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Evaporation Reduction Test of Premium Unleaded Fuel by the Smart Floating Roof Method in a Horizontal Cylindrical Tank

Bagui Emmanuel[1, *], Gbaha Prosper[2], N. Guessan Kotchi Rémi[3]

[1]Laboratory of Industrial Synthesis Processes, Environment and New Energies, Polytechnic Doctoral School, Yamoussoukro, Ivory Coast

[2]Mechanical Engineering and Energy Department, National Polytechnic Institute Félix Houphouet-Boigny, Yamoussoukro, Ivory Coast

[3]Laboratoire of Motors and Machines for Energy Conversion, National Polytechnic Institute Félix Houphouët-Boigny, Yamoussoukro, Ivory Coast

Email address:

Emmanuel.bagui@gmail.com (B. Emmanuel)

[*]Corresponding author

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Abstract: The floating roof is originally the device that is easily used in a vertical cylindrical storage tank for volatile products. It covers the evaporative surface which remains constantly circular, regardless of the level of the fluid in the tank. However, in a horizontal cylindrical tank, the extent and shape of the free surface of the fluid, the seat of evaporation, varies according to the residual stock. To this end, the concept of the intelligent or flexible floating roof arises from the problem of pollution and energy losses resulting from the excessive evaporation of unleaded premium fuel (SPb) in the Ivory Coast, in the city of Korhogo, which has a hot and dry climate. Therefore, the objective of this study was to design a floating roof suitable for horizontal cylindrical tanks with a fairly competitive evaporation reduction performance. This study was carried out on an experimental station where two identical tanks were tested in comparative trials. One with a floating polypropylene ball roof and the other without a roof. The respective residual volumes of the fluid in each tank were monitored regularly and concomitantly according to evaporation factors such as temperature and pressure. At the end of these tests, it was found that the flexible floating roof absorbed more losses, with an estimated non-evaporation rate of 88% compared to the tank without the flexible floating roof, whose rate was estimated at 80%, i.e. an added value of 08%. Thus, the layers of beads placed at the gas-liquid interface reduced the heat, mass and pressure transfer between the two fuel phases.

Keywords: Evaporation Reduction, Smart Floating Roof, Horizontal Cylindrical Tank, Premium Unleaded Fuel, Northern Ivory Coast

1. Introduction

In the context of petroleum product storage, economic and environmental concerns are becoming increasingly important [1]. In this context, the protection of the atmosphere by controlling gaseous emissions loaded with pollutants is becoming a major issue. Among the various sources of atmospheric pollution, industries emitting emissions containing volatile organic compounds (VOCs) are given particular attention [2]. This recommendation is in line with the requirements of the Paris Agreement [3], to which countries including Côte d'Ivoire have signed up in order to pool efforts to contain these phenomena with harmful economic effects.

It is in this context that the atmospheric storage of premium unleaded petrol (SPb) poses complex problems [4] in oil establishments. With a boiling point of between 40 and 210°C [5] and a calorific value of 32MJ, it is both highly volatile and energetic. According to the principles of thermodynamics [6], the storage of this petroleum product is exposed to risks of energy losses and significant greenhouse gas (GHG) emissions [7].

Indeed, the dreaded evaporation, when fuel is stored in an atmospheric tank, is an endothermic transformation process of a liquid into a gas [8]. Thus, under the effect of heat or other sources of energy, the molecules of the volatile compound will break up and the weighted particles will form a gaseous sky above the liquid [8]. When the atmospheric pressure is lower than the internal vapour pressure, a thermodynamic imbalance occurs, where the gaseous particles are exhaled into the ambient air [9] and vice versa. These pressure and temperature differentials induce a mass and energy transfer in variable directions, thus explaining the respiration of the tank [10]. Several interdependent parameters are associated with this phenomenon. The most influential are, on the one hand, temperature, atmospheric pressure, wind speed and air humidity and, on the other hand, the air-liquid interface, vapour pressure and the physicochemical nature of the fluid [11]. Similarly, the various studies carried out by Nicolas Gruyer [12] and Jérôme TRIOLET [13] have also confirmed that, in addition to the volatility of the fluid, thermodynamic imbalances and parameters extrinsic to the storage system of the volatile product are among the main factors influencing the evaporation process [13].

In theme of evaluation of these emissions, Dahma DIAB and al announced in 2017, carried out a study of VOC quantification at the Arzew refinery. The estimate gave nearly 7,108 tonnes of proven pollutants emitted from the hydrocarbon storage tanks. The pollution concerned the lower atmosphere, due to their impact on the environment and health [14]. In order to control these losses by evaporation, several other works were carried out, including that of Marnour MBOW, on the "Study of losses of products in physical stock at the ESSO-SENEGAL "Chernicals" depot [15]. These losses were evaluated at 5.70%. This study identified the causes of the leaks and the corresponding mitigation measures.

However, Régis CHAMAYOU noted that ambient temperature storage tanks made up almost all of the capacity in the tank farms, as he believed that they represented the logical and natural solution for storing liquids [16]. In these tanks, the products are kept in the physical state in which the site temperature maintained them. A more or less important vapour pressure was established above the liquid, depending on their degree of volatility [17]. In principle, this pressure conditions the equilibrium of the thermodynamic system constituted by the atmospheric storage. But it is quite unstable because of the direct communication of the interior of the tank with the ambient atmosphere, two environments with non-concordant pressure variability factors.

This is why BADORIS, in April 2005, showed that the floating roof avoids direct contact of the atmosphere with the liquid and the presence of a gaseous overhead, which are major sources of product loss for fixed roof tanks. When the floating roof is placed directly on the surface of the liquid, it inhibits any evaporation process [18], limiting pollutant emissions, as required by storage tank regulations. This device is mainly used for the storage of highly volatile liquids, whose absolute vapour pressure at room temperature is between 35 and 90 kPa or whose flash point is below - 40°C [19]. The products most concerned were light crude oils, naphthas and various gasolines.

An important contribution has come from the research of IMHOF Tank-Technik, with formal conclusions on the application of the floating roof. It states that the most effective and economical method of reducing emissions and product losses on the one hand, and fire and explosion risks on the other, for the overhead storage of volatile hydrocarbons, has always been the floating roof technology [20, 21]. But he added that the key requirements were the strength of the floating roof, the tightness of the seals around the perimeter and on the roof passages.

In fact, the oil industry has been confronted for a long time with the phenomenon of evaporation and emission of effluents from its finished products in storage, both in horizontal and vertical tanks. Today, the case of vertical tanks has been addressed by the application of the so-called rigid or watertight floating roof (TFE). This system is only applicable in vertical cylindrical storage tanks, with an average efficiency of 62.95%, for highly volatile products [22].

However, the problem remains and becomes more alarming for horizontal storage tanks. Since to date, the methods and studies initiated have remained ineffective in the face of the phenomenon of volatilisation of products in the said tanks, of which the case of premium fuel is more obvious, given its high volatility rate [23, 24]. Even the vapour recovery systems and vents currently used, although effective with a performance of around 80% emission reduction, also seem to face problems of technological adaptation and adoption and cost [31].

Indeed, in vertical tanks, the evaporation surface to be covered (Slg), remains identical to a same circle, whatever the level (H) of the contents. On the other hand, in service stations in general, these are cylindrical tanks with a hanse end and buried horizontally. In the latter storage system, the evaporation surface to be covered varies in shape and size depending on the contents. This is where the problem of the unsuitability of the ordinary floating roof and the option and sizing of a flexible or intelligent floating roof (FFR) arose.

This research was to answer the key question of how to ensure the suitability of a floating roof on an evolving evaporative surface and what form and technology of the device would be suitable. Faced with these questions, we were inspired by Marteau & Lemarié France, who demonstrated that hollow balls covering volatile fluid surfaces reduced heat loss by up to 75%, evaporation by 87% and air pollution by 98% [25]. This method of evaporation mitigation has also been used against evaporation from water reservoirs [25] in areas where the climate is similar to that of the northern part of Côte d'Ivoire, where our study took place.

In the north of this country, the town of Korhogo, located between longitudes 5°16' and 16°16' West and latitudes 8°32' and 10°20' North, presents a real environmental vulnerability, because of its hot and dry climate [26, 27]. This area is best suited to studies aimed at better assessing the effectiveness of measures to be recommended in the face of the impacts of climatic aggressiveness, including the evaporation of hydrocarbons.

The objective of this study was to mitigate evaporation in the horizontal storage of premium unleaded fuel with all the energy, economic and environmental benefits. It adopted the principles of thermodynamics through the design of a suitable intelligent floating roof.

To achieve this objective, it was necessary to first identify the balls involved in the design procedure of this floating roof and to install an experimental station to evaluate the impact of this device under the natural operating conditions of an oil depot.

2. Theoretical Principle of the Intelligent Floating Roof Experiment

2.1. Inventory of the Factors Involved in Tank Evaporation

According to equation F1 below, based on the Clément model [13], the evaporation flow depends on at least five (05) independent parameters [13] contributing together or separately according to their respective influence. They are generated by many induced causes including 1) ambient temperature, 2) atmospheric pressure, 3) frequency of pump services, stock gauging and potting.

$$J_i = K_i X \frac{M_i X F_i}{RXT}$$

F. 1: Formula for defining and calculating evaporation flux

The control of evaporation is therefore closely related to the control of these parameters on which the smart floating roof used on a horizontal cylindrical tank will act through four mechanisms: 1) absorbing part of the heat in the liquid, 2) damping the pressure difference, 3) reducing the inertia of the heated molecules, and 4) reducing the evaporation surface. These evaporation parameters can be summarised, in the case of this study, into four main groups of factors, namely:

Weighted frequency of filling and potting. The number of times per unit time that the dispenser pump is operated to draw fluid from the tank, multiplied by the amount of fluid displaced, is the weighted withdrawal frequency. The weighted stuffing frequency is the number of tanker unloadings into a storage tank, multiplied by the quantity unloaded. These frequencies are known either by a simple count of deliveries and quantities delivered to private vehicles (*sales*) or by the number of receipts and quantities received at the establishment's tank (*stuffing*). These operations put the stock or mass of the volatile liquid into turbulence and generate active evaporation [22];

Gauging with wetting of equipment

The physical measurements of the physical stocks result in systematic leakage of product through the wetting and drying of the gauge rule. It is carried out at each potting, at the opening, in the mornings and evenings, at the closing of the establishment. Electronic methods of stock estimation do exist. But they are subject to local realities and apprehensions that limit their widespread use. These devices are relatively more expensive and regularly break down.

Liquid temperature

The temperature of the fluid determines the vapour pressure inside the tank. It is an indicator of the intensity of the stored energy that is partially returned to the fuel molecules [22]. With the mechanism of energy transfer by convection within the fluid [28], and evapo-condensation in the gas space above the liquid, the temperature of the liquid is differently stratified [29]. It is lower in the surface layer, which is the site of evaporation, than in the preceding zone, which is warmer than the other layers [30]. This temperature, measured by a CUISY thermal probe, is only an average value [31] and solar vapour generation [32], the inter-face flow is driven by the vapour concentration gradient between the interface and the far field, as shown in Figure 1. Previous studies have shown that the diffusion process limits the overall transport in this case [33]. If the ascending and descending molecules are equal in number, equilibrium is achieved.

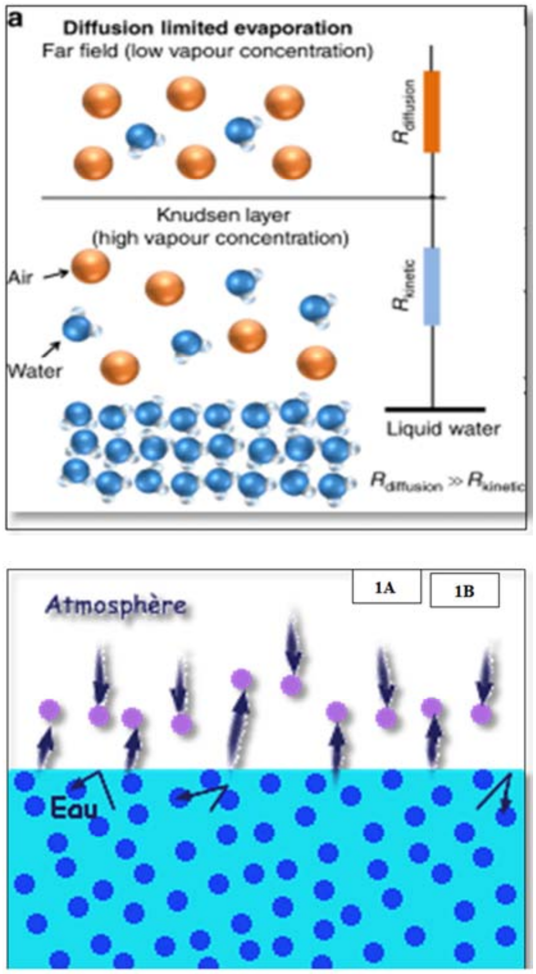

Figure 1. *Evaporation mechanism [43].*

Ambient temperature and atmospheric pressure

Changes in temperature and pressure cause an imbalance between the atmospheric pressure and the vapour pressure of the fluid [34]. This causes the atmospheric reservoir to breathe through a vent, resulting in passive evaporation of the fluid [35]. The SUNROAD multimeter is used to monitor these pressure and temperature variations.

Therefore, the ambient temperature factor has a transmitted impact on the heating of the product in a buried tank [36, 37].

In sum, of the documented theoretical causes of evaporation [38, 39], those related to technical or operational factors are the most critical and accessible [40]. These include: i) the volume of the gas head within the tank [40]; ii) the extent of the fluid/gas head interface; iii) the vapour pressure [38] and iiii) the storage and retrieval frequencies [40]. As a result of these operational factors, an engineered barrier system to this evaporation has been advocated, which is the rigid floating roof (RFT) in large vertical tanks, shown in Figure 3 below. The TFR aims to inhibit the physico-chemical process of evaporation [39, 41]. The principle consists of covering the free surface of the fluid with a rigid, watertight metal disc [39]. This cover, in normal operation, floats on the liquid and slides on the inside of the tank, following its horizontal circumference. This measure has shown its weakness in horizontal cylindrical tanks where the evaporation surface is evolving according to the tank stock.

2.2. Hypothesis of the Use of the Flexible or Intelligent Floating Roof as a Suggestion

Based on the rigid floating roof evaporation reduction model, shown in figure 3, our work focused on the use of the flexible or smart floating roof (T2F), this time applicable to horizontal cylindrical tanks. A description is given in Figure 4.

In the latter types of containers, according to the DT 110 Storage Tank Guide, published in April 2014 in its part C, it is stated that the further the fluid level moves away from the median plane of the horizontal cylinder, the smaller the extent of the air-liquid interface becomes. The evaporation area, which is at its maximum when the tank is half full, thus narrows symmetrically with respect to the median surface, in accordance with the filling or withdrawal level. The minimum number of layers of the balls is initially formed from the diametrical surface. It multiplies and adjusts in shape and texture according to the height of the liquid in the tank. It is this automatic readjustment of the balls, which are supposed to cover an evolving area, that justifies the flexibility or intelligence of the roof. These layers, even if porous, dampen and absorb a proportion of the kinetic energy of turbulence, produced during stock movements [41]. They also reduce the heat exchange between the storage system and the atmosphere [41]. Thus, evaporation will de facto be mitigated.

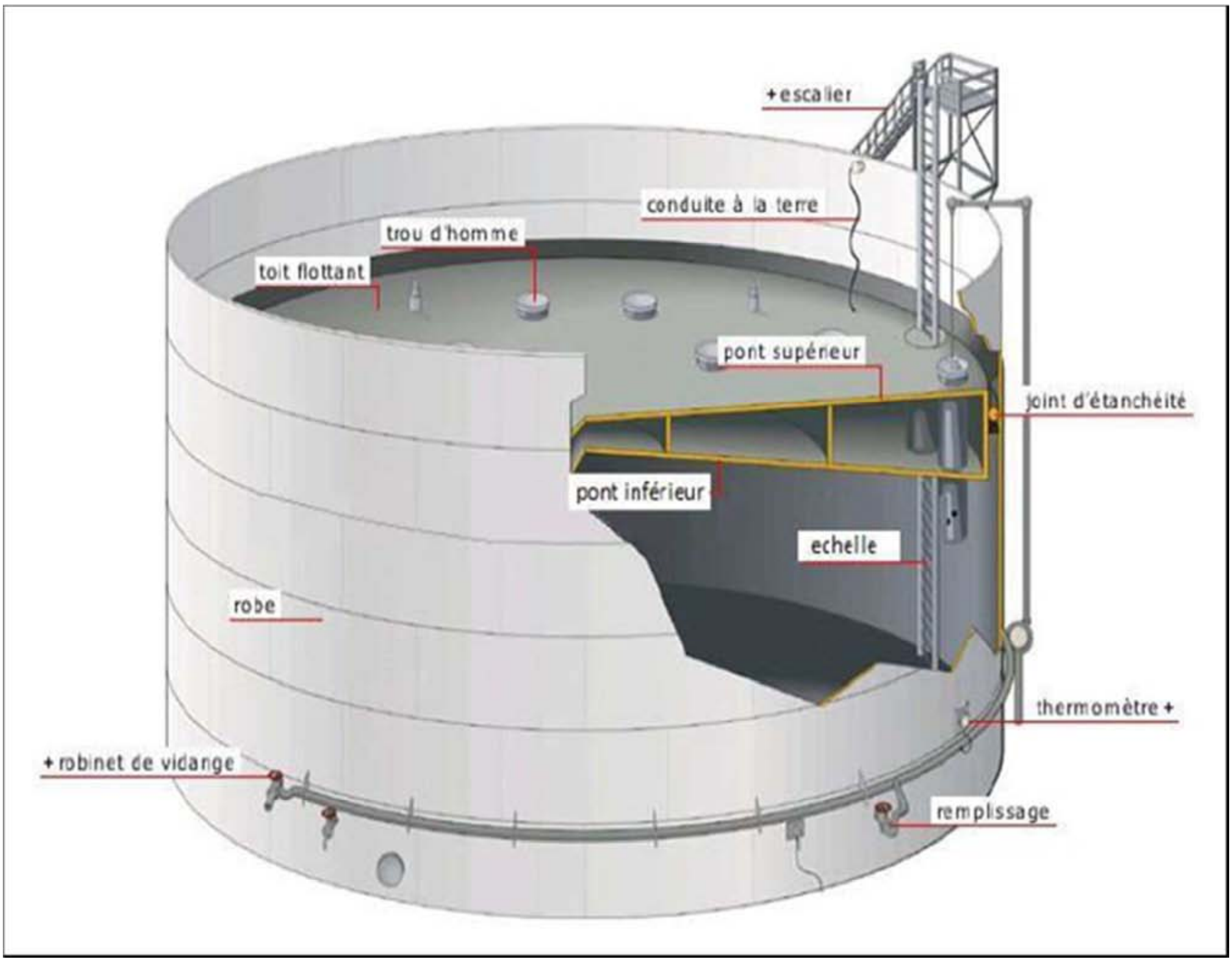

Figure 2. *Vertical tank with rigid floating roof [42].*

The vertical tank readily admits the double-deck floating roof adhering to the dress by a seal that does not change shape as the contained volume evolves: this is the rigid floating roof, unsuitable for the flexible roof suggested in Figure 3, below.

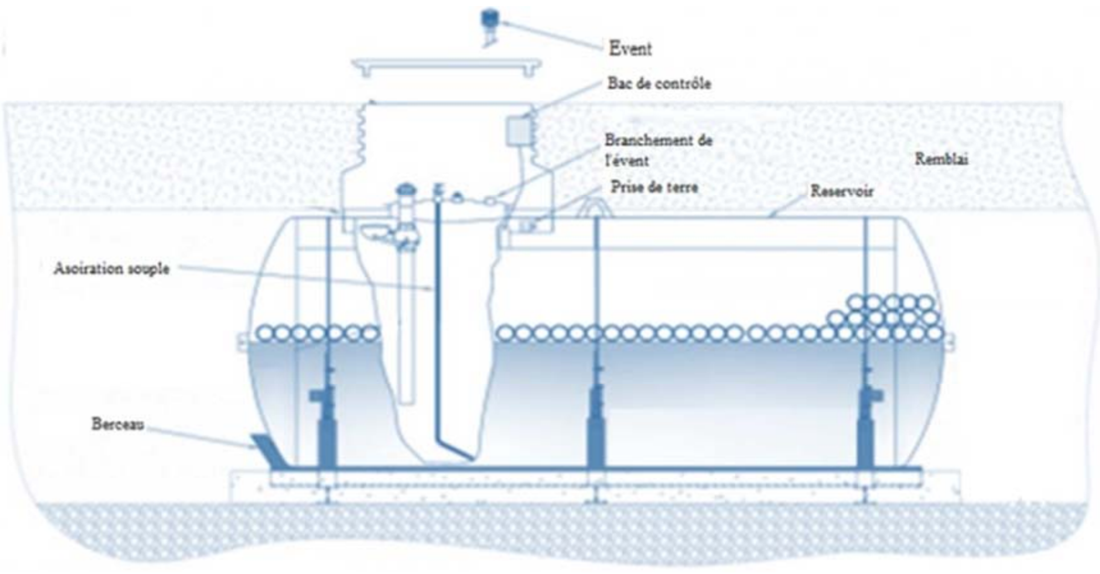

Figure 3. *Horizontal tank with flexible floating roof project.*

In this horizontal tank, the layers of balls placed at the liquid-gas interface could adapt to this variant form and form a flexible barrier, tight, against the factors of the evaporation mechanism. This gives it an intelligent character.

3. Experimental Procedure

3.1. Situational Analysis of the Impact of the Targeted Evaporation Factors

In order to assess the impact of the announced evaporation parameters of the fuel in the tank, a participatory observation was carried out at a control service station in Korhogo. The aim was to monitor, together with the manager of the establishment, the volume differences in relation to the suspected causes.

The evaluation of fuel losses was carried out with the formula F. 2. It expresses the difference between all orders to which is added the difference between the starting stock and the final stock, all subtracted from the total sale of the period considered. It shows the balance sheet.

$$E_V = \sum_{i=0}^{n} C_i + \sum_{l=1}^{m} (S_{t_0} - S_{t_m})_l - \sum_{k=1}^{p} (I_{t_p} - I_{t_0})_k$$

F. 2: evaporation loss formula

After 30 days of observations, the graph in Figure 4 was produced. It shows the fluctuations of the fluid losses inside the tank named A1, in relation to the evolution of the selected evaporation factors.

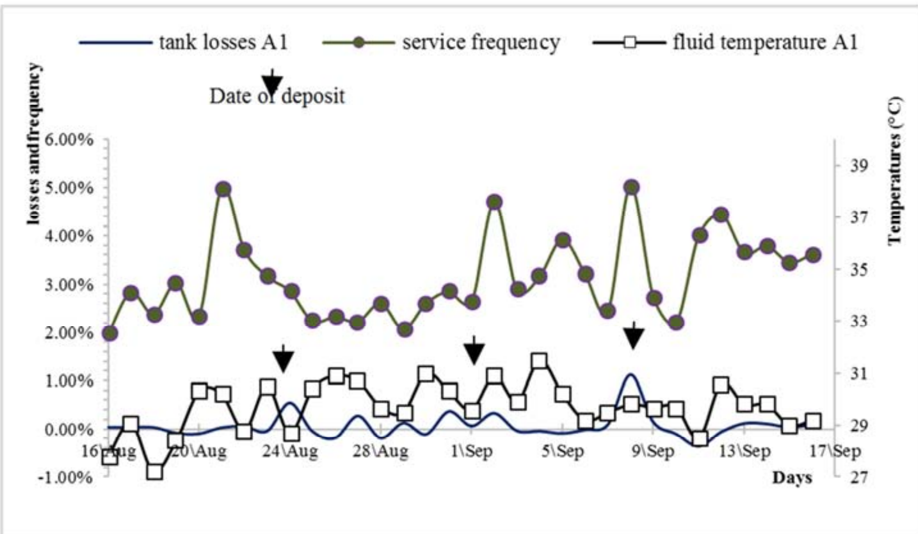

Figure 4. *Losses as a function of temperature and stock movements.*

When analysing the variations of all the curves representing the loss factors, it was found that the peaks and troughs coincide clearly with those of the loss pattern. This illustrates the correspondence and the phase shift of the influence of each factor on the loss in the underground tank. Thus, the stock movements had an immediate evaporative effect which was accentuated by the heating of the surrounding soil. As a prevention barrier, the intelligent floating roof project is necessary and requires adequate logs.

3.2. Log Selection Criteria for Floating Roof Design

To form the floating roof, hollow balls of different types and diameters were selected after several immersion tests in a sample of the unleaded premium fuel. They should meet the four groups of technical criteria listed in the following Table 1. The objective is to ensure buoyancy and resistivity relative to the petroleum product while searching for the right material.

Table 1. *Technical criteria for the selection of beads.*

N°	Log selection criteria	Justification
01	Thermal inertia	In order to be effective, these beads must be a physical barrier and have adequate thermal character: high thermal capacity and resistance to contain the heat flow at the surface of the fluid.
02	Radiation, sealing and vapour impermeability of super unleaded	In order not to absorb the fuel, the beads must be sealed against the vapour of the premium unleaded fuel. Therefore, the permeability is a function of the radius of the beads, as the gaps or pores between the beads change in size in the same direction as their diameter.
03	Unassailable by premium unleaded fuel	As petroleum products have a corrosive and dissolving power on several materials [44], the material to be chosen must be resistant to the chemical aggressiveness of unleaded premium fuel.
04	Density	In order to float better on the free surface of the fluid contained in the tank, these balls must have a much lower density than the fluid.

The constituent balls of the floating roof must have specified inclusive properties. This table gives details and justification of these criteria. The choice of balls therefore calls for a special procedure.

3.3. Log Selection Methodology

On the Ivorian market, several hollow or solid plastic beads made from recycled materials were offered for selection. These beads were soaked in the unleaded premium fuel with a measured density of 0.760 for twelve (12) months. This minimum time is nevertheless sufficient to appreciate the effect of the fuel on the roof, which is expected to operate for at least 5 to 10 years. This period corresponds to the regulatory periodicity for checking fuel storage equipment.

During this observation, most of these balls were consumed and drowned by the fuel with which they were soaked.

These were polypropylene balls that resisted corrosion from the unleaded premium fuel [44] and met the criteria for the flexible floating roof to be tested. According to the instructions for use, these balls had a diameter of 55 mm, a mass of 8 g, giving a density of 0.092 g.cm-3 with a sealed and polished surface. Figure 6 shows this bead chosen from all others that had undergone the selection test.

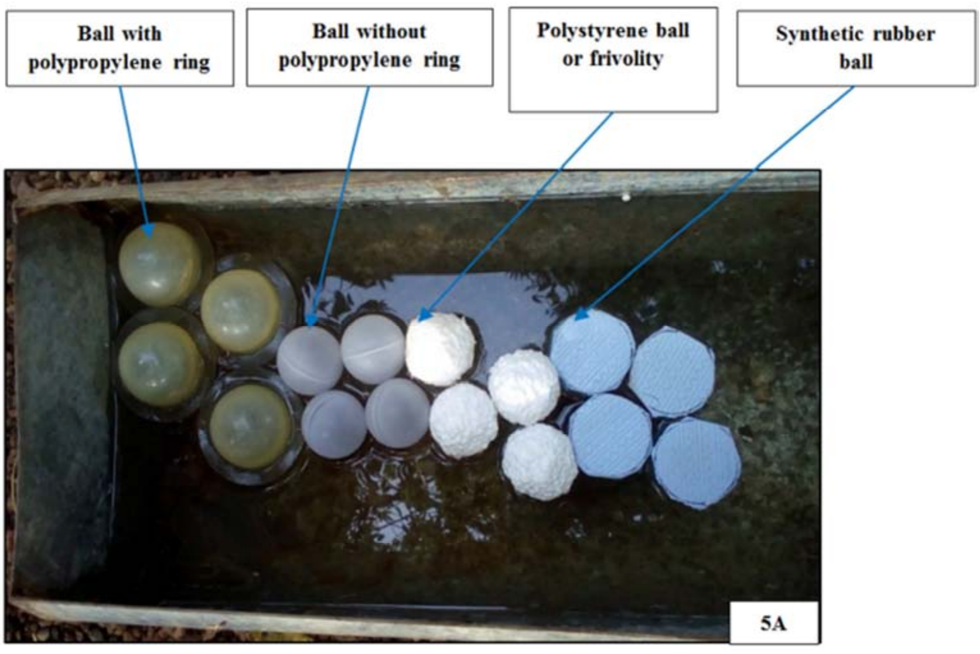

Figure 5. *Selection of beads.*

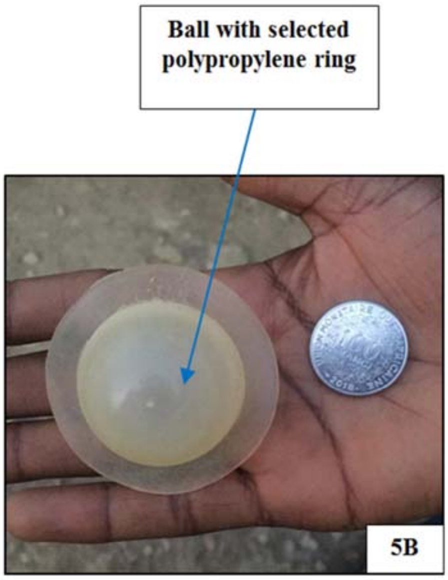

Figure 6. *Selected polypropylene ball.*

Figure 5 describes the experiment of immersing the beads in the premium unleaded fuel. Only the polypropylene bead, which has a ring, was more resistant. It is shown in Figure 6, at the scale of a 100f CFA coin.

3.4. Evaluation of the Impact of the Flexible Floating Roof on the Evaporation Process in an Atmospheric Tank

3.4.1. Installation of the Experimental Tanks to Evaluate the Flexible Floating Roof Made of Polypropylene Balls

For this test, two (02) galvanised steel tanks, better able to withstand corrosive hazards, were installed on a fitted aerial platform as shown in Figure 7. This above-ground arrangement facilitated handling. These tanks, each with a capacity of 15.70 litres, measured 0.2 m in diameter, 0.5 m in length and 0.1 m2 of internal diametral surface. This volume represents one tenth of the average capacity of the tanks at Korhogo service stations. This volume ratio justified the experimental ratios in relation to the calculation of effective losses.

3.4.2. Sizing the Floating Roof by Calculating the Number of Balls Required

The number of beads resistant to heat, chemical aggression and vapour tightness of the super unleaded and intended to cover the evaporation surface, is given by Math. en. JEANS [45]. This method had been applied by the Jean BREL petrochemical company for the conservation of dangerous and volatile products [46]. Math. en. JEANS established that the proportion of the surface "S" covered is independent of the diameter of the balls. This surface is the ratio of a circle to the hexagon that contains it. This gives:

$$S = \frac{\pi}{2\sqrt{3}} = 91\%$$

F. 3: Formula for calculating the area covered by BPP balls

Where S allows us to calculate "$_{NC}$", the number of balls per layer which is equal to the quotient of the surface covered by the diametrical section of the ball [45], i.e:

$$Nc = \frac{4S}{\pi d^2}$$

F. 4: formula for calculating the number of balls corresponding to the surface to be covered

The installation of the device in Figure 7 below was carried out using the model of Jean BREL.

Figure 7 shows the diagram and picture of the experimental set-up at two points:

In the diagram, tank 1 is the test sample. According to this formula, it should have 41 logs on the 1 m^2 diametrical layer; on the other hand, tank N°2 is the reference sample, without a floating roof, installed at 0.5 m from the other, representing the tanks currently used in service stations;

In the photo, in addition to the whole tanks, the diametrical layer of beads, in a closed tank, has been presented in an open tank.

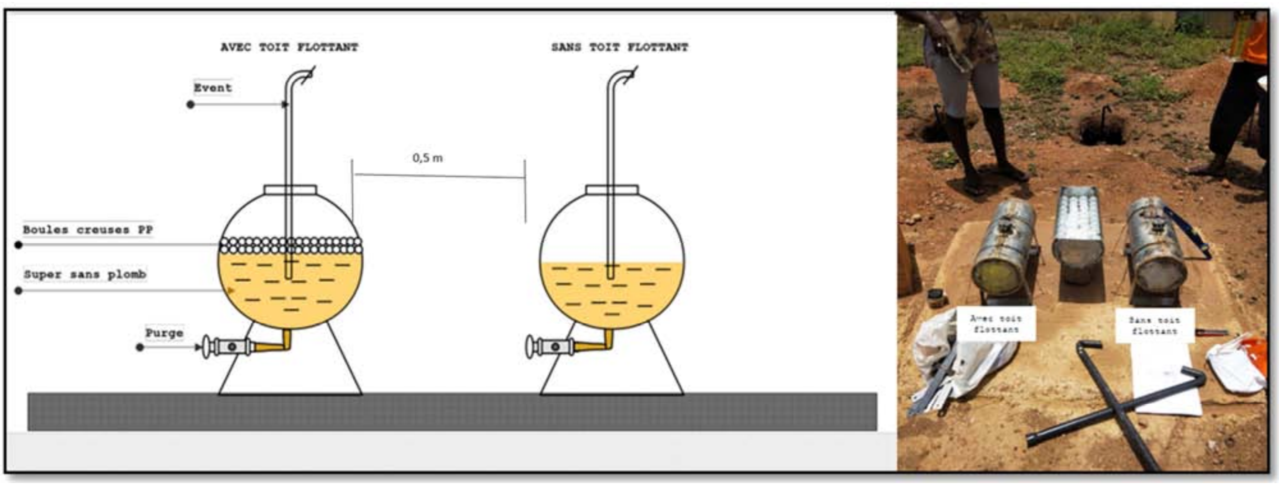

Figure 7. *Device for the flexible floating roof experiment.*

3.4.3. Measurement and Monitoring of Evaporation Indicators and Factors

The preparatory stage of the measurements consisted of the calibration of the tanks and measuring instruments. It involved:

1) a 20 cl measuring cylinder, to evaluate the ambient volumes;
2) a thermal probe and a density meter to identify the absolute volumes and densities of the volatile;
3) a volume measurement rule per tank, called the "T" gauge. This scale is graduated in volumes analogous to the levels of the fluid in said tank.

These manipulations made it possible to fix the initial variables such as the starting volume (V0) and the initial height (H0) on the gauge rule (Tn), specific to each sample. On the other hand, they indicated the constants such as the rolling volume and the quantity to be drawn off.

For this purpose, it was considered that whatever the natural evaporation factors, during one month, with a capacity of 16 litres, the quantity evaporated will never exceed one (01) litre. The liquid level was expected to remain within the range of high theoretical evaporation rates. This is the diametral level of the largest evaporation surface and a larger gas head. These boundary conditions impose an operating or volume safety range which can be between 9 and 7 litres per 16 litre tank.

By classifying the evaporation parameters, the measurements were carried out in two (02) phases, during which the indicators were taken concomitantly: a passive test phase and an active test phase were distinguished. This division is similar to the conditions and periods of actual operation of a tank at a service station, namely a so-called passive phase: in this phase, apart from gauging operations, only pressure and heat variations were targeted as factors influencing the evaporation flow [47]. In this phase, the storage device is at rest with no stock movement, as shown in Figure 8. Due to the low evaporation rate in the tank at rest and the availability of data collectors, the measurements were carried out six (06) times a day, at regular intervals of 2 hours. This periodicity helped to better perceive the variations. Thus, the samples were taken during the day when visibility and solar irradiation are obvious. They were taken at the following times: 8:00 am; 10:00 am; 12:00 pm; 2:00 pm; 4:00 pm; 6:00 pm, during the period from 1 to 31 March 2018, in relation to the thermal peak of the year in Korhogo [48]. In total, ninety-three (93) data for analysis were recorded. An active phase: in addition to gauging, the product was received and withdrawn from the tank, and the evaporation effects were considered. For this purpose, a rolling stock of 0.80 L, respecting the volume safety range of the experiment, was constituted per tank. Thus, after each introduction of 0.80 L into the tank, 0.20 L was withdrawn four times, corresponding to the unit graduation of the measuring tube. This series of operations was repeated five times per container and every 10 minutes. In total, five (05) withdrawals and twenty (20) withdrawals per tank were recorded, over a period of 4 hours.

Figure 8. *Active phase of the decanting-drawing operation.*

This picture shows the workshop where the evaluation of the smart top against the control tank without the top is taking place. The aim is to carry out simultaneous stock movements in both tanks and compare the rates of loss. The tank with the floating roof had apparently less loss of stored product. The conversion of apparent volumes to absolute volumes confirmed this definitively.

3*.4.4. Correction of Ambient Volume to Universal Absolute Volume*

The measured apparent volumes (Va) were converted to absolute volumes at 15°C (V15°C). This procedure consists of three steps:

simultaneous measurements of the residual quantity and the temperature of the product;

The choice of the correction factor corresponding to the measured temperature using an ARSTM chart from Table 54B [47] of apparent volumes at 15°C;

The multiplication of the measured quantity by the correction factor [47], as presented in formula F4.

$$\mathrm{V15°C} = \mathrm{Va} \times \mathrm{CC}$$

F. 5: formula for converting read volume to universal volume.

3.4.5. Estimation of Volume Losses

The elemental volume of the evaporated product is equal to the difference of the successive residual volumes from the initial volume. It is expressed by the following formula:

$$\mathrm{ei} = \mathrm{V0} - \mathrm{Vi}$$

F. 6: elementary instantaneous volume loss calculation.

4. Results

The work carried out has enabled us to understand the evolution and balance of losses with or without a flexible floating roof.

4.1. Evolution of Tank Losses in the Smart Floating Roof Experiment

4.1.1. Evolution of Cumulative Passive Losses

The two curves in Figure 9 show the evolution of cumulative losses per container, without stock movements.

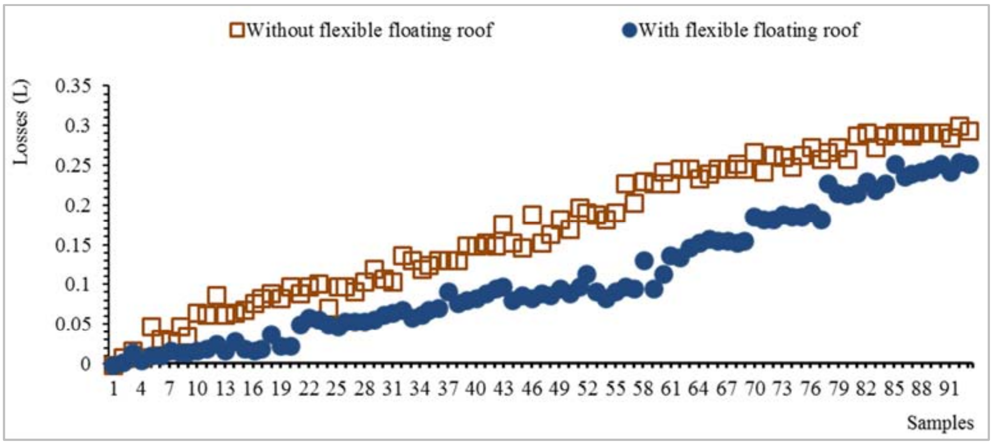

Figure 9. *Curve showing the influence of the flexible floating roof on climatic or passive losses.*

The tank without a roof recorded a higher increase in cumulative losses, with an estimated rate of 39.4.10-5 L/h, than the tank with a flexible floating roof, which recorded 33.9.10-5 L/h. Even in a stationary state, the flexible floating roof therefore conserves premium unleaded fuel better than the tank without a floating roof.

4.1.2. Evolution of Cumulative Active Losses

The evolution of the cumulative losses with stock movements, by container, has made it possible to draw up the graph below.

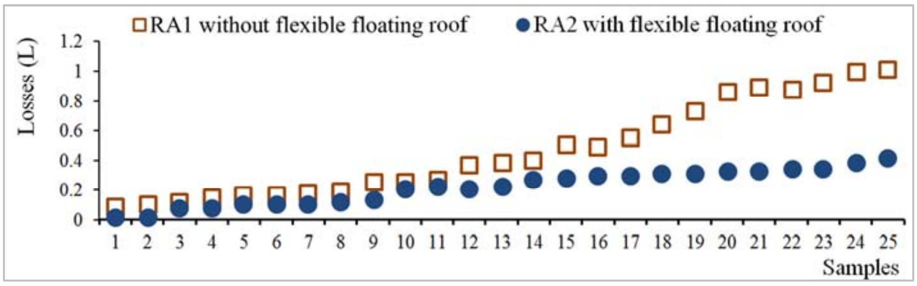

Figure 10. *Curve expressing the influence of the flexible floating roof on the operating or active floating losses.*

While the tank without a roof tended to lose 1L at the 25th drawdown, the floating roof showed 0.2L at the same time. These graphs confirm the evaporation-reducing effect of the flexible floating roof with the movement of the stocks.

4.2. Quantitative Assessment of the Influence of the Floating Roof on Evaporation in the Tank

The loss rates per sample are reported in an analytical illustration in *Figure 2,* below:

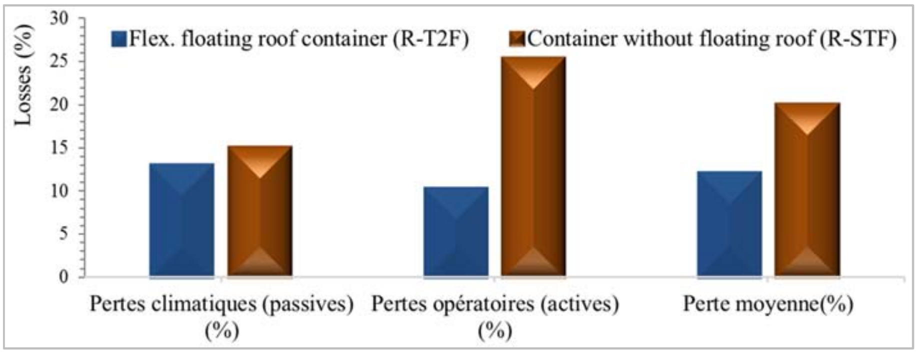

Figure 11. *Histogram of loss rates by cause and by tank.*

In the stationary (*passive*) state, losses are no more pronounced and differentiated than in the mobile (*active*) state of the stock. This finding confirms that withdrawals and depletions are equally important factors in stock losses. The distribution of these losses confirms the hypothesis that the container with the flexible floating roof absorbs losses to a greater extent. It has an estimated non-evaporation rate of 88% compared to the tank without the floating roof, which has an estimated 80% non-evaporation rate.

5. Discussions

5.1. Relative Performance of the Flexible Floating Roof System

At the outset, it should be pointed out that research into evaporation for fuel storage at petrol stations is a perilous innovation, as it has not been sufficiently addressed and discussed in the scientific community. The large vertical tanks, with their apparently high pollution potential, were more attractive to researchers than the small horizontal tanks, which are buried and have a low pollution potential, but are massively polluting.

Nevertheless, the experience of the flexible floating roof on these horizontal tanks, produced a yield of 12% of losses and an added value of 8% compared to the tank without floating roof which recorded 20% of losses. Thus, the floating polypropylene beads superimposed on the liquid surface exerted a triple decisive action, namely: i) the reduction of the surface area and the gas headspace which were the seats of evaporation [41]; ii) the absorption of part of the energy of the rising molecules according to their thermal inertia [41] and iii) the erection of the beads as a physical barrier against the escape of heated and weighted fuel particles into the atmosphere. A state of near thermodynamic and mass transfer equilibrium was approached at the interfaces of the ball-salt-gas and ball-fluid system, thereby inhibiting the evaporation process [41]. In one month, the smart floating roof saved 8 L of the 12 L intended for evaporation out of the 100 L set in motion in a tank of about 16 L.

At this laboratory scale, this results in an increase in value of 08% and therefore a saving of more than 8 m^3 of hydrocarbon gases that would have to be injected into the atmosphere per month, to the detriment of the environment. Thus, if the intelligent floating roof had been realised in Korhogo, then an annual energy saving of 128.10^6 MJ and 4.10^3 m^3 of greenhouse gases would have been achieved to the benefit of the climate, health and societies.

The result of this work has been consolidated by experiences elsewhere. Indeed, polypropylene beads (PPB) have already been used in Europe [49], in China in the petrochemical and agricultural industry against evaporation, emission of gases into the atmosphere and for thermal insulation [50]. According to Marteau & Lemarié France, hollow balls reduce heat loss by up to 75%, evaporation by 87% and air pollution by 98%. They have good resistance to chemical corrosion and operate at over 100 centigrade [44]. However, it should be noted again that this experiment would never have been initiated in the case of fuel storage, although the principle remains the same with the rigid floating roof of vertical tanks.

However, there are several methods to reduce hydrocarbon gas leakage during storage at service stations [51], including petrol vapour recovery techniques [31, 52]. The actions of this method are mainly focused on either refuelling stations (*Stage I*) or refuelling vehicles at the pump (*Stage II*). These are very complex processes with an efficiency of up to 87%. However, the socio-economic context must also be taken into account and a simpler solution must be preferred that is practicable, relatively efficient and accessible to the majority of operators in Korhogo. To this end, the flexible floating roof, made of polypropylene beads, with a loss rate of 12% of unleaded premium fuel, has the merit.

In terms of environmental protection, BPPs are insoluble at cold temperatures and do not present any toxicological risk at room temperature [44]. They only start to dissolve at 80°C, giving, among others, aldehydes, alcohols, ketones, acids and saturated, unsaturated or aromatic hydrocarbons. However, polypropylene (PP) burns easily. Its combustion gives off highly harmful gases such as carbon dioxide, carbon monoxide, aliphatic and benzene hydrocarbons and carbon black [53]. It will be necessary to prevent the occurrence of fire in this type of storage.

5.2. Apparent Difficulties in Implementing the Flexible Floating Roof System

Difficulties relating to the unavailability of logs and the permeability of the log sheets remain. Because not only were they imported, but the floating mat they formed was not watertight. These difficulties can be mitigated by reducing the diameters of the beads, duplicating the initial diametrical layers and importing bead manufacturing technologies. Therefore, it is possible to produce finer beads locally from local materials to be sourced, in order to produce a more watertight, micro-pored mat that adheres better to the storage tank wall.

6. Conclusion

The intelligent floating roof emerged with the problem of evaporation in a horizontal cylindrical tank of premium unleaded fuel. Based on the experience of the rigid roof in a vertical cylindrical tank, our study used polypropylene balls with a diameter of 55 mm and a density of 0.092 g.cm-3 in a horizontal tank. Following the evaluation of the reduction capacity of this type of floating roof, a non-evaporation rate of 88% was recorded compared to the tank without a roof with 80%, i.e. an added value of 08% with innumerable advantages. If the intelligent floating roof was applied in the city of Korhogo with its 50 service stations, then it would benefit annually from an energy saving of 128106 MJ with 4.103 m^3 of greenhouse gases not emitted, which would contribute directly to environmental pollution and climate change. This system is therefore of great benefit to the climate, health and the well-being of societies.

This solution has the advantage of being suitable for both horizontal and vertical tanks. Thus, the "flexible floating roof" or "smart roof" is a major innovation with multiple implications. This simple possibility of reducing hydrocarbon gas emissions is therefore more sustainable and appropriate. It will have a positive local impact on health and the socio-economic environment.

However, the appropriation and perfection of this technology by tropical states remains a challenge in the face of exponential growth in the consumption of premium unleaded fuel and in the number of horizontal tanks.

Appendix

Table 2. *Evolving losses in the floating roof experiment in passive mode.*

Order number	Without flexible floating roof	With flexible floating roof
1	0	0
2	0,0093	0,0026
3	0,0158	0,0148
4	0,0074	0,0048
5	0,0466	0,0103
6	0,0334	0,0124
7	0,028	0,0182
8	0,0482	0,0142
9	0,0365	0,0155
10	0,0667	0,0174
11	0,0627	0,0205
12	0,0867	0,027
13	0,0627	0,0164
14	0,0648	0,0294
15	0,0693	0,019
16	0,0786	0,0181
17	0,084	0,0195
18	0,0907	0,039
19	0,0827	0,0229
20	0,0987	0,0234
21	0,0892	0,0503
22	0,0988	0,0601
23	0,1005	0,0552
24	0,0718	0,0493
25	0,0973	0,0461
26	0,0995	0,0538
27	0,0938	0,0528
28	0,1047	0,0537
29	0,1197	0,0556
30	0,1083	0,06263
31	0,1053	0,0652
32	0,1389	0,068
33	0,1309	0,0608
34	0,1209	0,0621
35	0,1249	0,068
36	0,1303	0,0712
37	0,1331	0,0914
38	0,133	0,077
39	0,1493	0,08
40	0,1509	0,08273
41	0,1523	0,0907
42	0,1483	0,094
43	0,1783	0,0973
44	0,1518	0,08
45	0,1459	0,0857
46	0,1875	0,08269
47	0,1523	0,088
48	0,1655	0,087
49	0,1819	0,09402
50	0,1717	0,0906
51	0,1988	0,0994
52	0,1932	0,1135
53	0,1874	0,0911
54	0,1836	0,0847
55	0,1913	0,0926
56	0,2274	0,0978

Order number	Without flexible floating roof	With flexible floating roof
57	0,2049	0,09644
58	0,2312	0,1317
59	0,2265	0,0942
60	0,2442	0,11259
61	0,2275	0,1385
62	0,2473	0,1345
63	0,2455	0,1464
64	0,233	0,1523
65	0,2402	0,1584
66	0,2446	0,1545
67	0,2475	0,1568
68	0,2536	0,154
69	0,2455	0,1559
70	0,267	0,1865
71	0,2439	0,182
72	0,2633	0,1831
73	0,2602	0,1903
74	0,2501	0,18559
75	0,2655	0,1859
76	0,2723	0,1931
77	0,2567	0,1822
78	0,2683	0,2278
79	0,2742	0,2151
80	0,2571	0,21375
81	0,2869	0,2146
82	0,292	0,22953
83	0,272	0,2194
84	0,2873	0,2279
85	0,2903	0,2527
86	0,2904	0,2379
87	0,2873	0,23884
88	0,2911	0,2434
89	0,2913	0,24595
90	0,2925	0,2516
91	0,2859	0,24344
92	0,2991	0,2549
93	0,2933	0,2527

Table 3. *Evolving losses in the floating roof experiment in active mode (operating mode).*

Order number	RA1 without flexible floating roof	RA2 with flexible floating roof
1	0,09	0,019
2	0,098	0,019
3	0,118	0,079
4	0,145	0,079
5	0,156	0,097
6	0,169	0,105
7	0,179	0,10501
8	0,188	0,12501
9	0,248	0,14001
10	0,259	0,21001
11	0,272	0,22101
12	0,372	0,20101
13	0,392	0,22101
14	0,4	0,27101
15	0,5	0,28501
16	0,49	0,29901
17	0,55	0,30023
18	0,64	0,30423
19	0,72	0,30423
20	0,86	0,32423
21	0,89	0,33323
22	0,87	0,34023
23	0,92	0,34823
24	1	0,38823
25	1,01	0,40823

Table 4. *Distribution of evaporation rates by cause and tank.*

	Climate losses (passive) (%)	Operating losses (active) (%)	Average loss (%)
Container with a flexible floating roof. (R-T2F)	12,87	10,21	12
Container without floating roof (R-STF)	14,93	25,25	20

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