REDUCTION OF EVAPORATION LOSSES IN OIL AND OIL DERIVATIVES STORAGE TANKS: A CASE STUDY FOR WAREHOUSE IN POŽEGA (SERBIA)

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One of the biggest problems related to mandatory tanks of oil and oil derivatives are evaporative losses in the tanks. It is well known that the storage, manipulation and transport of oil and oil derivatives results in the evaporation of the liquid. In the case of tanks where commodity reserves are stored for a long period of time, the most pronounced problems are "breathing" losses and degradation of the quality of petroleum products. Many of these volatile organic compounds also have a strong negative impact that is harmful to human health and the environment. The aim of this research is to improve system in order to reduce evaporative losses in the tanks which are used for mandatory reserves of oil and oil derivative in warehouse in location near Požega in Serbia as well as to reduce the harmful impact on the environment with the proposed improvement measures.

Key words*: tanks, oil and oil derivatives, evaporative losses, temperature*

1. INTRODUCTION

The storage, manipulation and transport of oil and oil derivatives results in the evaporation of the liquid. Many volatile organic compounds (Volatile Organic Compounds - VOC) found in oil and its derivatives have the characteristic of being harmful to human health and the environment. Determining the mass of vapors is important in order to establish the appropriate balance and, based on that, financial losses, but also to assess the impact on the environment [9, 10, 13].

The parameter most often used to determine the level of volatility of oil derivatives is called Reid vapor pressure (RVP) and is determined according to the ASTM-D-323 standard. It represents the vapor pressure at a temperature of 100°F (37.78°C) and is found experimentally for various types of petroleum products. True vapor pressure (TVP) is a function of real temperature and can be determined based on the known RVP.

The tanks can be vertical and horizontal. Vertical cylindrical tanks are most often used. Their constructions can be with: fixed conical roof; fixed domed roof; internal floating roof; external floating roof; domed roof. It is estimated that in refineries vertical tanks are significantly more common [1].

The vertical tanks with fixed roofs, where losses due to evaporation are more pronounced, will be treated in this paper. The reason for this phenomenon is the accumulation of the gas phase (hydrocarbon vapor) in the free space between the surface of the liquid and the roof.

The losses that occur in tanks are classified into storage losses (standing storage losses are also called breathing losses) and working losses. Storage losses, i.e. "breathing" losses, are caused by the expulsion or expulsion of the gas phase due to changes in the storage temperature and barometric pressure. These losses occur in the absence of any change in the level of the stored liquid phase in the tank, so they are also called static losses [13].

The operating losses occur due to the filling and discharging process. Filling the tank raises the level of the liquid and thus compresses the gas phase above the liquid. The gas is released to the outside when its pressure exceeds the set pressure value of the safety valve. On the other hand, due to the emptying of the tank, the pressure drops and a vacuum is created in the gas space. By opening the protective valve, the air enters the tank, becomes saturated with the vapor of oil derivatives, expands and exceeds the volume of the gas phase space.

As the tanks that are the subject of research are used for storing commodity reserves and are not subjected to frequent filling and emptying processes, they have pronounced static losses, which will be the subject of this paper.

An important side effect that occurs during the storage of petroleum products is the degradation of the quality of the stored fuel. Due to the suction of air from the outside environment, fuel oxidation occurs over time. In addition, moisture from the air, water vapor, is introduced into the tank, which then condenses and affects the quality of the stored petroleum product. It can therefore be concluded that the goal is to preserve both the quality and quantity of the stored derivatives.

2. METHODOLOGY FOR CALCULATING LOSSES DUE TO EVAPORATION

The methodology that is used in this research for calculating losses due to evaporation is been presented in the literature [2, 11, 12]. The equation for calculating annual static losses, i.e. storage losses, where are: H_{VO} [m] - tank height; D [m] - tank diameter; K_E - vapor space expansion factor; K_S - vented vapor saturation factor; ρ_V [kg/m^3] - derivative pair density.

$$L_S = 365 H_{VO} \left[\frac{\pi}{4} D^2\right] K_E K_S \rho_V \tag{1}$$

The expansion coefficient of the vapor space is defined as the ratio of the volume of the air-vapor derivative mixture that is displaced in the daily cycle of evaporation (V_{GF}) and the volume of the space occupied by the gas phase in the tank (V_V). The term "gas phase" can be considered a mixture of air and steam derivatives.

$$K_E = \frac{V_{GF}}{V_V} \tag{2}$$

The derivation of expressions, i.e. determining the value of the vapor space expansion factor is presented in the literature [2], where $K_E = 0.04$. In the case where the actual vapor pressure at a given temperature is greater than 0.1 psi, the factor K_E can be determined with greater accuracy using the equation where are: ΔT_V [°C] - range of daily vapor temperature (gas phase derivatives); T_{LA} [°C] - mean daily temperature of the surface of the liquid phase; Δp_V [psi] - the difference between the maximum and minimum steam voltage during the day; Δp_B [psi] - range of set values of the breathing valve; p_A [psi] - atmospheric pressure; p_{VA} [psi] - vapor pressure at daily average temperature. It is known that 1 psi equals 6.894 kPa or 6.89 mbar.

$$K_E = \frac{\Delta T_V}{T_{LA}} + \frac{\Delta p_V - \Delta p_B}{p_A - p_{VA}} \tag{3}$$

From the equation (3) for K_E it can be noted that the value of this factor depends on the vapor pressure in the tank, therefore it is necessary to measure the pressure in the gas space of the tank in order to precisely determine the losses.

The range of daily vapor temperature for gas phase derivatives is defined using the equation, where are: ΔT_A [°C] - daily ambient temperature range; α - solar absorption factor (coefficient) of the tank, which depends on the color of the surface of the tank; I [kW/m^2] - total daily solar irradiation obtained from meteorological data tables [3].

$$\Delta T_V = 0.72 \Delta T_A + 0.028 \alpha I \tag{4}$$

Difference of maximum (T_{max}) and minimum (T_{min}) ambient temperature from meteorological is given from data tables for tank location [3, 4].

$$\Delta T_A = T_{max}[°C] - T_{min}[°C] \quad (5)$$

Based on the maximum and minimum values of daily temperatures, obtained from meteorological data tables, it is possible to define and determine the mean value of the daily ambient temperature for a given location of the tank:

$$T_{AA} = \frac{T_{max}+T_{min}}{2} \quad (6)$$

If the temperature of the liquid phase ($T_L = T_B$) of the oil derivative stored in the tank is not measured, it can be approximately determined using the value of the average daily ambient temperature, using the equation:

$$T_L = T_B = T_{AA} + 6\alpha - 1 \quad (7)$$

The average daily liquid phase surface temperature (T_{LA} is an important quantity used to calculate the derivative vapor pressure at the mean daily liquid phase surface temperature $p_{LA}(T_{LA})$. It is calculated based on the equation:

$$T_{LA} = T_{AA} + 0.56(6\alpha - 1) + 0.0079\alpha I \quad (8)$$

Whereby it is determined that:

- the maximum temperature of the surface of the liquid phase of the derivative in the tank $T_{Lmax} = T_{LA} + 0.25\Delta T_V$

- the minimum temperature of the surface of the liquid phase of the derivative $T_{Lmin} = T_{LA} - 0.25\Delta T_V$

Based on the known value of RVP, the actual vapor pressure (TVP) of oil derivatives at a given temperature can be determined, using the appropriate equation (9), where are the units of physical quantities: T [°C], RVP [kPa], p_V [kPa].

$$TVP(T) = p_V(T) = RVP \cdot 10^{[(0.000007047RVP+0.01392)T+(0.0002311RVP-0.5236)]} \quad (9)$$

Based on this equation (9) the vapor pressure at the mean daily temperature p_{VA} (T_{LA}), the daily maximum vapor pressure $p_{Vmax}(T_{Lmax})$ and the daily minimum vapor pressure $p_{Vmin}(T_{Lmin})$ can be determined. Using the equation (9) from the literature [2], the current value of the gasoline vapor pressure stored in the tank was calculated and compared with the value read from the vapor pressure gauge installed in the tank, with a difference of less than 0.1%.

The difference between the maximum and minimum steam voltage during the day is determined based on:

$$\Delta p_V = p_{Vmax} - p_{Vmin} \quad (10)$$

The pressure setting range of the breathing valve is determined based on the formula (11) where are: p_{BP} [psi] - set pressure of the discharge valve; p_{PV} [psi] - set vacuum of the exhaust valve.

$$\Delta p_B = p_{BP} - p_{BV} \quad (11)$$

With high breather vent levels, the total level of "breathing" losses (steady-state evaporation losses) of the derivative tank with a low vapor pressure level will be low and negligible.

The outlet vapor saturation factor of the stored liquid is defined as the ratio of the average daily concentration $\overline{C_{out}}$ of the stored vapor (vapor of the stored liquid) in the discharged (outlet) steam and the daily average saturated vapor concentration $\overline{C_{zas}}$:

$$K_S = \frac{\overline{C_{out}}}{\overline{C_{zas}}} = \frac{1}{1+0.053 p_{VA} H_{VO}} \tag{12}$$

The above equation for determining the size of the factor K_s is derived using a theoretical model for the mass transfer process of stored vapor from the surface of the liquid through the breathing valve during the daily cycle of evaporation.

The derivation of the loss equation storage of petroleum liquid derivatives gives the expression for the density of the derivative pair [5], where are M_v [g/mol] molecular mass of a pair of derivatives and R_u is universal gas constant $R_u = 8.31451$ [J/molK].

$$\rho_v = \frac{M_v p_v}{R_u T_v} \tag{13}$$

3. DESCRIPTION OF THE ANALYZED SYSTEM

The subject of this research is warehouse with the storage tanks in location near Požega in Serbia, presented in the Figure 1. The data on tanks that are the subject of research were collected during the summer 2022. The summer quality gasoline (vapor pressure up to 60 kPa) is stored in four tanks marked T3, T7, T8 and T9 on behalf of the Ministry of Mining and Energy of the Republic of Serbia. There are five more storage tanks within the warehouse, of which three (T1, T2 and T3) are in use by company NIS Serbia, and two (T5 and T6) are newly built and not yet in use. In addition to the storage tanks themselves, the warehouse also includes a railway transfer station, a truck transfer station and a pumping station for transporting petroleum products.

Figure 1 View of the warehouse in Požega in Serbia

Protego		
Type	VD/TS-200-IIB3	
Flange	DN 8''	PN 150lbs
Serial no.	008103650-10-01	
	Pressure	Vacuum
Set pressure [mbar]	+6,5	-4,5
Flow [m^3/h]	1100	1000
Design pressure [mbar]	+7,5	-5

Table 1 Breathing valve data

Tanks T3, T7, T8 and T9 have the same dimensions and construction, and that is why tank T3 is taken as a representative in this research. The outer surface of the tank is white. The type of roof is a conical fixed roof (cone roof). The tanks also contain an internal aluminum membrane that reduces losses due to evaporation but we do not know the state of the membrane system. The diameter of the tank is 25 m, while the filling level is approximately 10m. The volume available for storage of oil derivatives is 5000 m^3 per tank. The tank is filled approximately every 5 years, after which the gasoline is stored as a commodity reserve and only losses due to evaporation occur. All tanks have safety valves, breathing valves, radar measurement of the liquid level, a probe for measuring the temperature and water level, a fork for limiting the maximum filling level, devices for determining the density of the liquid, etc. The data read from the breathing valve plate is presented in Table 1.

If the ambient temperature exceeds 30℃, the tank is forced to cool down. The capacity of the cooling water pump is 100 m^3/h. During the day, the tanks are periodically cooled and cooling water is accumulated from the nearby river.

Meteorological tables with the necessary data were obtained through the software Meteonorm v8.03 and from the literature Meteorological yearbook 1 - Climatologically data, issued by the Republic Hydro meteorological Institute [3, 4]. The results were formed on the basis of climatic conditions for the period of 12 years, from the 2006 to the 2017. The database contains the maximum and minimum monthly temperature at the location where the tank is located, Požega, as well as the average monthly solar irradiation on the horizontal surface. The parameters which are used in this research are presented in tables in the literature [6].

Based on the methodology outlined in Chapter 2 and for the parameters collected and experimentally obtained for a representative tank, results were obtained depicting losses on an annual and presented at the Figure 2, level for a tank with a fixed roof. The tank stores the summer grade gasoline corresponding to a RVP value of 8.3 psi (57.2 mbar). The influence of the aluminum membrane will be also taken into account in the paper.

Based on the obtained results of the calculation of monthly losses in the observed period, it is possible to observe the regularity of the intensity of gasoline loss due to evaporation. Every year of the observed period, the losses were most pronounced in the months of June, July and August, that is, in the summer period. The reason for this is not only high daily ambient temperatures, but also a significant difference between daily maximum and minimum temperatures. Thanks to high temperatures during the day, losses occur due to intensive evaporation of the liquid phase and the creation of high overpressure in the tank. On the other hand, at night, due to the sudden drop in the ambient temperature, a vacuum is created in the tank, which causes pronounced evaporation of the liquid phase and an increase in the concentration of the gas phase in the space above the liquid phase.

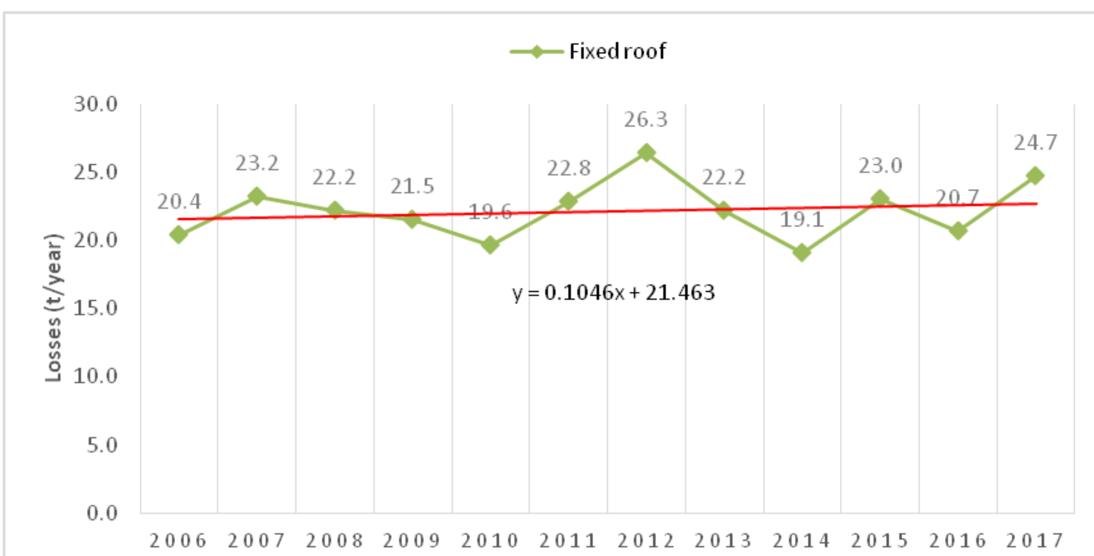

Figure 2 Change of total annual losses of tanks with the fixed roof

The average values of monthly losses in the period from the 2006 to the 2017 range from 0.4 t/month to 4 t/month.

The values of total annual losses for the observed period are presented in Figure 2. From this figure, it can be seen that the losses were most pronounced in the 2012, when they amounted to 26.3 t/year, while the lowest value was 19.1 t/year in the 2014. When the obtained values for the 12 years are averaged, an average of 22 t/year is obtained.

The accuracy of the highlighted calculations was checked using the software program Tanks 409d [7]. The program was created by the US EPA and is based on the same methodology as this research (according to API standards). The parameters that were used in the highlighted calculations were entered into the software program and the mean annual value of losses was obtained, which is 20.1 t/year. The difference between the results obtained in the research and through the program is 8.6%.

The presence of an aluminum membrane reduces losses due to evaporation. The membrane floats on the surface of the stored liquid and adheres to the walls of the tank. In this way, the evaporation surface of the liquid phase is reduced, which affects the reduction of the intensity of evaporation. However, since we do not have data on the state of the membrane system, sealing, deformations of the tank casing, etc., the efficiency of the membrane can be estimated based on empirical data. It is considered that the reduction of losses by the aluminum membrane is 70% compared to a tank with an ordinary fixed roof.

Figure 3 presents the total annual losses for the observed time period with the influence of the aluminium membrane.The presented results were obtained as follows, where are: L_S– tank losses with aluminum membrane; $L_{S.0}$- tank losses with a fixed roof; $K_m = 0.3$ is coefficient that takes into account the influence of the membrane.

$$L_S = L_{S.0}K_m \tag{14}$$

As in the case of tanks with a fixed roof, based on the obtained results of the calculation of monthly losses in the observed period, it can be observed that the losses are most pronounced in the summer months. The average values of losses of the observed system are from 0.1 t/month to 1.2 t/month for the period of the 2006 to the 2017. In the case of annual values that are presented on the Figure 3, it can be noted that the losses were the most pronounced in the 2012, when they amounted to 7.9 t/year, while the minimum 5.7 t/year was obtained in the 2014. By comparing the change of annual losses for the cases with a fixed roof and with a membrane presented in the Figure 4, their proportionality can be observed.

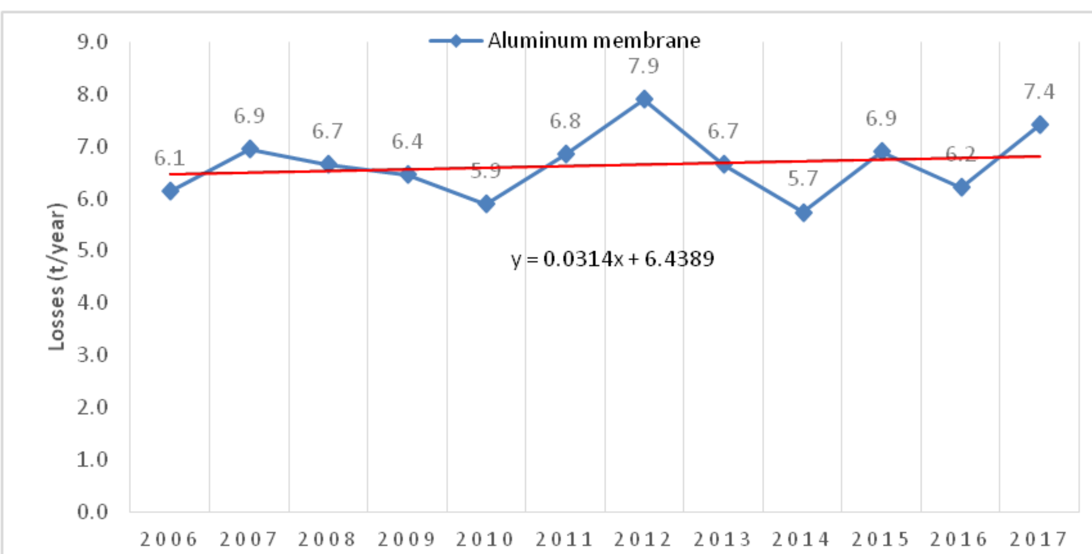

Figure 3 Change of total annual losses of tanks with the aluminum membrane

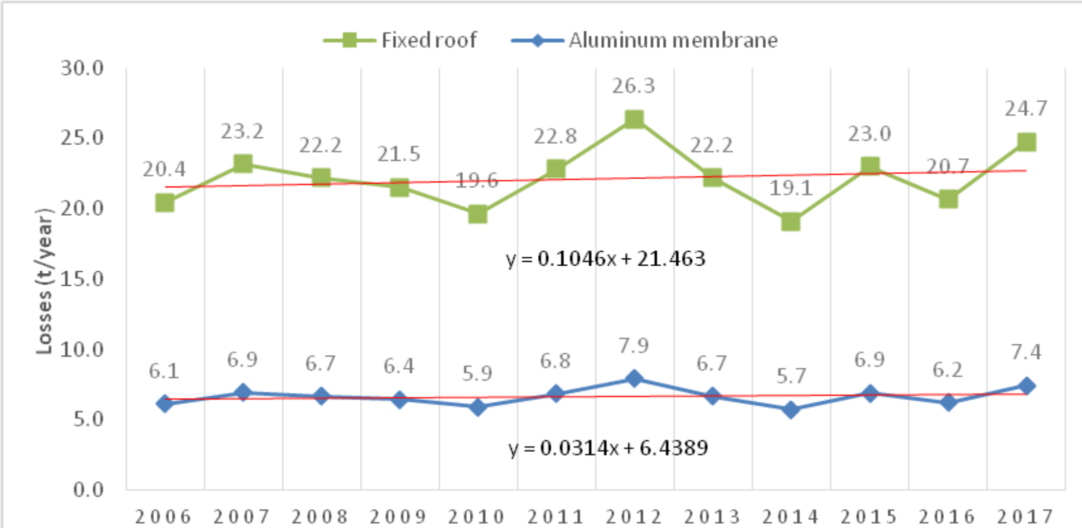

Figure 4 Comparison of losses of tanks with the fixed roof and with the aluminum membrane

4. SYSTEM IMPROVEMENT

The storage tanks are equipped with a measuring system that provides continuous measurement of the level of the liquid phase, the temperature of the liquid and gas phase of the stored derivative. By installing a gas phase pressure gauge and based on loss equations, the conditions were created for the formation of an improved storage control system, which supervises and controls the process of storage of derivatives from the aspect of measuring and determining daily, monthly and annual losses. Also, the system measures and registers the daily change in temperature of the liquid phase, temperature of the gas phase and pressure of the gas phase, and based on the dynamic changes of these values, it activates the system for cooling the tank with water. By continuously measuring the pressure of the gas phase, the system controls and determines the state of the pressure-vacuum ("breathing") valve, its set values of "overpressure" and "under pressure", as well as its activation time. This improved derivatives storage monitoring system, first of all, increases the safety of the warehouse and creates conditions for control and reduction of storage losses in the warehouse.

In order to reduce storage losses and enable multi-year storage without degrading the quality of derivatives, it is suggested to install a nitrogen protection system, called Nitrogen Blanketing System for the storage tank. Based on the experience and practice of use in other storage facilities, where a similar problem was solved, this system proved to be an extremely good solution. The injected nitrogen, in the space of the gas phase of the tank, reduces the vapor pressure of the derivative and prevents the entry of air with oxygen and water vapor in the composition, which degrades the quality of the stored derivative, especially during a long period of storage. The expected loss reduction is over 70%, while the long-term storage of derivatives is without changing the most important parameters that affect quality. After this loss reduction, the average annual losses would amount to 2 t/year. In Figure 5 is presented the change of losses in the case when this system is installed.

As is presented in this research the derivative stored in an above-ground tank is subjected to a cycle of daily heating and cooling and that this is the main cause of losses due to evaporation, and that the biggest cause of heating is daily solar irradiation, the idea of using the canopy for tanks that protects or removes the influence of solar irradiation on increasing the temperature of derivatives in the tank. The expected loss reduction by upgrading the tank canopy is about 70% with a pronounced effect of reducing cooling water consumption. In this way, the energy independence of the warehouse would be ensured. In the event of the adoption of this proposal, as well as the nitrogen protection system, the average annual losses would amount to 0.6 t/year. In Figure 6 is presented the change of losses for the mentioned case.

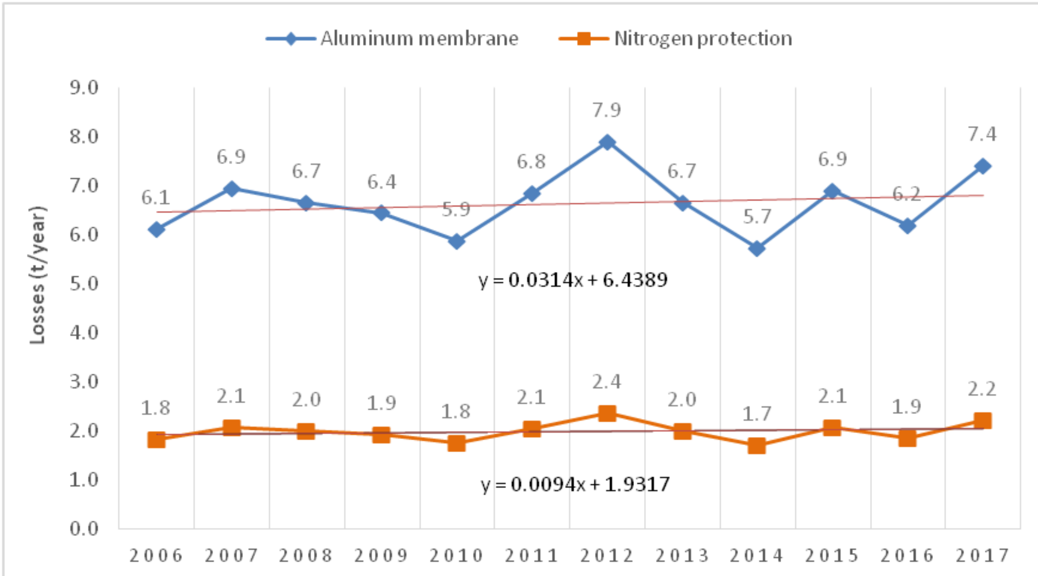

Figure 5 Comparison of losses of tanks with the aluminum membrane and with the built-in nitrogen protection system

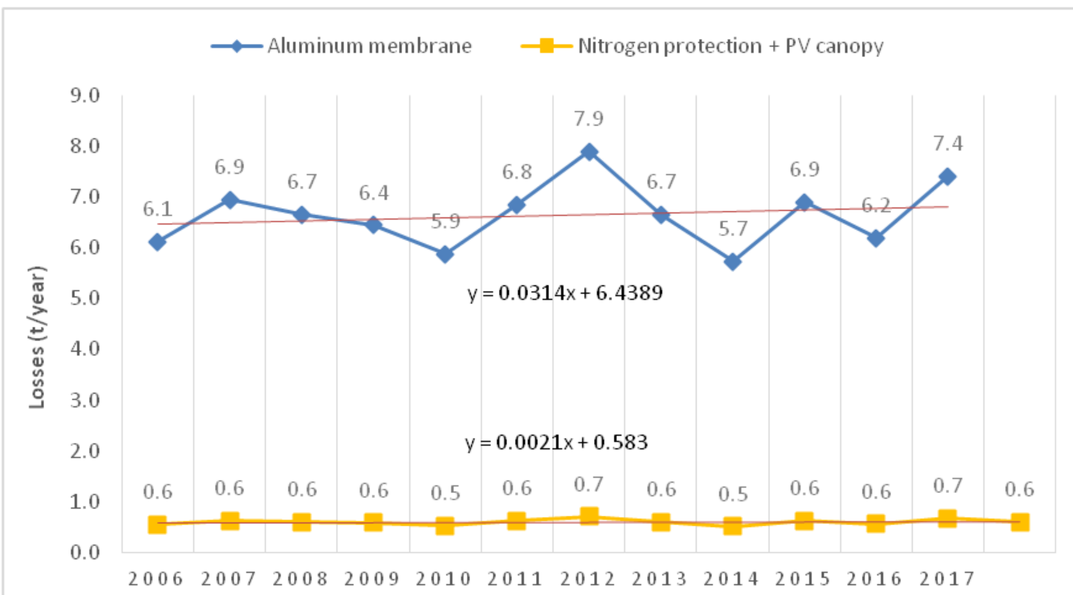

Figure 6 Comparison of losses of tanks with the aluminum membrane and tanks with the built-in nitrogen protection system and PV canopy

Another benefit of this proposal is that, if the entire surface of the tank were to be built over with the canopy, an area suitable for the installation of a photovoltaic (PV) power plant with a power of 1.2 MWp would be obtained. For detailed calculations of the solar potential of the target location in Požega in Serbia the professional software package PVsyst, developed by scientists from the University of Geneva in Switzerland, was used in the study [8]. The geographical coordinates of this location are: N 43º50'45"and E 20º2'4". For the target location in Požega, the following values were obtained by calculation using the mentioned software: the average global irradiance on the horizontal plane on a yearly basis is 1294 kWh/m^2, the average diffuse irradiance on the horizontal plane on a yearly basis is 622.3 kWh/m^2, the average temperature on a yearly basis is 10.6℃ and the wind seed on a yearly basis is 0.6m/s calculated for the observed period of years. The target location of the warehouse has a good solar irradiation potential and it is located on a suitable terrain for the construction of a PV canopy. In Figure 7 a map of the path of the Sun for the target location is presented. In order to use the surface of the PV canopy as efficiently as possible, the installation of high-efficiency PV modules from manufacture Candidan Solar CS6U-350P 350 Wp is suggested.

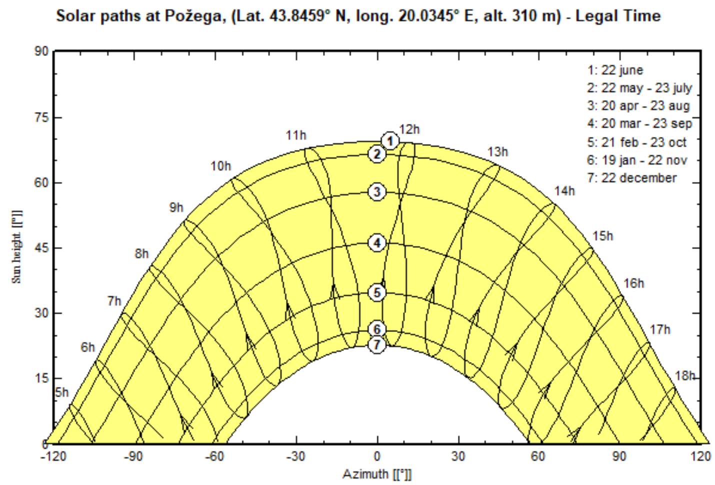

Figure 7 A map of the path of the Sun for location Požega [8]

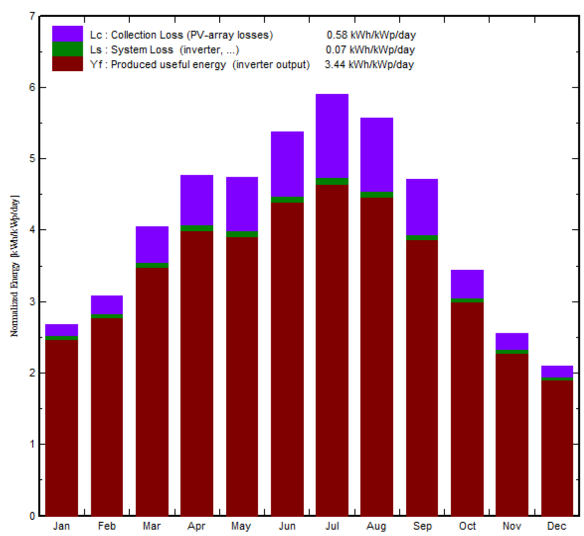

Figure 8 A normalized productions for location Požega [8]

As part of this system improvement, a complete analysis was performed in the software PVsyst. Based on the conducted results, the following conclusions can be drawn. The construction of a roof area of 6667 m^2 is possible for the realization of the PV canopy over the tanks. The roof surface must be covered with a sheet metal cover, at least 0.5 mm thick, which would physically separate the internal cable connections of the PV panels from the potentially explosive environment that can be created when the safety valves react or gas leaks into the atmosphere.

The roof surface of the PV canopy should be oriented in the south direction with the tilt angle of 30^0. On the available roof surface, it is proposed to install a PV panel that would follow the slope and orientation of the PV canopy roof. The predicted installed power of the PV panel is 1.2 MWp with the estimated net annual production of PV panels of 1569 MWh per year (Figure 8).

Conclusion

The goal of this research is to make technical and technological improvements which achieve the reduction of evaporative losses in the tanks during storage and reduction of VOC emissions by defining proactive solutions such as an important factor in cleaner production and proposes appropriate measures for that. In this paper, the subject of research is the tanks where commodity reserves are stored for a long period of time in location near Požega in Serbia. The most pronounced problems of these tanks are "breathing" losses and degradation of the quality of petroleum products. In this paper, the calculation was made for tanks with a fixed roof which are used for mandatory reserves in the warehouse in Požega, based on the characteristic of the tanks and on the parameters collected and experimentally obtained for a representative tank taking into account meteorological conditions. The accuracy of the data obtained by the calculations was verified using the software program Tanks 409d.

The evaluated average loss by evaporation of gasoline from a tank with a fixed roof with the dimensions of the representative tank located in the warehouse in Požega amounts to 22 t/year. This result was verified using the software program Tanks 409d, through which losses of 20.1 t/year were obtained. If we take into account the reduction of evaporation due to the presence of the aluminum membrane, the efficiency of which is estimated to be 70%, the average losses are 6.6 t/year.

Considering that the state of the membrane system cannot be known with certainty, but can only be estimated based on empirical data, therefore as first improvement measure, it is recommended to install a gas phase pressure gauge, through which the parameters (pressure, temperature) needed for the continuous determination of the intensity of gasoline evaporation losses could be determined along with the already existing measuring system of the tank.

The second measure is a significant improvement of storage conditions can be achieved by installing a nitrogen protection system, called Nitrogen Blanketing System. The use of nitrogen has a double effect: losses due to evaporation are reduced, but the quality of the oil product is also maintained. In this research it is estimated that in this way losses can be reduced by 70%. After this loss reduction, the average annual losses would amount to 2 t/year and that was presented in this research.

The third significant improvement measure is the construction of PV canopy above the tanks. A significant factor that contributes to the evaporation of the stored petroleum product is the irradiation on the horizontal surface. The effect of direct solar irradiation can be reduced by installing the canopy roof over the tanks, thus reducing losses by an additional 70%. If the entire surface of the tank were to be upgraded with PV canopy, it would be suitable for the installation of a PV power plant with a power of 1.2 MWp with the estimated net annual production of PV panels of 1569 MWh per year. At the same time, in this way, conditions would be created for the installation of a PV power plant that would ensure the energy independence of the warehouse. In case of adoption of this improvement, as well as improvement in the form of installation of nitrogen protection system, the average annual losses would amount to 0.6 t/year.

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