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EXPERIMENTAL INVESTIGATION OF GASOLINE FUEL EVAPORATION AT HIGH TEMPERATURES WITHIN TANK TRUCKS

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Abstract
This study provides an experimental simulation of the evaporation from the gasoline fuel in truck-tanks, which are subjected to high-temperature summer weather-like conditions, such as those found in Iraq. A 50 L capacity stainless-steel tank of controlled environment with 20 L commercial RON 95 gasoline content was used to analyze the thermal loading impact on fuel vapor pressure, mass loss and volumetric changes in three different temperatures (30, 50 and 70 °C). Mission measurements recorded over a 6 h period have shown a strong positive relationship between temperature and evaporative losses; vapor pressure increased from 30 to 80 kPa and mass loss, for example, rose from 50 g to 225 g and volume loss increased from approximately.062 L to.27 L. These results illustrate the exponential effect of thermal stresses on gasoline, indicating that it is possible for tank-truck fuel to become dangerously pressurized and experience considerable financial loss when exposed to high temperatures. The results emphasize the importance for enhanced thermal management, insulation and safety facilities in fuel transfer systems where hot climates are prevailing.

Keywords: Gasoline Fuel Evaporation, High Temperatures, Tank Trucks.

Introduction

The contamination of the air has persistently posed a significant challenge in several metropolitan centers globally, prompting international and European rules on car emissions to become progressively more rigorous annually to mitigate severe impacts on human health and the environment [1]. 1) Emissions from the engine exhaust resulting from incomplete or incorrect combustion; 2) Emissions from the fuel system owing to evaporation into the atmosphere (evaporative emissions). Evaporative emissions generated by automobiles mostly result from gasoline evaporation during refilling at service stations, as well as from tanks, storage facilities, and the penetration of fuel though the fuel system's walls [2]. They may be categorized as operating losses, hot soaks, diurnal emissions, refueling losses, and a little impact from permeation [3].

Till a few years prior, petrol vapors were emitted directly into the atmosphere via the tank top and a vent system linked to the vehicle's tank [4]. Conversely, the fuel tank must be capable of venting to the outside to prevent vacuum or pressure formation [5]. Throughout refilling, a certain quantity of gasoline vapors is released from the fuel filler neck, which unavoidably evaporates into the atmosphere. This supply system may continually produce harmful evaporative emissions 24 hours a day, particularly when the vehicle is stationary and exposed to direct sunlight [6]. These

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contaminants undergo a photochemical interaction with air and sunlight, resulting in the formation of smog [7]. The requirement to provide vehicles with a control and absorption system for emissions from evaporation is crucial to prevent the dispersion of petrol vapors from the tank into the atmosphere [8]. This venting system comprises anti-spill valves that inhibit gasoline leaking during a roll-over, vapor separators located either inside or external to the tank, and an activated carbon filter (carbon canister) [8]. The filter captures emissions that evaporate once the vehicle is stationary and throughout the engine's warm-up period [9]. When the engine is operating at elevated temperatures, the Electronic Control Unit (ECU) activates a purge solenoid valve that links the canister to the intake manifold (low pressure), facilitating the removal of vapors from the canister, which are then combined with air and sent into the engine's combustion chamber [10,11]. The Euro 6 c/d requirements have significantly intensified vapor emission control compared to previous standards. The progression towards a hybrid setup makes the problem more pertinent. Numerous experts were intrigued by the issues of emissions from evaporation throughout the years [12].

Fuel evaporation is associated with the temperature attained by the fuel (T_{tank}) and may occur during both stationary and operational phases. The sun radiation, road surface temperature, and ambient air temperature are the primary sources of heat that could result in a substantial rise in T_{tank} when parking. The gasoline tank is often evacuated to the environment via a pressure relief valve, ensuring that the tank pressure remains marginally above atmospheric levels. Should the amount of pressure inside the tank exceed that threshold, a combination of air and petrol vapors can get discharged into the atmosphere. Contemporary automobiles have a vented tank system that incorporates an activated-carbon canister, which adsorbs and retains hydrocarbons to mitigate atmospheric emissions. Over 95% of fuel vapor production is shown to be captured by the carbon canister; nevertheless, it possesses a finite adsorption capacity and requires frequent purging to desorb the accumulated hydrocarbons [13].

Conversely, throughout driving, road surface and ambient air temperatures, solar radiation, the hot engine and exhaust system, as well as the fuel pump and fuel return—if applicable—constitute the primary heat sources which might substantially elevate the T_{tank}, consequently resulting in the evaporation of the lighter petrol fractions and an associated rise in pressure within the tank. The US EPA characterizes running loss emissions as evaporative hydrocarbons released during vehicle operation [14]. In other terms, running loss emissions include vapor venting during vehicle operation [15]. The primary reason for operational losses in contemporary cars is the release of minor quantities of hydrocarbons from the fuel cap and vapor canister because of elevated tank temperatures [16]. Most of these HCs are contained inside the canister. Throughout being operational, a portion of the combustion air traverses the canister, eliminating hydrocarbons and redirecting them to the engine's intake for combustion. In some instances, the equilibrium between the fuel evaporation rate, the volume of fuel delivered to the engine, and the purge flow rate via the canister results in a net discharge of air/fuel vapors from the tank via the vent and the canister should the canister be saturated, the gasoline vapors will be emitted into the atmosphere [4]. These emissions transpire only when driving and are referred to as running losses. The refueling procedure is another significant source of evaporate emissions. Upon the introduction of liquid fuel into the tank, the existing air/petrol vapor combination is displaced and might be emitted into the atmosphere. Refueling emissions are elaborated upon in other sources [17] and fall beyond the purview of the present investigation.

The primary objective of this study is to provide unequivocal quantification and analysis of the thermally driven evaporation characteristics of gasoline in travelling tanker trucks by empirically characterizing the concurrent nature of vapor pressure, mass loss, and volume contraction because of artificially heated condition to scientifically establish well-grounded basis for improving the safety in transportation through hot-climate areas. This experimental study is innovative, since it replicates the real environment of a fuel tanker and provides an integrated analysis (in terms of temperature range 30, 50 and 70 °C) on evaporation mechanisms within temperatures previously omitted in this topic of research and yet highly attractive from operational point of view—namely high sensitivity of gasoline to thermal stress in arctic or desert climate. By establishing empirical relations that correlate temperature rise to exponential growths in the evaporative losses, the study has profound implications toward development of high-performance thermal-management strategies, better engineered insulation materials and evidence-based regulatory standards regulating fuel-transport operations.

Factors Affecting Gasoline Vaporization

Effect of High Temperatures

The speed of fuel evaporation is highly dependent on the temperature. A rise in temperature results in higher energy of liquid molecules and they are more likely to escape surface elasticity forces and become gaseous. Fuels, particularly those with high vapor pressures, e.g., gasoline, are very sensitive to changes in temperature. The evaporation rate is not a linear function of temperature and increases with increasing temperature, especially in the open or uncontrolled situations. At elevated temperatures, for example in the summer or within the fuel tanks when they are exposed to direct sunlight, evaporation of fuel is greatly accelerated inducing a substantial loss of fuel and an increase emission of volatile organic compounds (VOC) in the environment. Not only do these emissions result in economic effects, but they also degrade the quality of the atmosphere by producing smog and ground-level ozone, both of which are harmful to human health and ecosystems. Pushing this to the limit, however, can make flammable contents inside fuel tanks – such as those in cars and/or transport trucks – go through an overheating phase and increase internal tank pressure to potentially dangerous levels without effective protection or ventilation measures.

Consequently, it is important to control the temperature of fuel during storage or transport. This requires efficient thermal insulation solutions, cooling systems in case of emergency as well as sophisticated tank designs to reduce evaporation and secure safety operations. The temperature relation to the fuel evaporate rate is generally described mathematically by a model expressed as an Arrhenius type equation, or Antoine type equation models. When the fuel evaporation is also considered, above can be simplified as follows:

$$E = A \cdot e\left(\frac{vL}{R \cdot T}\right) \quad (1)$$

Whereas:

E: Rate of evaporation (kg/m²·s) or relative unit.

A: A coefficient that depends on the nature of the liquid and wind speed (empirical constant).

vL: Latent heat of vaporization (J/kg).

R: Universal gas constant (≈ 8.314 J/mol·K).
T: Absolute temperature in Kelvin (K).
e: Natural logarithm.

Materials and Methodology

Description of the Experimental System

Tank Model

A 50 L truck tank (316 stainless steel) was then scaled down to confirm the corrosion of it together with a chemical reaction with the fuel. tanks were purpose-built to replicate the original design of fuel transport vehicles and featured a 5 cm diameter fill, vent and probe access penetrations. It was insulated with a 5 cm thick glass wool layer to reduce heat loss.

Fuel Used

20L of commercial RON 95 gasoline was employed in each trial to guarantee adequate evaporation space within the tank and reproducible results under practical conditions. Table 2 presents physical and chemical properties of the gasoline.

Table 2: Physical and Chemical Properties of Gasoline (RON 95)

Property	**Value**
Commercial Name	Gasoline (RON 95)
Chemical Composition	Mixture of hydrocarbons (C_4–C_{12})
Density at 15 °C	0.745–0.760 g/cm³
Boiling Range	30–200 °C
Vapor Pressure at 37.8 °C	45–65 kPa
Kinematic Viscosity at 40 °C	~0.5 mm²/s
Flash Point	Approximately –43 °C
Autoignition Temperature	~280 °C
pH Value	Not applicable
Water Solubility	<0.1 g/L
Energy Content	~44.4 MJ/kg
Color and Odor	Colorless to light yellow, strong characteristic odor

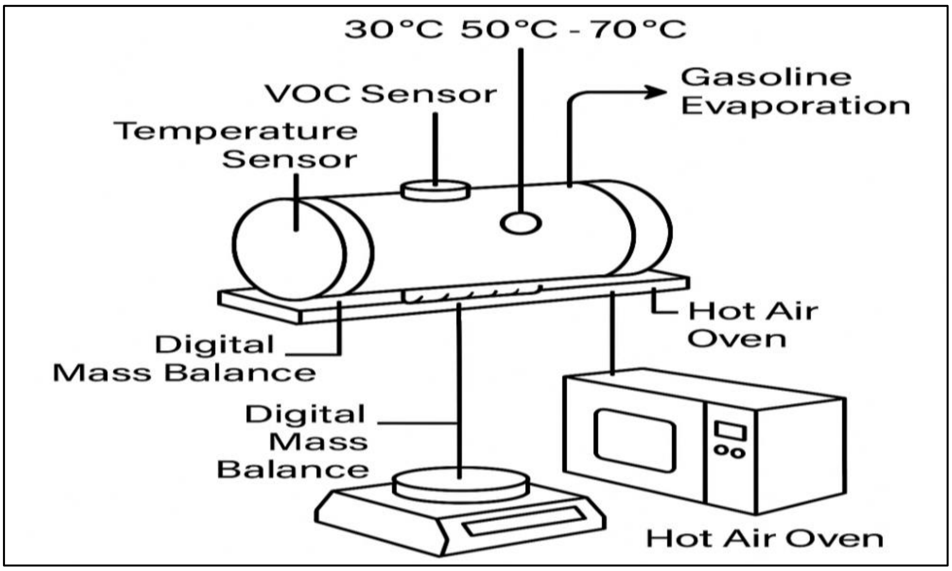

Figure 1. A detailed diagram of the laboratory work and the equipment used.

Experimental Conditions

Tested Temperatures

The experiment was conducted at three specific ambient temperatures:

- (30°C) representing a moderate day.
- (50°C) representing a hot summer day.
- (70°C) representing extreme conditions simulating direct sunlight exposure in a closed environment.

The temperature was controlled using a 2.5 kW industrial hot air oven equipped with a PID controller to maintain the temperature within ±1°C.

Measurement Times

Measurements were taken every 30 minutes over a total evaporation period of 6 hours, recording the mass or volume lost, the concentration of volatile organic compounds (VOCs), and the internal temperature and pressure.

Measurement Instruments

- Digital Mass Balance: Accurate ±0.01 g for measuring the total mass loss of benzene.
- MQ-135 VOC sensors: for measuring volatile organic compound (VOC) concentrations inside the tank compartment in ppm.
- Temperature and pressure gauges:
  - PT100 temperature sensor with an accuracy of ±0.5°C.
  - Digital barometric pressure sensor with an accuracy of ±0.01 bar.

Figure 2: Tools and equipment used.

Measurement and Calibration Method

Instrument Calibration

The mass gauge was calibrated using approved standard weights (Class M1), and the VOC sensors were calibrated using a standard gas containing 100 ppm of organic compounds. A water bath was used to verify the accuracy of the PT100 sensors within ±1°C.

Measurement Procedure

1. The tank was filled with a specified quantity of gasoline.
2. The tank was sealed and placed inside the thermal furnace.
3. The experiment was initiated by recording the initial values.
4. Readings were recorded every 30 minutes.
5. The evaporation rate was calculated using the mass or volumetric difference after each time interval.

Approximate rate of evaporation

Langmuir's evaporation equation can be used:

$$E = \frac{P \cdot M}{2\pi RT} \quad (3)$$

Where:

(E): Rate of evaporation (kg/m²·s)

(P): Vapor pressure at temperature

(M): Molecular mass of benzene (~100 g/mol)

(R): Universal gas constant

(T): Absolute temperature (K)

Results and Discussion

Table 2 lists effects of temperature on the process of gasoline evaporation in the case with 20 L/days RON 95 gasoline is studied under a closed system (Reaction 4). The simulated results indicate that, with the temperature elevated from 30°C to 70°C, the vapor pressure increases obviously by about 30–80 kPa, leading to a notable increase in mass evaporation rate after 6 h from 50 g to about 225 g. Conversely, the volume loss rises from 62–270 mL This again shows that temperature is an important parameter which affects the evaporation rate.

Table 2: Summary of Gasoline Evaporation Results Using 20 Liters as the Initial Quantity

Temperature (°C)	Vapor Pressure (kPa)	Evaporation After 6 Hours (g)	Volume Loss (mL)
30	30	50	62
50	55	121	155
70	80	225	270

The influence of the temperature on the evaporation rate of gasoline after 6 h is represented in Figure 3, and there is observed a highly direct correlation between the temperature and evaporation rate. This evaporation rate was 50 g for a 30°C temperature, increased to 121g at 50°C and it leapt up to be 225g at the boiling point of gasoline (70°C), which is due to few physical phenomena depending on fluidity and thermal characteristics of gasoline. The tendency for this is because gasoline has a substantial rise in vapor pressure as the temperature increases. Heating gasoline increases the kinetic energy of its molecules up to a point where they have enough energy to break their intermolecular forces and evolve into gas phase. In addition, at the increased temperatures, the surface viscosity of the liquid reduces with an attendant increase in molecules movement towards the surface and evaporation rate [18]. These results agree with previous reports. Gupta and Kumar [19] have shown that gasoline has high evaporative ability for temperature above 50°C, as follows an exponential increase in the vapor pressure. Similarly, an U.S. Environmental Protection Agency (EPA) report concluded that the rate of evaporation in the exposed or unventilated fuel tank increases significantly with increasing temperature, which can result in significant loss of gasoline for hot environments under certain conditions. Thus, interpretations of the figure point out the perils attendant in subjecting gasoline to elevated temperatures as during transportation or storage in tanks. Precautions should be taken to reduce evaporation losses and environmental contamination.

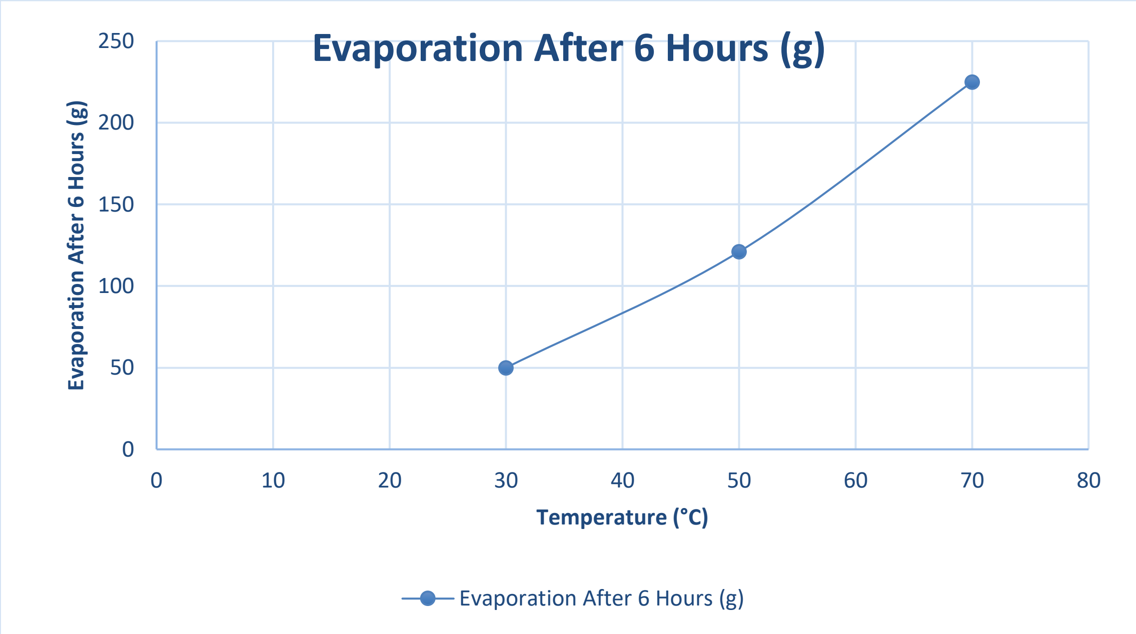

Figure 3. Results of the evaporation rate of gasoline used at different temperatures.

The relationship between temperature and the volume loss of benzene after being heated at various temperatures for six hours is shown in Figure 4, which indicates that its volume decreases remarkably with the augmentation of temperature. A significant increase in the volume loss of benzene was observed at 30, 50 and 70°C with values reaching up to 62 mL, 155 mL and 270 mL respectively due to temperature effect which is a clear indication about vaporization process when higher temperatures assist molecules to move from the liquid phase into the gas state, thus affecting on volume loss during the testing. This is because there will be much greater vapor pressure at higher temperatures – when it comes to benzene, the number of molecules able to break away from intermolecular forces and move into the gas phase. Recent research has shown that benzene, as a low molecular weight volatile organic compound (VOC), is influenced by the air temperature, with increasing rate of evaporation as a function of both time and temperature [20]. The study by Jiang et al. [21] also find that volume 35 losses from evaporation in open exchanges increase rapidly to critical levels within a few hours for open or un-insulated storage tanks when cooling/ventilation is inadequate. Moreover, a recent work of Jafari et al. [22] points out that control of the vehicle fuel tank temperature is important to reducing volumetric losses and evaporative related emissions. This research suggest the application of life jackets and covers for thermal insulation to reduce influences from the surrounding environment.

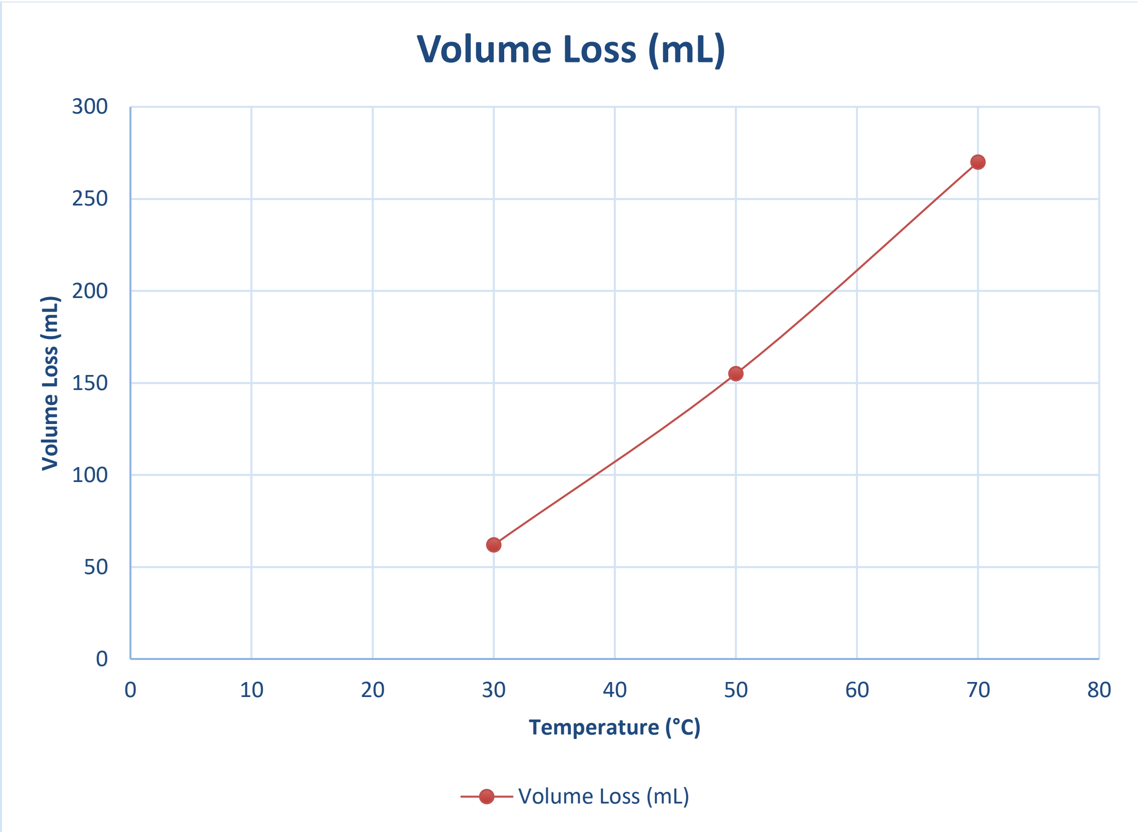

Figure 4. Results of the reduction in the volume of gasoline used at different temperatures.

The relation between temperature and gasoline vapor pressure is presented in Fig 5. The curve shows a conveniently direct proportion of vapor pressure with temperature. At 30°C vapor pressure was about 30 kPa, and 55 kPa at 50°C and finally 80kpa at70°C This trend mimics volatile liquids as such a gasoline in their thermodynamics principles. Vapor pressure is the pressure of the gaseous molecule at equilibrium with its liquid state, which directly depend on temperature. With increasing temperature, the liquid molecules' kinetic energy grows and this permits a larger number of molecules to make the gas–liquid transition leading to an almost exponential rise in vapor pressure [23]. With the small molecular weight of gasoline, along with a simple hydrocarbon structure, its temperature response is greater than that for much heavier fluids which may be why pressure rises so steeply every 20°C. The study by Fowles et al. [24], gasoline possesses almost exponential vapor pressures increasing in temperature because of the nearly-exponential curve of vapor pressures as a function of temperature illustrated in Figure 5.

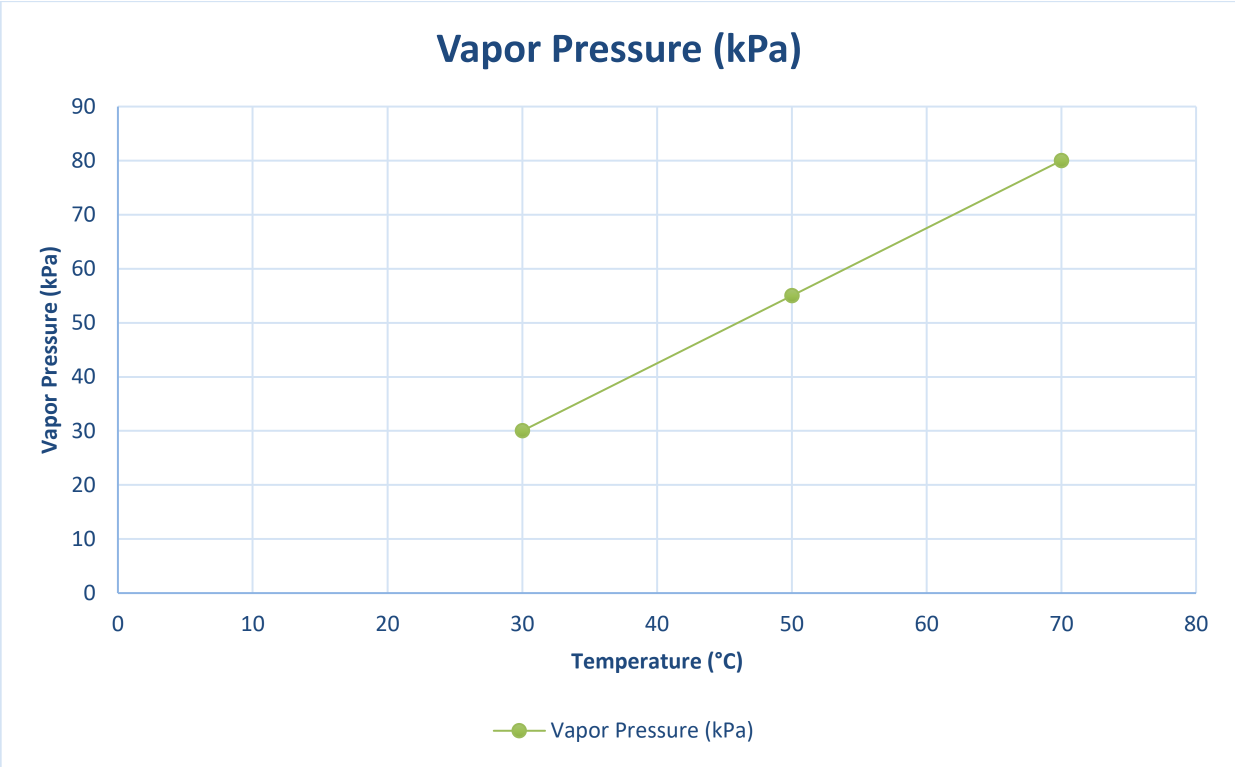

Figure 5. Vapor pressure rate results for gasoline used at different temperatures.

Conclusion

• Experiments have shown that higher temperatures lead to a significant increase in the rate of gasoline evaporation inside transport tanks, with the evaporation rate doubling from 50 g at 30°C to 225 g at 70°C over a period of 6 hours.

• It has been shown that gasoline vapor pressure increases proportionally with temperature (from 30-80 kPa), increasing the ability of molecules to transition to the gaseous state and thus increasing the rate of mass and volume loss.

• The loss in gasoline volume increased from 62 ml to 270 ml between temperatures of 30 and 70 °C, reflecting real operational losses that require addressing.

• High temperatures in Iraq, especially in the summer, lead to critical operating conditions for fuel tankers, increasing the likelihood of leaks, emissions, and even explosions if not engineered.

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