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Design Optimization of an Automotive Fuel Tank for the Minimization of Evaporative Losses of Gasoline Due to Thermal Conduction: Experimental & Analytical Approach

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Environment is being polluted due to several toxic gases like CO, CO_2, NO_x, and HC every day. The sectors responsible for disturbing the balance of atmosphere are mainly industrial and transportation. CO mainly evolved because of lack of oxygen during combustion, NO_x evolve if combustion occurs at high temperature and HC released to the atmosphere from exhaust and evaporation of fuel from the fuel tank. Data collection and analysis revealed that the total evaporation loss is around 6 to 7 %. In this paper, an experiment was performed on a two-wheeler tank, which is made of carbon steel sheet metal. Carbon steel sheet metal is one of the major cause of gasoline evaporation due to its high thermal conductivity. In the experiment, evaporative losses of gasoline is quantified along with the heat transfer analysis on the fuel tank body. Experimental results revealed that evaporative loss in C-steel tank is 15.92% and in composite tank with insulated layer is 0.44%. Therefore, the obtained results must have a positive impact on environment i.e. low HC emission into the environment.

1. Introduction

Pollution of environment is not only due to emission of hydrocarbon from the exhaust gases of vehicle, but hydrocarbons present in gasoline are also responsible factor. Transportation plays a major role in GHG (greenhouse gas) emission which is directly associated with climate change et al., 2018).It is released into the environment from the tank of automobile when it is refueled and additionally all through transportation and storage because of evaporation. Due to the evaporation of gasoline, organic vapor is released into the atmosphere, which causes huge energy waste and severe environmental pollution like ozone pollution. and Around 1.5 – 2% gasoline is evaporated in to the atmosphere, when it is shifted from producer to customer and around 40% of the hydrocarbons(emitted by road transport) comes from the evaporation from the fuel system of automobile with gasoline engines (Aulich et al., 1994; Hilpert et al., 2015; Jurušs and Seile, 2017). MAC curve is a tool to target emission reduction in industrial sector(Atkins, Neale, Wu, & Walmsley, 2018). Authors have also used CFD simulation air speed distribution and pollutants of exhaust (Zhan et al., 2018). It is also observed that due to solar radiation, temperature of gasoline in fuel tank increases and evaporation takes place, which is hazardous to human health. (Petrol, In, & Tanks, 2010) explained HC release during refueling storage of gas stations and transferring the fuel to fuel tank and its effects on human health and environment. It has been observed that the attendants on gas stations and the drivers of the vehicle are mainly surviving from the health risk because of inhaling HC (Javelaud et al., 1998; Karakitsios et al., 2007). Table 1 shows the statistics of USA and Canada gasoline consumption, with a presumption that if a small 0.1 % of HC is considered to be released in environment. When gasoline is evaporated, its composition and properties also varies because different components evaporate at different rate. It is a general phenomenon of the gasoline and occurs in all type of equipment fuel tanks. When gasoline is filled in tank, light component is evaporated first which is essential element for octane benefits during cold start. Because when cold start occurs these light component forms most of the air fuel mixture. In the absence of these light components

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mixture becomes lean which causes higher temperature, pre ignition, detonation and finally it damage the piston (Aulich et al., 1994; Hilpert et al., 2015; Jurušs & Seile, 2017).

Table 1: Gasoline consumption per Annum (Statistics Canada, 2009)

Country	Consumption/Citizen	Release of HC/capita to the atmosphere
USA	430 gallons	1.6 Liter
Canada	450 gallons	1.7 Liter

Hartle (1993) studied on presentation of Methyl tert-Butyl Ether and benzene among benefit station specialist and administrators. In his examination author depicts NIOSH (National Institute for Occupational Safety and Health) exposure evaluation procedures and presents consequences of the individual and mass fuel tests gathered for investigation of MTBE and benzene. Preparatory factual examinations shows that regardless of whether the other work practice and site-particular factors are controlled (i.e., measure of fuel pumped, measure of benzene in the fuel, and so forth.) vapor recuperation has no huge impact on decreasing exposures to benzene among the chaperons (Petrol et al., 2010). In a specialized survey of fuel evaporative losses from the retail gas outlets crosswise over Canada, 2009 (Petrol et al., 2010) gas loss in storage tank is because of the joined impact of gas conveyance to the capacity tank and the discharging activity.

Table 2: Gasoline outlet evaporative losses Canada, 2009

Evaporative losses	
	Liters
Total Evaporative losses	58,300,000
Operational losses, outlets	37,300,000
Refueling losses, vehicle	21,100,000

From, Table 2, it is clear that evaporative losses was very high in 2009 and that can be minimized by providing a proper insulation on the fuel tank. Refueling losses are outcomes of evaporation due to vapor collection in tank under solar radiation. Most of the author throughout the word developed various methods for determination of fuel losses in storage tank. Levitin and Tryascin, (2016) use factual saturation pressure method for determination of fuel losses in storage tank. Evaporative losses are of two types, qualitative and quantitative losses. Quantitative losses are caused by evaporation and qualitative losses are caused fluid decomposition. In this paper, evaporative loss has been calculated by using weight balance method. Thermal analysis has also been done based on the latitude location of Dehradun, Uttarakhand India in which temperature of gasoline has been determined by using energy balance based on solar irradiation

1.1 Two wheeler fuel tank (Existing Design) & problems associated with it

The existing two-wheeler fuel tank is made of carbon sheet metal, which has high thermal conductivity. When vehicle is directly exposed to the sun light, it raises the surface temperature of the fuel tank, which accelerates the rate of fuel vaporization. Few decades before fuel vapors were channelized into the air directly. With the simple modifications like sealing leaks, venting of fuel tanks into crankcase, the emission was minimized up to certain extent but it was not sufficient to meet the stringent emission norms in later years.
As per LEV (Low Emission Vehicle) III program, evaporative emissions standards calling for zero evaporative emission losses by 2022. In this work, evaporative loss of fuel tank has been investigated numerically and experimentally by using the weather condition of Uttarakhand, Dehradun India. The composite tank used here are effective enough to minimize the evaporative losses from 15.62% to 0.44%. In existing design mostly carbon steel are used to store gasoline in a two-wheeler, which leads to HC emission and vapor lock problems in the vehicle. In numerical analysis gasoline, the temperature has been calculated from 0900-1500 Hr for composite tank using insulating layers. The paper also presents the weight balance method to find evaporative losses experimentally. This paper consists of four section in which review of research has been done in the first section. In all sections, the emphasis is given on HC emission due to evaporative losses of gasoline. In the second section, methodology used for this research work has been mentioned. The methodology includes the existing and current design of fuel tank for numerical and experimental analysis. The results obtained from the numerical and experimental evaluation is mentioned in third section, where all the losses are shown graphically. In last section conclusion of this research work is given along with future work and expected outcomes.

2. Methodology

The existing two wheeler tanks are made of C steel or Mild steel (Figure 1a), also the sheet metal used is very thin. The thermal conductivity of metal is far higher than a cheap insulator. Due to the high thermal conductivity, heat carrying capacity is greater, resulting in fast heating of fuel. As the amount of evaporation of liquid is somewhat proportional to the temperature so heating of sheet metal causes more evaporation of gasoline. Multiple layers of insulation is one of the good options instead of mild steel or C steel. PVC, glass wool etc are the cheap & easy available insulators. A layer of PVC has been provided outside the C steel tank and the minor gap between the PVC and C steel layer has been filled with glass wool or other thermal insulator as shown in Figure 1b. The composite layer of C steel, glass wool & PVC will help reduce the heat transfer from outside to inside the fuel tank.

Figure 1a: C Steel Fuel Tank *Figure 1b: Composite layered fuel tank*

2.1 Solar variables (Dehradun – 30.41497^{0}N, 77.9673^{0}E)

Local apparent time is utilized to figure the hour angle took after by two correction. First correction is due to difference between longitude of a location and the meridian on which the standard time is based and the second correction is due to variation of the earth's orbit and the rate of rotation (Sukhatme & Nayak, 2007). Table 3 shows the variation of local apparent time of Dehradun, India based on longitude of location.

$$\begin{aligned} Local\ apparent\ time \\ &= Standard\ Time \mp 4(Standard\ time\ longitude - Longitude\ of\ location) \\ &+ equation\ of\ time\ correction \end{aligned} \quad (1)$$

The equation of time correction can be calculated from the following empirical relation [13]:

$$E = 229.18(0.000075 + 0.001868\cos B - 0.032077\sin B - 0.014615\ \cos 2B - 0.04089\sin 2B \quad (2)$$

$$Where, B = \frac{(n-1)360}{365}, n = \ day\ of\ the\ year \quad (3)$$

n = 106, according to 15 April
For angular measurement of time, hour angle is taken which is equivalent to 15^0 per hour.

$$\cos\omega_s = -\tan\phi\ \tan\delta \quad (4)$$

Where, ω_s = hour angle
Φ = latitude, δ = declination

$$\cos\theta = \sin\phi\sin\delta + \cos\phi\cos\delta\cos\omega \quad (5)$$

Table 3 shows the variation of hour angle with standard time, which can be calculated by using LAT (Local apparent time). Hour angle is negative before 1200 Hrs and positive after 1200 Hrs. Hour angle can be used for the calculation of angle made by beam radiation with the normal to a flat portion of the fuel tank. With a specific end goal to discover the intensity of beam radiation falling on the fuel tank surface, it is important to change angle made by solar radiation to a proportionate esteem relating to the normal on the fuel tank surface. For horizontal surface, angle of inclination can be calculated by the equation given below (Sukhatme & Nayak, 2007). Where, ω = hour angle
δ = declination angle, ϕ = Latitude, θ = Beam radiation inclination

Table 3: Apparent Time, declination angle, latitude, hour angle, angle of incidence and global radiation calculation

Standard Time	Standard Time Longitude	Longitude of Location	B	Time Correction	Local Apparent Time	n = day of the year	Declination (δ)	Latitude (ϕ)	hour angle (ω_s)	Θ (Angle of Incidence)	Ig (Global radiation)
900	82.5	77.97	103.56	-2.43	879.44	106	23.04	30.41	48.08	35.32	680.35
1000	82.5	77.97	103.56	-2.43	979.44	106	23.04	30.41	33.08	69.86	844.73
1100	82.5	77.97	103.56	-2.43	1079.44	106	23.04	30.41	18.08	93.95	953.65
1200	82.5	77.97	103.56	-2.43	1179.44	106	23.04	30.41	3.08	36.90	999.94
1300	82.5	77.97	103.56	-2.43	1279.44	106	23.04	30.41	-11.92	96.13	980.54
1400	82.5	77.97	103.56	-2.43	1379.44	106	23.04	30.41	-26.92	66.30	896.72
1500	82.5	77.97	103.56	-2.43	1479.44	106	23.04	30.41	-41.92	57.62	754.04

Table 3 shows the variation of angle of incidence of solar radiation with respect to the standard time. The hourly global radiation on a horizontal surface on 15 April in Dehradun between 0900 and 1500 h is obtained by using Table 3.

$I_g = I_b + I_d$ (Sukhatme & Nayak, 2007) (6)

Hourly global radiation on horizontal surface can be calculated by calculating I_b (beam radiation) and I_d (Diffuse radiation) individually. It has been found heat flux was maximum at mid of the day, which causes rapid evaporation of gasoline from the tank.

2.2 Net Radiation Exchange at Surface

Net radiation heat transfer through the carbon steel is obtained by using the energy balance under steady state heat transfer**.**

$$J = E + \rho G \quad (7)$$

Calculation of temperature across a composite layered made of carbon steel, glass wool and PVC has been done for fabricated composite layered fuel tank. This calculation shows decrement of 13.53°C in the temperature on the other side (PVC side) of the composite layer.

Variation of heat flux with time are shown in Table 4a, which is further used to calculate temperature of surface in composite fuel tank. Thermal conductivity of materials used in composite fuel tank are shown in Table 4b, which can be further used to calculate resistance to heat transfer.

Table 4a: Heat flux variation with time

Standard Time	**q (W/m^2)**
900	680.3538
1000	844.7261
1100	953.6474
1200	999.9412
1300	980.5356
1400	896.7195
1500	754.037

Table 4b: Thermal conductivity of material

Material	Thermal Conductivity (W/m^{2}K)
Carbon steel	0.5377
Glass Wool	0.04
PVC	0.16

From Table 5, that temperature across carbon steel, Glass wool and PVC keep on decreasing due to increase in resistance offered by material.

Table 5: Temperature across carbon steel, Glass wool and PVC

q (W/m^2)	**T_1**	**T_2**	**T_3**
680.3538	47.34696	38.84254	37.56688
844.7261	49.29001	38.73094	37.14707
953.6474	50.26432	38.34373	36.55564
999.9412	50.40336	37.9041	36.02921
980.5356	49.76426	37.50757	35.66906
896.7195	49.32305	38.11406	36.43271
754.037	48.97662	39.55116	38.13734

Figure 2 shows the calculated variation of temperature inside the fuel-tank w.r.t. time. Which clearly reflects that temperature inside the fuel tank is lesser than the surface temperature of carbon steel, i.e. the composite layer is effective to reduce the heat conduction and keep the lesser temperature inside the fuel tank.

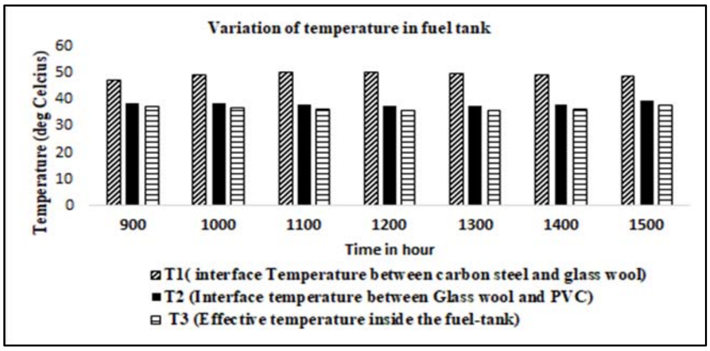
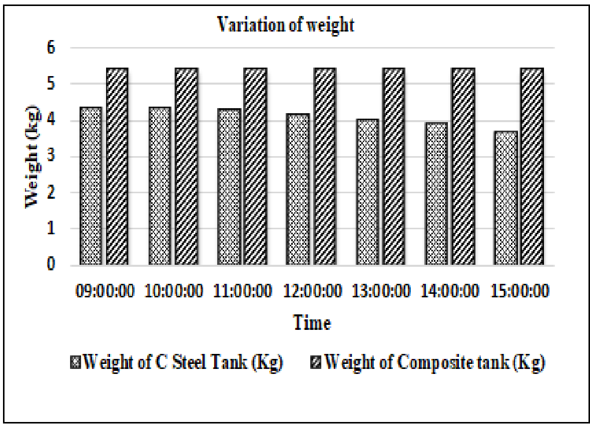


Figure 2: Temperature variation across composite fuel tank

3. Experimental analysis

To perform the comparative experiment both the fuel tank (Fuel tank made of only carbon steel & the other composite layered fuel tank) have been kept under the direct exposer to the sun light for equal time duration. Weight of the tanks have been measured with gasoline of equal quantity in both the tanks (i.e.1Litre). Temperature sensors were used to measure the ambient temperature as well as the temperature inside the fuel tanks, therefore fuel cap were kept open during the experiment.
Now the tanks have been kept for 5-6 hrs under the direct exposer of sunlight and temperure variation in side the fuel tank & weight of the tank has been measured frequently. The following observations have been recorded while performing the experiment.
Initial weight of C steel fuel tank = 4.332kg &
Initial weight of composite layered fuel tank = 5.406kg
Weight of C steel fuel tank at the end of experiment = 3.642kg &
Weight of composite layered fuel tank at the end of experiment = 5.382kg
Loss in weight of C steel fuel tank = (4.332-3.642) kg =0.69kg = 690gms &
Loss in weight of composite layered fuel tank after = (5.406-5.382) kg = 0.024kg = 24gms
Hence it is observed (Figure. 3a) that the rate of decrement in the weight of C steel tank is faster than the composite layered tank; which shows that fuel evaporation in C steel tank is occurring faster than the composite layered tank. These values may vary in the case of closed fuel tank cap.



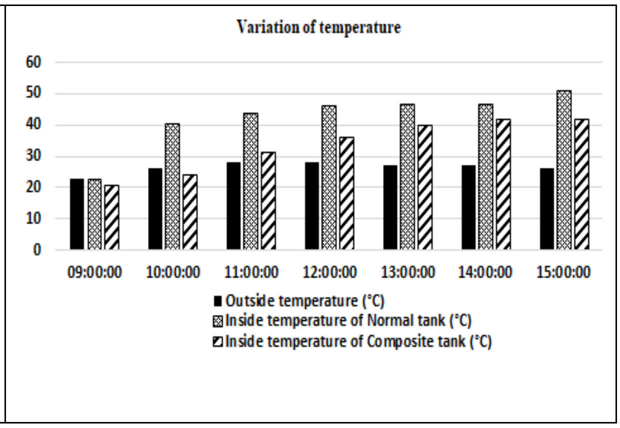


Figure 3a: Decrement in weight *Figure 3b: Temperature variation inside the fuel tank*

The graph (Figure. 3b) shows the temeperature variation inside the fuel tanks during the experiment. Which reflects effective temperature inside the C steel fuel tank is higher than the effective temperature inside the composite layered fuel tank. This temperature variation has been observed w.r.t. to the recorded ambient temperature.

4. Conclusion

Analytical study has been validated through experimentally for both insulated and non-insulated fuel tank. In analytical study only inside temperature of fuel tank has been calculated by considering the intensity of radiation between 0900 to 1500 hrs, which is very close to experimental results. In this study, it has been found that temperature inside composite layered fuel tank has been lowered more effectively than carbon steel fuel tank.

In experimental study, temperature inside the fuel tank and weight of fuel tank (filled with 1 L of gasoline) has been observed under solar radiation between 0900 to 1500 hr in the month of April. Experimental study reveals that weight of carbon steel fuel tank decreases at the faster rate than insulated tank i.e. gasoline is being loosed at faster rate in carbon steel fuel tank. It clearly reflects that the evaporation of gasoline in carbon steel fuel tank is faster than the insulated tank. In this study, it has also been observed that rate of change of temperature inside the carbon steel fuel tank is faster than the composite layered fuel tank, which is the main responsible factor for the rapid evaporation of gasoline.

Nomenclature

Ω	Hour Angle	Q	Heat flux
Φ	Latitude	J	Radiocity
Δ	Declination angle	G	Irradiation
Θ	Beam radius inclination	P	Transmissivity
I_0	Hourly extraterrestrial radiation	E	Emissive Power
S	Solar Constant	K	Thermal conductivity
I_g	Global Radiation		

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