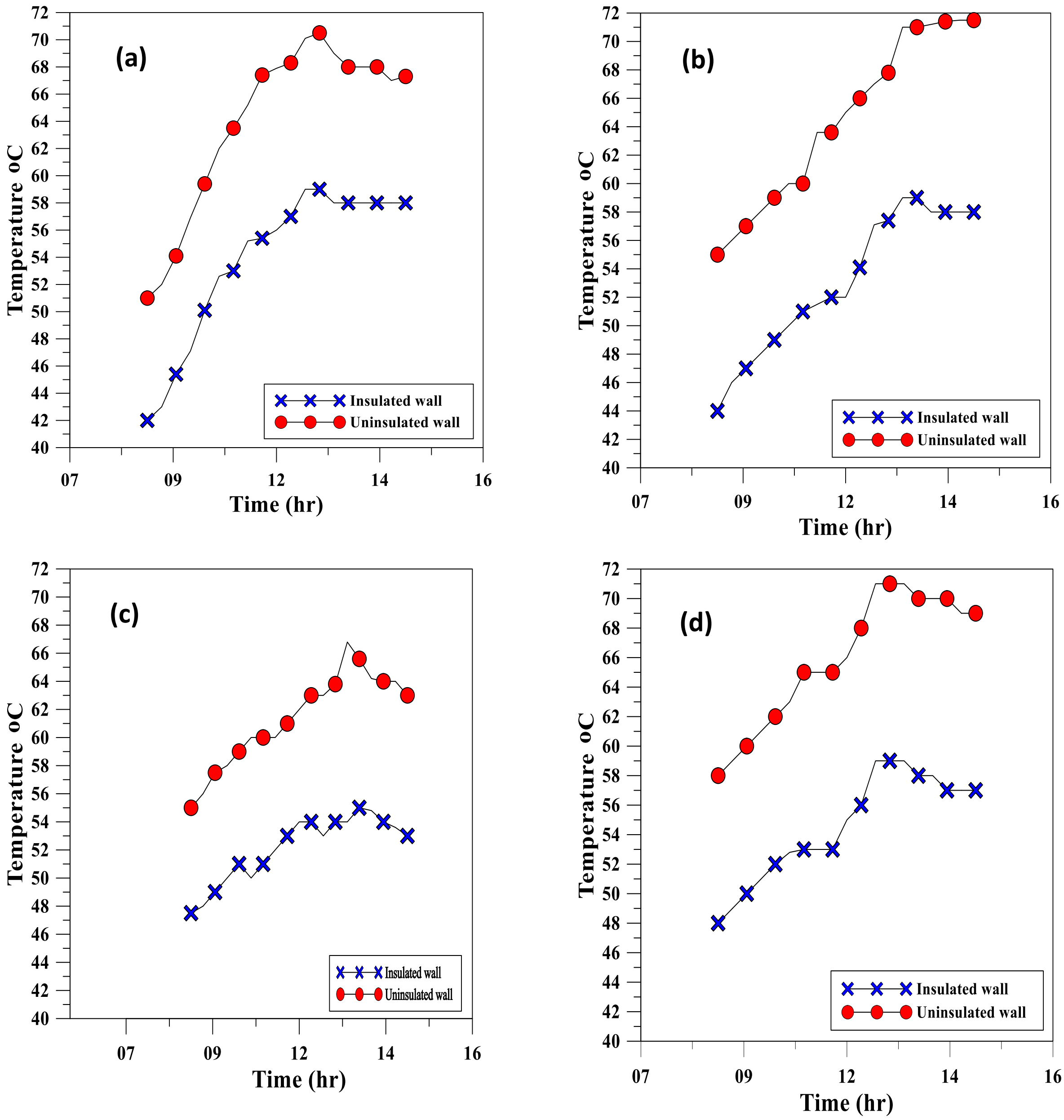

Fig. (4): History of insulated and uninsulated tank wall temperature for fill level of : a) 80% , b) 70%, c) 50%, d) 20% .

Table (2) Percentage reduction in surface temperature for insulated tank.

Time (hr)	80% fill level	70% fill level	50% fill level	20% fill level
9:00	17.6%	20.0%	13.6%	17.2%
11:00	16.5%	15.0%	15.0%	18.4%
13:00	16.3%	15.3%	15.3%	16.9%
15:00	13.8%	18.8%	15.8%	17.3%

Figures (5, a, b, c, d) show the temporal variation of LPG temperatures (liquid and vapor phase) during daylight hours for insulated and non-insulated tanks.

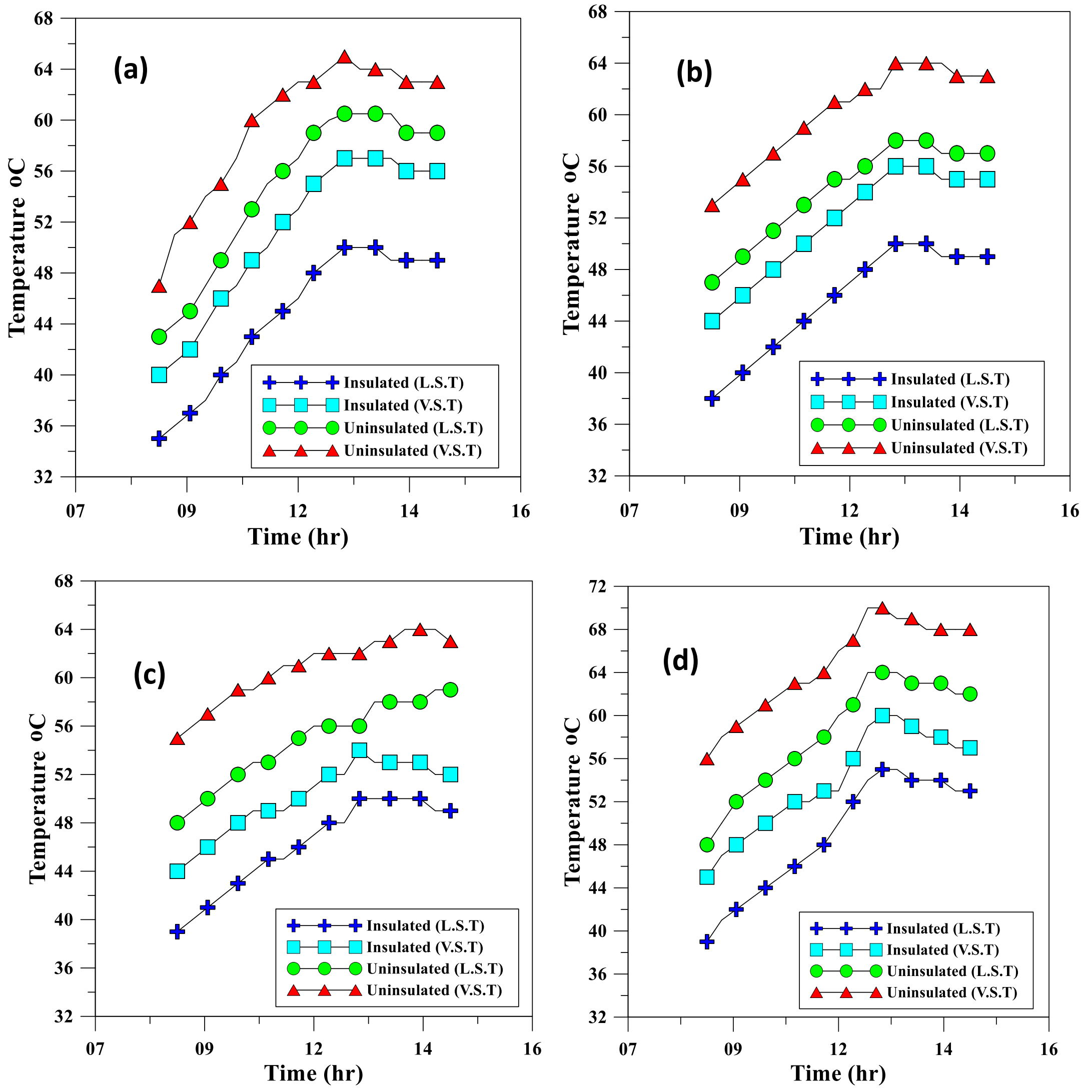

Fig. (5): History of LPG (liquid and vapor phase) temperature inside the insulated and uninsulated tanks for fill level of: a) 80%, b) 70%, c) 50%, d) 20%

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Comparison of these figures indicates that the liquid phase temperature of LPG in insulated and non-insulated tanks is lower than that of the vapor phase. This increase is due to the fact that it received heat directly from the hot walls, and because of the low heat transfer coefficients between the wall and vapor phase. The Table (3) can be clearly seen that the maximum drop in liquid and vapor phases temperature of LPG for the insulated tank during daylight hours.

Table (3) Percentage reduction in LPG (liquid and vapor phases) temperature for insulated tank.

Time (hr)	80% fill level		70% fill level		50% fill level		20% fill level	
	Liquid	Vapor	Liquid	Vapor	Liquid	Vapor	Liquid	Vapor
9:00	18.6%	20%	19.1%	16.9%	18.7%	20%	18.7%	19.6%
11:00	18.8%	18.3%	16.9%	15.2%	15.0%	18.3%	17.8%	17.4%
13:00	17.3%	12.3%	17.3%	12.3%	10.7%	12.9%	14.0%	14.2%
15:00	16.9%	11.1%	16.9%	11.1%	16.9%	17.4%	14.5%	16.1%

By reducing the fill level inside the tanks, a large part of the tank walls will be exposed to heat thus it raises the temperature of the LPG liquid as shown in Figure (6).

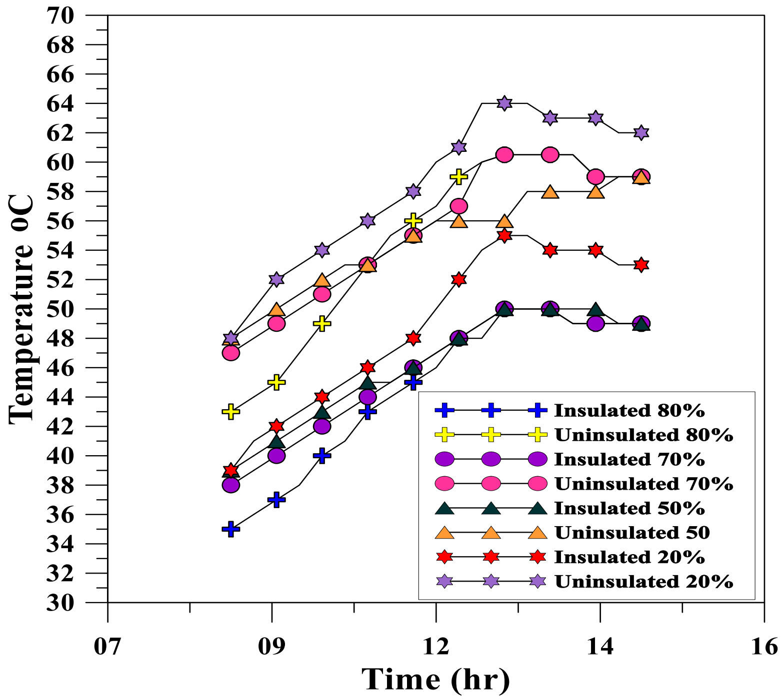

Fig. (6): History of LPG (liquid phase) temperature inside insulated and un insulated tanks for different filling levels.

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Figures (7, a, b, c, d) show the temporal variation of LPG pressure during daylight hours for insulated and non-insulated tanks.

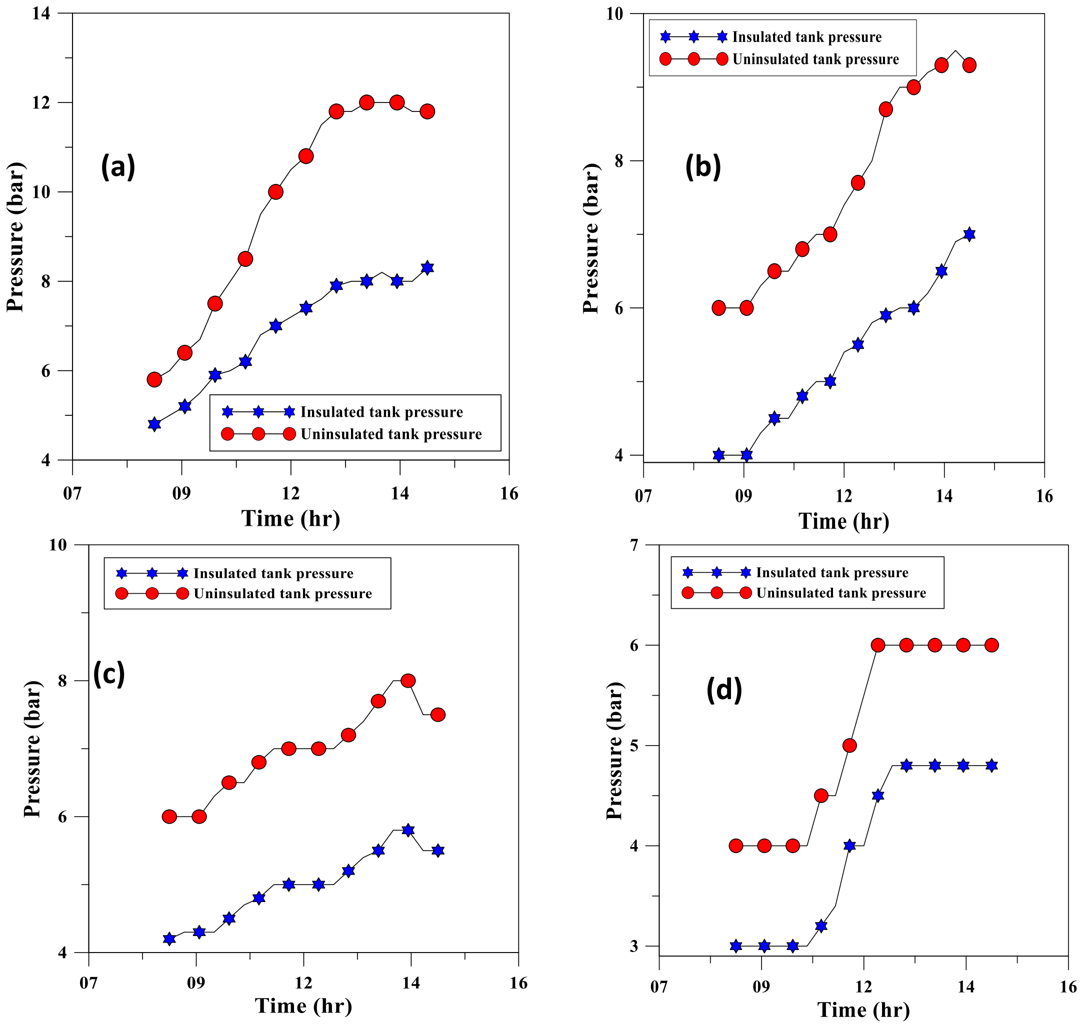

Fig. (7): History of LPG pressure inside insulated and uninsulated tanks for fill level of: a) 80%, b) 70%, c) 50%, d) 20%

Note that the pressure increases significantly in the non-insulated tank, as the tank surface temperature rises, it will increase the evaporation process inside the tank and generate more steam and since the specific steam area will increase the pressure. The maximum drop in pressure of LPG for the insulated tank during day time are given in Table (4). It should be noted that this type of insulation used in the experiment has a good effect in reducing the temperature of the liquefied petroleum gas tank compared to without insulation. From a thermal point of view and also financially, tank insulation is the best option not for application. It is clear from these figures that the type of dielectric used is effective in reducing the impact of solar radiation on LPG.

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The effect of solar radiation on LPG storage tanks in Iraq is due to the fact that Iraq's location geographic, through summer exposed higher sunlight. This issue is related to the use of gas in the summer and the risks of storing it at storage sites and also when used as fuel in cars and cooking. It has also been shown that insulation may significantly reduce the temperature of the inner tank. the thickness of the insulation can be increased for better results.

Table (4) Percentage reduction in LPG pressure for insulated tank.

Time (hr)	80% fill level	70% fill level	50% fill level	20% fill level
9:00	17.2%	33.3%	30.0%	25.0%
11:00	27.0%	29.4%	29.4%	28.8%
13:00	33.0%	32.1%	27.7%	20.0%
15:00	29.6%	24.7%	26.6%	20.0%

5. Conclusions

The internal pressure for the LPG tank rises above the safety valve limits especially in Iraq in summer resulted a gas leakage from tank. In this work an attempt to eliminate excess tank heating, perlite expanded particles are used as a new thermal insulator to reserve the temperature and pressure of LPG and to reduce the risks from storage and transportation of this important material.

Per the discussion of the obtained experimental results the following conclusions can be extracted:

1. The maximum out surface tank wall temperature of un-insulated tank for the 20% filling ratio was (62 °C) for solar radiation equal to (757 W/m2) and ambient temperature (44.5 °C).
2. The maximum effectiveness of the new thermal insulator in reducing the temperature of the LPG-liquid in the storage tank is (21.1%) before solar radiation and (18.8%) at solar radiation.
3. The maximum effectiveness of the new thermal insulator in reduction the pressure of liquefied petroleum gas in the storage tank wall is (14.7%) before solar radiation and (25%) at solar radiation.
4. The temperature of the external surface of a tank shall be of varying degrees, with the highest temperature of the outer surface in contact with the vapor phase is (69 °C) and the lowest temperature at bottom outer surface tank is (55 °C).
5. From the analysis of the results, it was confirmed that the use of the new thermal insulator ensures the safety of LPG storage during the summer months.

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