An Evaluation of Evaporative Emissions of Gasoline from Storage Sites and Service Stations

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Abstract

Evaporation loss is the natural process in which a liquid is converted to a vapor and subsequently is lost to the atmosphere. Petroleum is one of the most important mineral resources and should be conserved using all practical means. The reduction of evaporation loss of petroleum will give attractive economic returns as well as reducing air pollution. The objective of this study is to evaluate the evaporation loss of gasoline from storage sites including the standing and working losses of the storage tank, losses during loading from the storage site to a tank truck and from the tank truck to an underground storage tank and finally during a refueling operation at a service station. The case study was supported by the Petroleum Authority of Thailand (PTT) and carried out at their site. The results from this case study are then used to estimate the total evaporation loss of gasoline in Thailand. Using 1994 data, this paper estimates a total gasoline evaporation loss of 21,000 tons/year throughout Thailand. This is based on the information that PTT supplies 25 % of gasoline in Thailand. The results should be of concern to the petroleum industries and also to government agencies with a view to promoting some regulations in Thailand.

Keywords: air pollution; gasoline, evaporative loss,standing storage loss, working loss, displacement loss

1. Introduction

Nowadays, Thailand has a serious air pollution problem which is caused by pollutants in exhaust gases. To reduce pollutants in vehicle emissions, according to the Ministry of Commerce gasoline specification (announced in 1993), the distillation temperature of fuels at 10 % and 50 % evaporation is reduced in order to improve combustion. This makes the fuel more volatile. Gasoline is composed of different hydrocarbons with different boiling points in the range of 30-200 °C. Some hydrocarbons can be released into the atmosphere at ambient temperature. Hydrocarbons give rise to photochemical oxidants when hydrocarbon compounds and oxides of nitrogen react in the presence of sunlight. Resulting health problems include coughs, eye irritation and poor air quality.

2. Objectives

Evaporation loss is common in all branches of the petroleum industries. Common sources of evaporation are: storage tanks, production, refining, and transportation (loading). In this study, only the evaporation loss of gasoline from storage tanks and losses during loading; which are losses from the storage site to a tank truck and from the tank truck to an underground storage tank and finally during refueling operation at service stations, are investigated.

3. General description of gasoline storage tank

Three types of tanks are used for the storage of gasoline at depots: fixed roof, internal floating roof and external floating roof tank.

- Fixed roof tanks have a vertical cylindrical shell and are covered with a non-moving roof. The tank is welded throughout and is designed to be vapor and liquid tight. The fixed roof may be cone shaped, dome shaped or flat. This tank type has a pressure/vacuum vent mounted on the tank roof to protect against damage from overpressure and overvacuum. A typical fixed roof tank is shown in Figure 1.

- Internal floating roof tanks consist of a cylindrical shell and both a fixed roof cover and a floating deck which rests on the liquid surface. This tank can be divided into two types: a tank in which the fixed roof is supported by a column within the tank and a tank with a self-supporting fixed roof which doesn't have a supporting column.A typical internal floating roof tank is shown in Figure 2.

- External floating roof tanks have a cylindrical shell and floating roof which rises and falls as the liquid level changes. This tank has no stationary roof cover.A typical external floating roof tank is shown in Figure 3.

Floating decks are used to reduce the evaporation of the liquid surface. Floating decks rest on the liquid surface. Floating decks have an annular rim space between the perimeter of the deck and the tank shell to allow travel of the deck within the tank. The deck also has a rim seal for closing the rim area to control evaporation loss. Typical rim seal systems are shown in Figure 4 - Figure 8.

3.1 Evaporative loss from fixed roof tanks

3.1.1 Standing storage loss

Standing storage loss from fixed roof tanks is evaporative loss of stock vapor resulting from thermal expansion and contraction of air-vapor mixture resulting from the daily temperature cycle. During the day time, the tank shell and roof are exposed to direct, diffuse and ground-reflected solar radiation including heat exchange with surrounding ambient air. Air-vapor mixture within the tank is heated by exchanging heat with the tank. This heat causes air-vapor mixture in the vapor space to expand and increase both in pressure and temperature. When the pressure in the tank exceeds the pressure-vacuum vent (PV vent) pressure setting. PV vent opens to release vapor from the tank until the pressure reduces to below a set point. When the pressure falls below the PV vent vacuum set point, air is drawn into the tank. The fresh air upsets any existing saturation equilibrium by diluting vapor concentration so more liquid vaporizes from the liquid surface to restore equilibrium. The stock vapor mixed with the air is drawn into the tank. When the PV vent pressure setting has been exceeded the vapor is forced out of the tank resulting in evaporative loss.

3.1.2 Working loss

Working Loss from a fixed roof tank is the vapor loss that is expelled from the tank resulting from a change in liquid level in the tank and the combined effect of both filling loss and emptying loss. During the filling operation, the liquid level rises up so that the air-vapor mixture within the tank is compressed. The internal pressure increases until its reaches the

PV vent pressure setting, PV vent opens and the air-vapor mixture is discharged from the tank to maintain the vapor space pressure near the PV vent pressure setting. Moreover, as the liquid is withdrawn from the tank, the pressure of vapor space decreases. When the pressure drops below the PV vacuum vent, air enters the tank through PV vent to maintain total pressure in the tank. Liquid evaporates from the liquid surface to establish equilibrium conditions with the entering air. After the tank emptying has stopped and PV vent has closed, the liquid surface will continue to evaporate so the pressure will tend to rise. When the pressure exceeds PV vent pressure setting, the vapor is vented from the tank resulting in emptying loss.

3.2 Evaporative loss from external floating roof tanks

3.2.1 Rim space loss mechanisms

The main factor which induces rim space loss is wind. Wind blowing over the floating deck causes a pressure difference across the floating roof. Air flows up and over the top of the floating deck to produce a lower pressure zone above the roof and a higher pressure zone below the floating roof. The pressure difference induces losses in two ways. In the first case, the pressure difference causes air in the vapor space beneath the seal to move around the circumference of the tank. This air flushes hydrocarbon mixture through the gap between the tank shell and the seal. The vapor concentration below the deck falls causing more liquid to vaporize in order to re-establish equilibrium. The magnitude of the loss depends upon the tightness of the seal system which controls the gap between the tank shell and the seal.

3.2.2 Withdrawal loss Mechanisms

When the floating roof descends by the withdrawal of liquid in the tank, so the inner tank wall is covered with a film of liquid which vaporizes when exposed to the atmosphere.

3.3 Evaporative loss from internal floating roof tanks

Sources of evaporative loss during standing storage include the rim seal area, the apertures for fittings which penetrate the floating deck and the bolted seam in the floating deck.

3.3.1 Rim seal area loss mechanisms

In the case of the rim space between the floating deck and the tank wall a vapor space exists beneath the seal. When air within the space between the bottom of the seal and the liquid passes through the gap between the tank shell and the seal there is a reduction of hydrocarbon concentration so more liquid vaporizes in order to re-establish the equilibrium concentration. Another potential mechanism is vertical mixing of vapor in the gap between the tank shell and the seal resulting from diffusion and air turbulence. The temperature and pressure change causes the rim vapor space breathing. As the rim vapor space temperature increases, an expansion of gas occurs in the rim vapor space which expels the air-vapor mixture to the atmosphere. As the rim vapor space temperature decreases, the vapor in the rim space contracts. Fresh air is drawn into the rim vapor space resulting in reduction of concentration of hydrocarbon vapor in this space and so more liquid evaporates. This results in an expulsion of vapor from the vapor space.The change in vapor temperature can cause varying air solubility. When the stock liquid temperature increases, gas solubility decreases thus air evolves from the stock liquid. This gas which leaves the liquid may carry some hydrocarbon vapor with it. The magnitude of emission depend upon the type of seal and the size of the gap between the tank shell and the seal.

3.3.2 Withdrawal loss mechanisms

Withdrawal loss occurs during stock liquid withdrawal. When the floating deck descends with the liquid level, some liquid remains in a coating on the tank wall and the support column. When this liquid is exposed to the air, some evaporation occurs to the atmosphere before the exposed area is again covered.

3.4 Displacement loss

When the storage tank is used and some fuel is drawn, a vapor space is created above the liquid surface. Some of the liquid which remains in the tank vaporises into the vapor space until it reaches saturated conditions within the air which is drawn into the tank during fuel drawout. When the tank is filled with liquid, the vapor is compressed in the tank. Air-vapor mixture is forced out through a vapor vent which represents a displacement loss. This loss is similar to the working loss in a fixed roof tank. The difference is, vapor in the fixed roof tank will be released only when pressure in the tank exceeds the PV vent pressure setting. Displacement losses occur during the loading of fuel from a storage tank to a tank truck and from a tank truck to an underground storage tank and also during vehicle refueling at the service station.

4. Calculation

The evaporative loss from storage tanks was determined by using data from two depots, Prakanong and Sriracha. The general type of storage tank in this study can be divided into: fixed roof, internal floating roof and external floating roof tanks.

4.1 Standing storage loss of fixed roof tank

The information that is needed to calculate the standing storage loss of fixed-roof tank, is as follows:

- Properties of the stored liquid, including the type of fuel, Reid vapor pressure, storage temperature and the level of liquid storage.
- Data about the tank, including tank diameter, height of tank shell, type of roof, roof height, color of paint, the pressure-vacuum vent setting and tank location.
- Meteorological data such as minimum and maximum ambient temperature and solar radiation.

4.2 Working loss of a fixed roof tank

The information that is needed to evaluate the working loss of a fixed roof tank is as follows:

- Properties of the liquid such as the type of fuel, bulk liquid temperature, Reid vapor pressure, vapor molecular weight.
- Annual net throughput (associated with increasing the liquid level)
- Capacity of the tank

4.3 Standing storage loss of the external floating roof tank

The information that is needed to calculate the standing storage loss of the external floating roof tank is as follows:

- Properties of the stored liquid, including type of gasoline, average reid vapor pressure, average storage liquid temperature and average molecular weight of stock vapor.
- Details of the tank, including the tank diameter, the tank construction (welded or riveted).
- Type of seal system
- Wind speed in the area

4.4 Withdrawal loss of the external floating roof tank

The withdrawal loss of the external floating roof tank can be calculated from the following information:

- The total volume of liquid stock that is withdrawn from the tank
- Properties of liquid stock: type of liquid stored, average liquid density
- Tank shell condition
- Tank diameter

4.5 Standing storage loss of the internal floating tank

The standing storage loss of the internal floating roof can be estimated from the following information:

- Properties of the liquid including stock type, Reid vapor pressure, average bulk liquid temperature in the tank and the average molecular weight.
- Tank diameter and tank type which is divided into column-supported and self-supported fixed roof types.

- Details of the floating deck construction: welded or bolted seams and length of bolted deck seams
- Rim seal system type
- Deck fitting types and number

4.6 Withdrawal loss of the internal floating roof tank

The withdrawal loss of the internal floating roof tank can be estimated from the following information:

- Stock type
- Annual net throughput
- The total volume stock which is withdrawn from the tank which results in a decrease in the liquid level.
- Average liquid stock density
- Tank diameter
- Number of columns and the effective column diameter
- Tank shell and column condition

Evaporative losses from fixed roof, external and internal floating roof tanks were calculated in accordance with procedures specified in [1], [2], [3] and [4] respectively.

4.7 Displacement loss

The displacement of vapor occurs during

- Loading gasoline from a storage tank to a tank truck
- Dispensing gasoline from a tank truck to an underground storage tank
- Delivering gasoline from an underground store to a vehicle tank

The amount of displacement vapor emission in the first case can be estimated from data which was obtained from Prakanong depot. The data used to calculate displacement vapor loss from the other cases was obtained from PTT service stations at Sanampoa.

The displacement is related to the following variables:

- Stock type
- True vapor pressure which relates to the Reid vapor pressure, the vapor temperature
- Amount of gasoline delivered

In this study, displacement loss during the loading of gasoline from a storage tank to a tank truck indicates only losses from the tank truck. Displacement losses were calculated in accordance with procedures specified in [5],[6], [7],[8].

5. Other information for evaluating evaporative loss

5.1 Type and total capacity of storage tank

- Fixed roof tanks, 8 tanks, total capacity 15.95 million litres
- Internal floating roof tank, 14 tanks, total capacity 76.30 million litres
- External floating roof tank, 2 tanks, total capacity 36.10 million litres

5.2 Gasoline distribution

The displacement from gasoline distribution was estimated from the following information

- The amount of gasoline which was pumped from the storage tanks to tank trucks are as follows;
- At Prakanong depot 1,295,000 litres/day
- At Sriracha depot 59,000-355,000 litres/day

5.3 Amount of PTT gasoline sold in Bangkok and immediate regions

The amount of PTT gasoline sold in Bangkok and immediate regions is about 50-58 % of the total PTT gasoline sold in Thailand.

5.4 Amount of PTT gasoline which was sold in Thailand

The amount of PTT gasoline which was sold in Thailand in 1984 was about 25% of the total gasoline sold in Thailand.

6. Results

The result of the calculated evaporative loss in each step is combined with the above additional information. The result will be used for evaluating the total evaporative loss.

6.1 Storage tanks

- Fixed roof tanks
  - Standing storage loss = 75 tons/yr
  - Working loss = 590 tons/yr

- External floating roof tanks
  - Standing storage loss = 7 tons/yr
  - Working loss = 0.03 tons/yr
- Internal floating roof tanks
  - Standing storage loss = 70 tons/yr
  - Working loss = 1 ton/yr

A piechart which shows the losses from the storage tank at Prakanong and Sriracha depot is shown in Figure 9.

6.2 Displacement vapor during loading from storage tanks to tank trucks

= 770 tons/yr

6.3 Displacement vapor during filling fuel from tank trucks to underground storage tanks

= 670 tons/yr

6.4 Refueling vapor emission

= 630tons/yr

Total loss of gasoline

= 2,815 tons/yr

A flowchart which presents the evaporative loss during loading is shown in Figure 10.

A piechart which shows the distribution of losses is shown in Figure 11. The same piechart is also shown in [9].

If PTT gasoline market sales in Bangkok and immediate regions is about 50-58 % of total amount of PTT gasoline sales then the estimated total loss which arises from the sales of PTT gasoline in Thailand is

= 5,250 tons/yr

The sales of PTT gasoline is aproximately 25 % of the total amount of gasoline sales in 1994 in Thailand. Thus the estimated total loss is

= 21,000 tons/yr

A flowchart for estimating the total evaporative loss of gasoline is shown in Figure 12.

7. Emissions control

Control of losses from the storage tank can be done by methods which are introduced in [10] and concluded in Table 1.However, the standing storage loss from storage tanks is very much lower than the losses from distribution systems. Distribution losses should, therefore, be considered as a priority. A short term modification to reduce displacement loss during loading gasoline was done by connecting a vapor vent line which returns displaced vapor from the headspace back to the storage tank. A future method for controlling evaporative losses is to adapt a vapor recovery system. The cost of this method is quite high because it needs special equipment to convert hydrocabon vapor to liquid before liquid fuel is sent back to the storage tank [8]. Furthermore during gasoline loading, the splashing of liquid gasoline can cause small droplets to disperse into the vapor within the tank. This emission can be controlled by reducing the amount of turbulence created when the liquid is introduced. With splash loading, liquid is introduced at the top of the container and there is significant turbulence and entrainment of small liquid droplets in the expelled vapor. Using bottom or submerged loading significantly reduces the turbulence lowering the vapor generation [10].

8. Recommendation for future work

- As described, evaporation loss from the storage tank and loss from loading are two of the four common sources of evaporation loss in the petroleum industries. The evaporation loss from production and refining should, therefore, be further investigated.

- Gasoline is one of the volatile organic compounds (VOCs). The other VOCs can also be emitted from a wide variety of sources. Emission control of VOCs which are emitted from those sources should be studied.

9. Conclusion

The evaporation loss of gasoline from storage tanks and loss during loading at each main step were studied. The case study was carried out at the sites of Petroleum Authority of Thailand (PTT).Information about storage tank types and distribution systems was obtained from Prakanong and Sriracha depots and the service station at Sanampoa. This information was used to evaluate the evaporative loss of gasoline. The largest source of emissions are the evaporative loss from gasoline distribution which include during loading gasoline to storage tank (21%), the transfer from storage tanks to tank trucks (28%), the transfer from tank trucks to underground storage tanks at the service station (24%) and the refueling loss (22%). These emissions together constitute around 95 % of the total. The remaining 5 % result from standing storage losses from storage tanks.
The estimated evaporative loss from the data obtained from Prakanong and Sriracha depot can be used to estimate the total gasoline evaporative loss in Thailand. The total evaporative loss in Thailand in 1994 was estimated by assuming that approximately 50-58 % of total PTT gasoline sales was in Bangkok and the immediate regions and that the total PTT gasoline sale is about 25 % of the total gasoline sales in Thailand. It was estimated that the average total national loss is 21,000 tons/year.

The rate of evaporation loss depends on several factors. Among them, the true vapor pressure is the main cause of the vaporization.Evaporation losses control requires continuity of attention to operating procedures. To control loss from the storage tank, the system must be kept gastight. In transportation, careful consideration of the methods of loading is significant. Good maintenance and operational practices to control loss are as important as good equipment. When all persons involved have an adequate understanding as well as an interest in the problem, evaporation loss can be minimized. The results from this study should be of concern to the petroleum industries and also to the Thai government with a view to promoting regulations.

10. Acknowledgement

The work was given financial support by the Petroleum Authority of Thailand (PTT), whose assistance is gratefully acknowledged.

11. References

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Table 1 Storage Tank Emissions Control

Fixed-roof tanks

- Install vapor balance system
- Install vapor recovery/destruction
- Install internal floating roof

External floating roof tanks

- Check condition of existing seals
- Replace vapor mounted primary with liquid mounted primary seal
- Control losses from roof fittings
- Install secondary rim seal
- Convert tank to internal floating roof design
- Install vapor recovery/destruction

Internal floating roof tanks

- Check condition of existing seals
- Replace vapor mounted primary seal with liquid mounted seal
- Control losses from roof fittings
- Install secondary rim seal
- Install vapor recovery/destruction

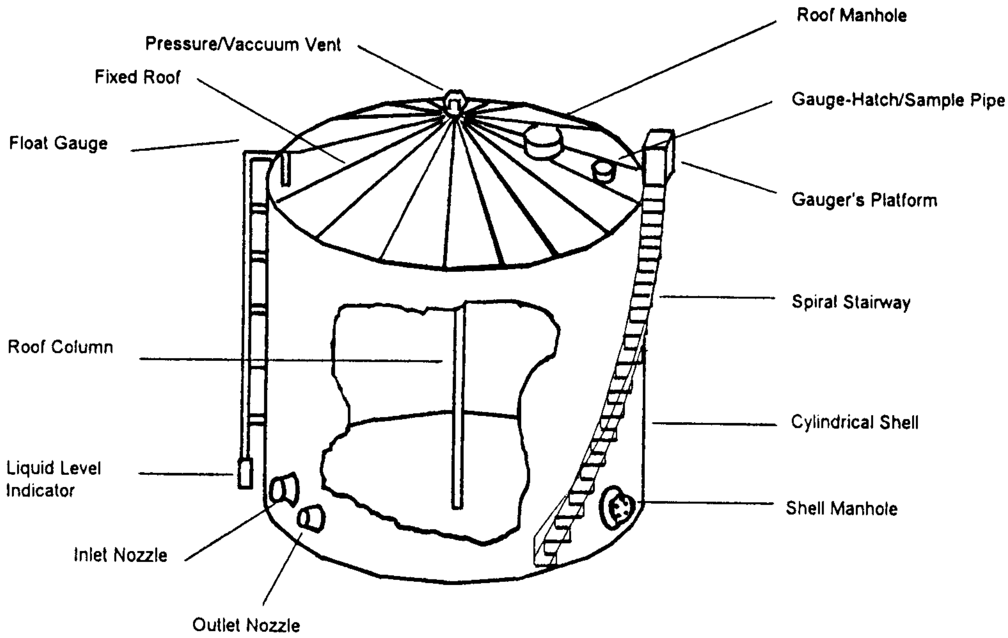


Fig 1. Fixed Roof Tank

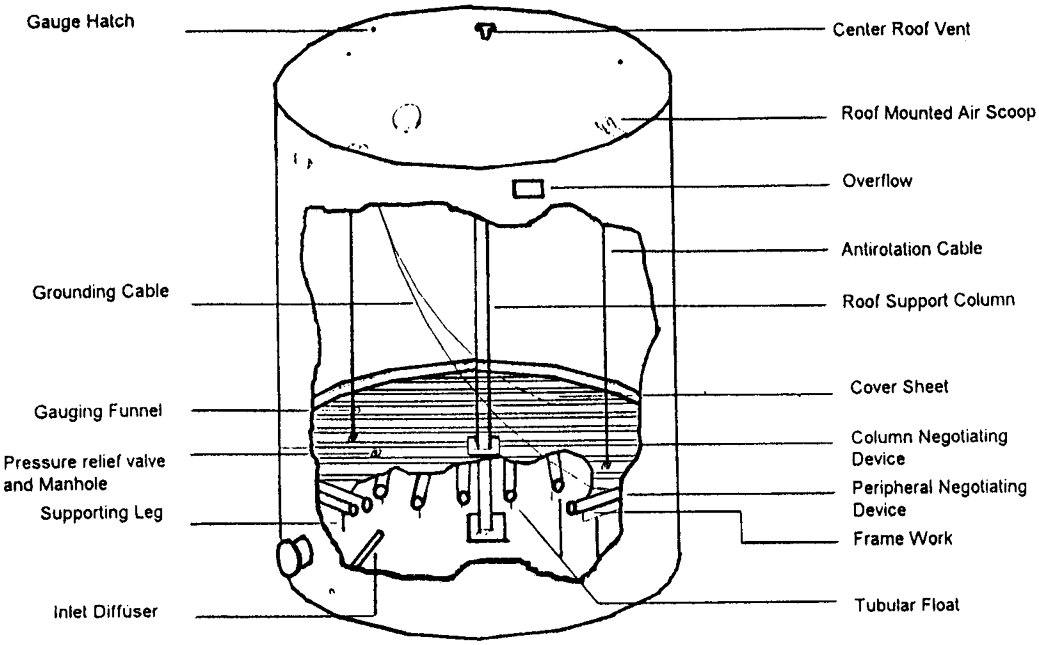


Fig 2. Internal Floating Roof Tank

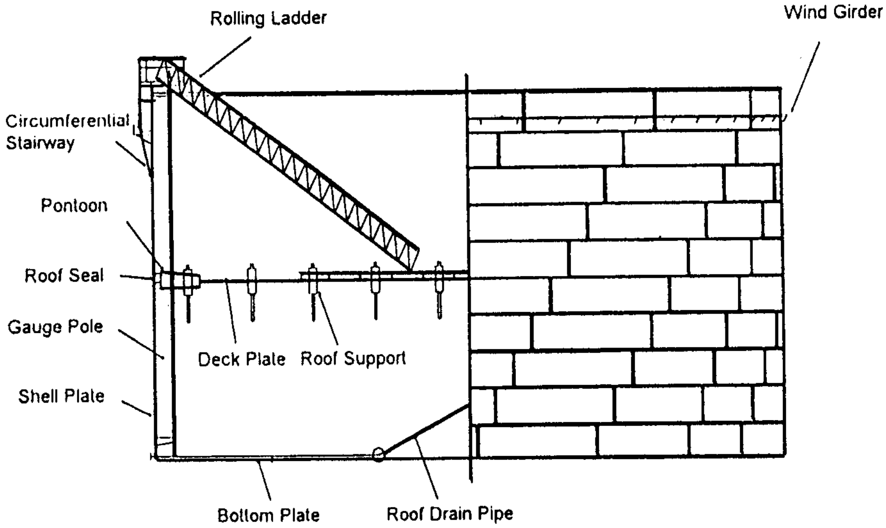


Fig 3. External Floating Roof Tank

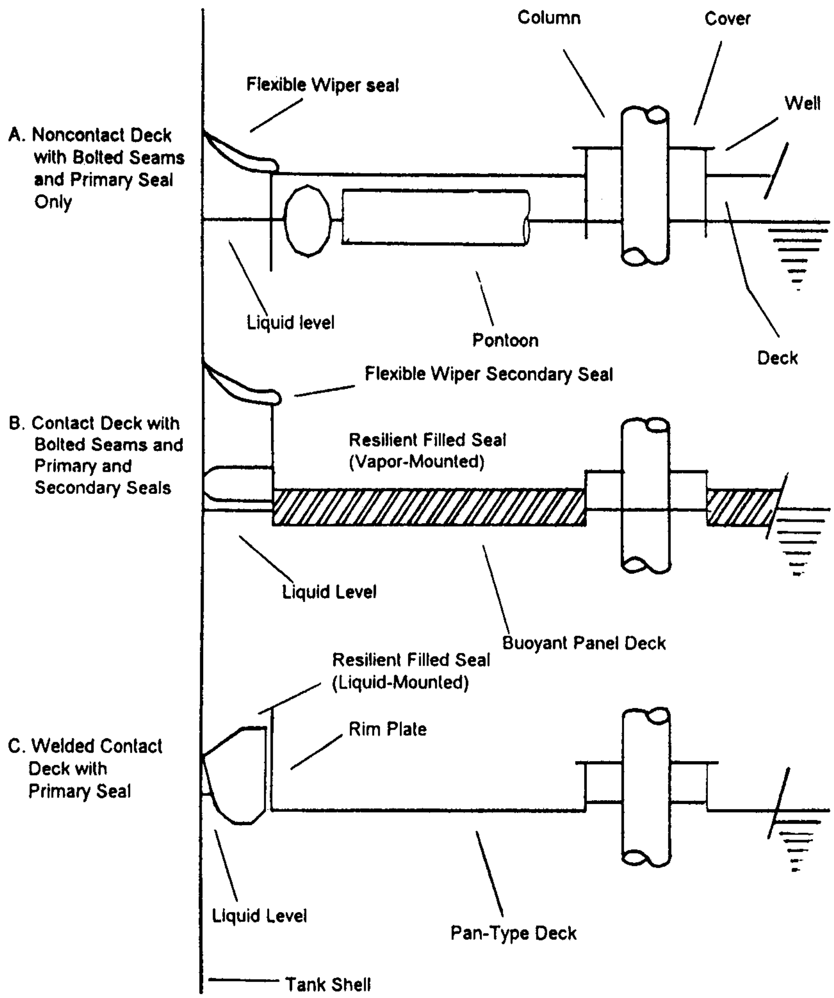


Fig 4. Typical Internal Floating Decks and Typical Rim Seal Systems

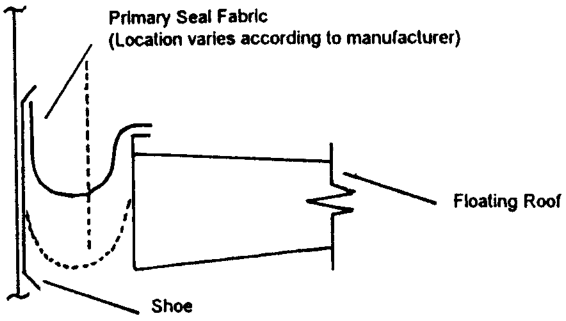


Fig 5. Mechanical Shoe Seal

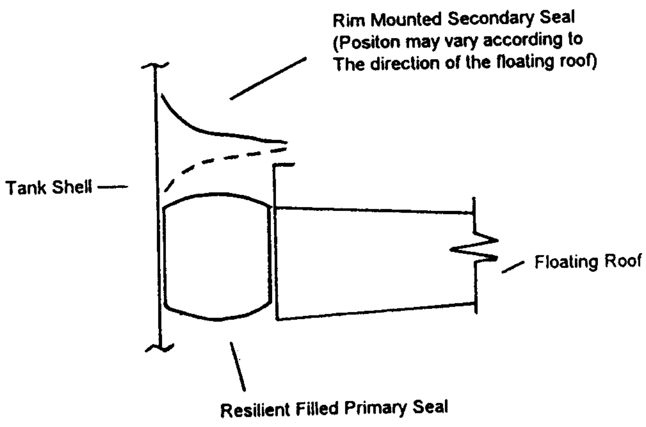


Fig 6. Resilient Filled Primary Seal with a Rim-Mounted Secondary Seal

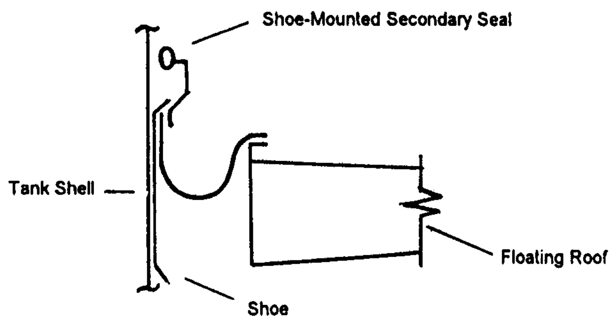


Fig 7. Mechanical Shoe Primary Seal with a Shoe Mounted Secondary Seal

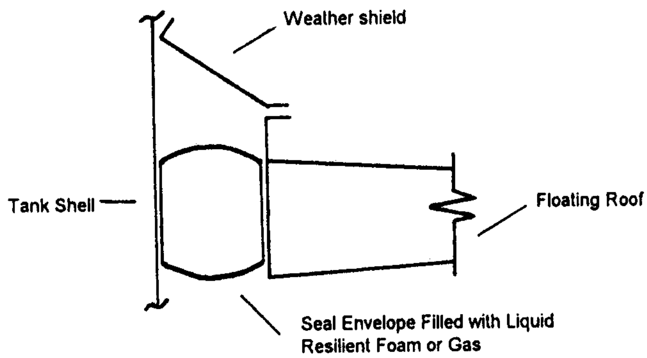
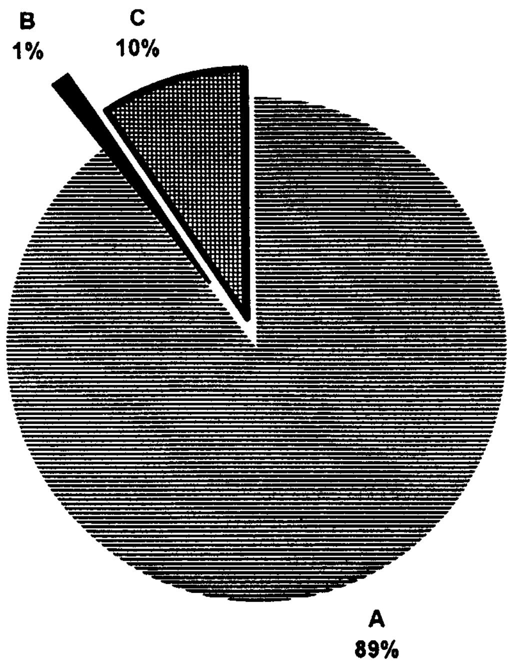


Fig 8. Resilient Filled Primary Seal with a Weather Shield



Total Evaporative Loss from 3 Types of Storage Tanks	743	tons/yr
A : Evaporative Loss from Fixed Roof Tank (8 Tanks)	665	tons/yr or 89 %
B : Evaporative Loss from External Floating Roof Tank (2 Tanks)	7.03	tons/yr or 1 %
C : Evaporative Loss from Internal Floating Roof Tank (14 Tanks)	71	tons/yr or 10 %

Fig 9. Amount of Evaporative Loss from Storage Tanks at Prakanong and Sriracha Depot

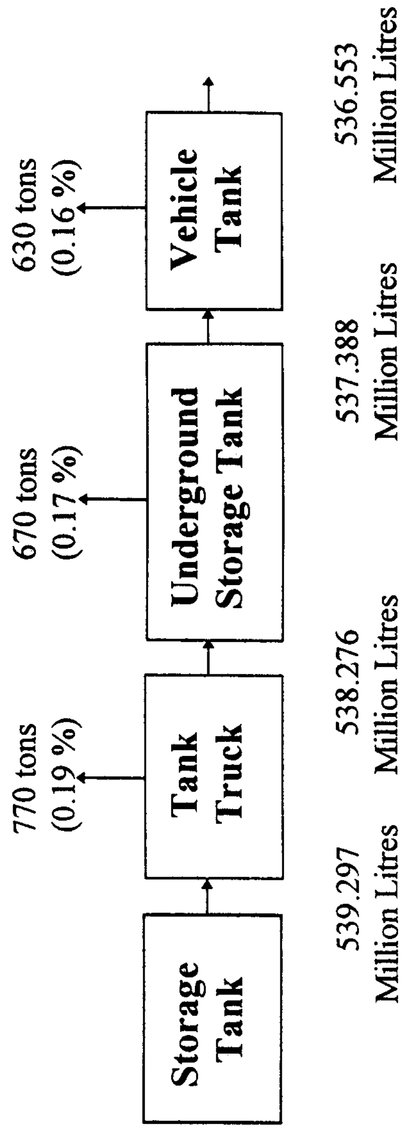
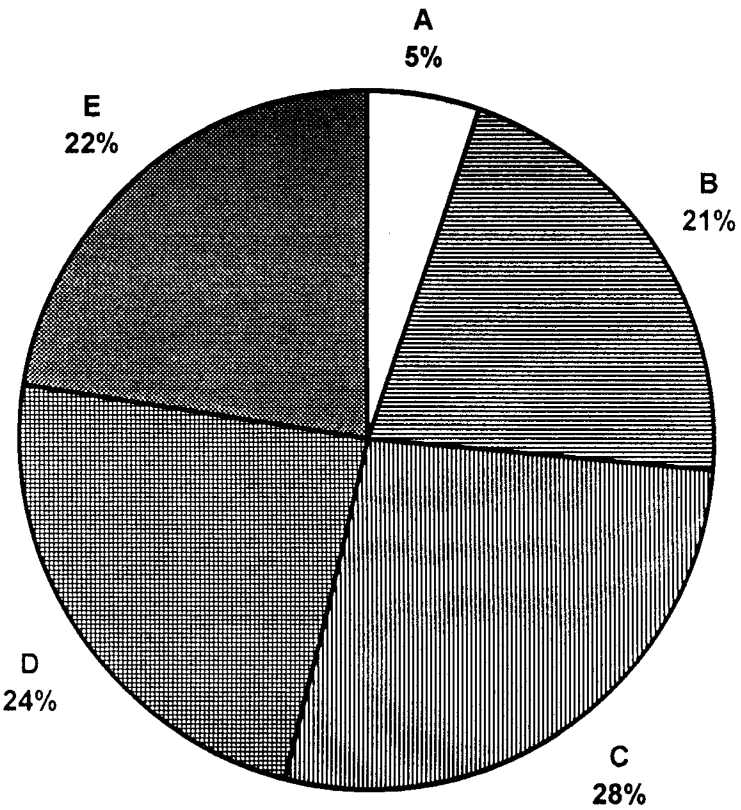


Fig 10. Flowchart of Evaporative Loss during Loading



Total Amount of Evaporative Loss from Storage Tanks and Loading Operation 2,815 tons/yr

A: Standing Storage Loss from Storage Tank	152	tons/yr or 5 %
B: Working Loss from Storage Tank	590	tons/yr or 21 %
C: During Loading from Storage Tank to Tank Truck	770	tons/yr or 28 %
D: During Loading from Tank Truck to Underground Storage Tank	670	tons/yr or 24 %
E: During Loading from Underground Storage Tank to Vehicle Tank	630	tons/yr or 22 %

Fig 11. Total Amount of Evaporative Loss from Storage Tanks and Loading Operation at Prakanong and Sriracha Depots

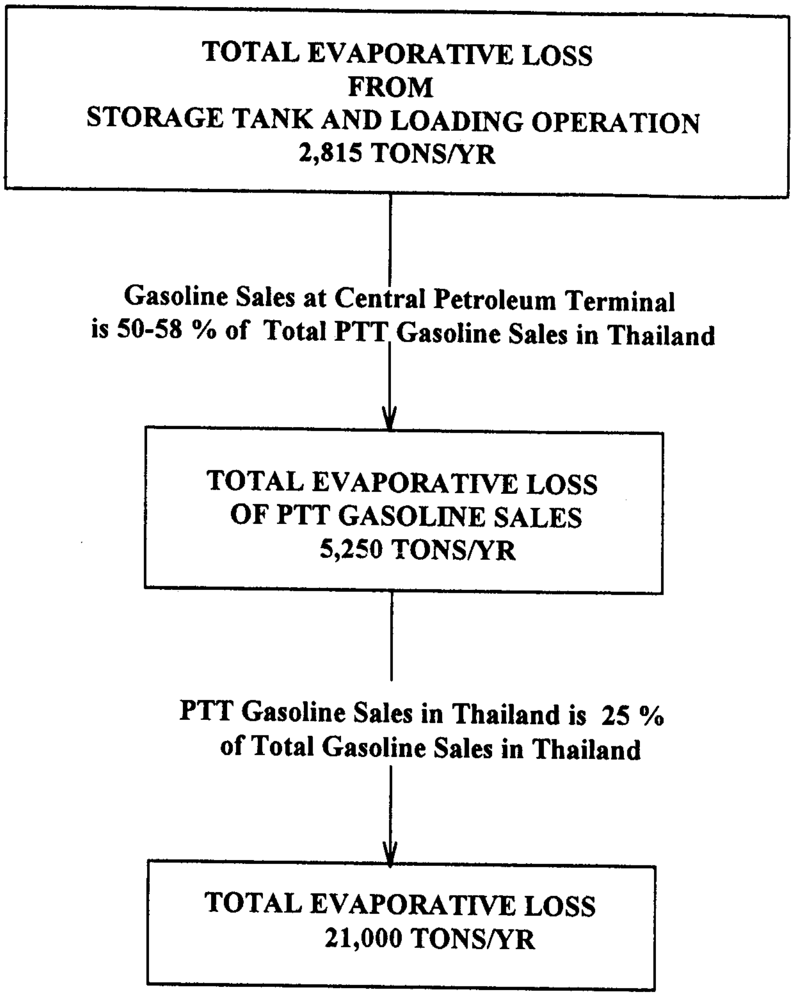


Fig 12. Flowchart for Evaluating Total Evaporative Loss in Thailand