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EVAPORATION LOSS MEASUREMENT FOR STORAGE TANKS
Course No. 2150

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INTRODUCTION

In the 1950's hydrocarbon evaporation loss from storage tanks was studied to develop emission estimating equations. At that time, the primary driver for knowing the evaporation rate was system loss control. During the early 1990's, the US Environmental Protection Agency (EPA) began programs for stricter record keeping and reduction of storage tank emission.

This forced industry to scrutinize the accuracy of existing evaporation loss estimating equations and to develop improvements to various tank appurtenances in an effort to lower hydrocarbons emissions. Much of the EPA activity was focused on floating roof tanks. This paper will review:

- Sources of emissions from floating roof tanks
- Research and development to improve emission loss equations
- Testing of existing fittings
- Testing of design improvements to lower emissions
- Development of EPA approved test protocol for improved equipment designs
- Future areas of emission research in floating roof tanks

In order to help the reader follow the organization and sequence of events of this paper, the major topics listed above will be listed in bold underlined capital print. The subsections within each major section will be in capital print only.

SOURCES OF FLOATING ROOF TANK EMISSIONS

There are two types of floating roof tanks commonly found in industry. They are the External Floating Roof Tank (EFRT) and the Internal Floating Roof Tank (IFRT). On an EFRT, the floating roof is exposed to the atmosphere. With an IFRT, the floating roof is covered by a fixed roof at the top of the shell. The fixed roof of the IFRT is either supported by the tank shell or support columns.

Floating roof emissions are usually generated at three sources. These are the floating roof deck, floating roof fittings, and the roof to shell seal. Each of these sources are influenced differently by external conditions.

FLOATING ROOF

Most of the floating roofs found in the industry are either:

- Welded roof deck (all seams are welded together)
- Bolted contact roof deck (seams are bolted and roof makes contact with the liquid)
- Bolted non-contact roof deck (seams are bolted and roof does not make contact with the liquid).

Most EFRT's are built using welded roofs. Because of the welded roof, no emissions occur through the floating roof. This reduces the sources of emissions on EFRT's to tank seals and roof fittings.

IFRT's use all three types of decks. Therefore, IFRT's can have emissions from all three sources. However, ambient wind, which effects evaporation rate, has less of an impact on IFRT's due to the shielding affect of the fixed roof.

FLOATING ROOF FITTINGS

For the most part EFRT's and IFRT's have similar roof fittings. However, there are some distinct differences which are noteworthy. EFRT's can have emergency overflow roof drains that empty excess rain water into the product below the floating roof. IFRT's have roof columns that penetrate the floating roof to support the fixed roof above. Although there are several more fittings that are specific to each type of roof design, these are only a few examples of the different types of fittings. Some of the major contributors to emissions are the slotted gauge pole, roof legs, column legs and emergency overflow roof drains.

FLOATING ROOF SEAL

The final source of tank emission found on both EFRT's and IFRT's originates from tank seals. Tank seals emit vapors at the point where the seal touches the tank shell or through gaps found in the seal fabric.

There are many types and styles of tank seals. The ones most noteworthy are wiper seal, shoe seal, and envelope seal. When a seal is used by its self, it is referred to as a primary seal. When it is used to cover another seal, it is referred to as a secondary seal. If the seal touches or extends into the liquid, it is referred to as a liquid mounted seal. When the seal does not touch the liquid, it is referred to as a vapor mounted seal.

Wiper seal are found in both EFRT's and IFRT's. They are usually made of a light weight foam or rubber material. The wiper seal is attached to the floating roof and is used to seal of the vapor space between the floating roof and the tank shell. Wiper seals can be used as either primary or secondary seals.

Shoe seal uses a series on overlapping or adjoining plates (shoes) which extend into the liquid and ride up and down the shell wall as the roof raises and lowers. The plates are supported by the floating roof with a mechanism that promotes contact of the shoe against the shell. The area between the top of the shoe and the floating roof is sealed off with a fabric that connects to both of them. Most shoe seals are used as a primary seal.

Envelope seals are covered fabric sleeves which are filled with an expanding material or gas to span the area between the floating roof and the shell. The envelop seal can be mounted above the liquid (vapor mounted) or in the liquid (liquid mounted). Envelope seals can be used as either a primary or secondary seal.

RESEARCH AND DEVELOPMENT TO IMPROVE EMISSION LOSS EQUATIONS

Since the 1950's, the American Petroleum Institute's (API) Committee on Evaporation Loss Measurement (CELM) has research data and developed equations for emission estimation. During that time, the emphasis was on general equation development and emissions from critical sources. Non-critical sources were estimated based on emission rates from similar devices based on the ratio of exposed surface area of a known device. However, with EPA regulations mandating tighter emission controls, the CELM decided to take a more in- depth look at the physics and mechanics of evaporation loss to verify existing emission equations and loss factors.

In order to determine the best plan for updating the equations and factors, API documentation files from previous research was analyzed. This information was used to develop a research plan to pinpoint key areas of improvement needed with emission equations and factors.

Based on the above analysis, the CELM decided to:

- Perform a statistical review of the equations
- Review and improve the emission equations
- Update emission loss factors

EMISSION EQUATION STATISTICAL RESEARCH

There are several key factors that determine the evaporation rate of hydrocarbons in storage tank fittings. These factors are:

- Type of product
- Actual ambient vapor pressure (which is contingent on temperature)
- The fitting loss factor for each device
- Actual wind speed at the device

In order to determine the significance of each of these factors, statistical analysis was conducted whereby the value of the factors were varied by ±20% and compared to the change in emissions. From this, the CELM was able to determine which fittings were the main emission contributors and which factors in the emission equations needed to be researched. Knowing the impact of each factor reduced the risk of researching areas that were not cost affective from an emissions reduction point of view.

EMISSION LOSS EQUATION MODIFICATION

The statistical review found that the ±20% variance in wind speed (1.56 MPH to 7.8 MPH) had a ± 39% impact on emissions. Wind speed is a component in emissions for all fittings. With wind speed being such a critical factor, the CELM researched all the physical aspects of wind phenomena on tanks and concluded that there was no adjustment in the equations to correlate ambient wind speed to the actual wind speed at fittings on the floating roof. From practical experience, Committee members knew that the shell of an EFRT shielded most of the ambient wind as the product and floating roof were at lower levels in the tank.

Research conducted by a contractor on scale models was used to analyze wind speed and direction for various locations on a floating roof. These test were conducted on scale models that represented a 200 ft. diameter, 100 ft. diameter, and 48 ft. diameter tank. Wind speed and direction tests were also conducted at various roof height to shell ratios. These tests would determine if the phenomena were similar on all tanks or varied with tank size.

The test revealed that three distinct phenomena occurred at different shell to roof height ratios for each tank. First, when the floating roof was at a high lever, the wind speed on the roof was approximately 90% of ambient and in the same direction as ambient. When the floating roof was at a midpoint level, the wind direction on the middle of the tank roof varied. The wind speed at this level slowed down to approximately 30% of ambient. Finally, when the floating roof was at low levels, the wind speed increased to approximately 60% of ambient and was in the opposite direction on the roof and along the tank shell. Note that the wind direction along the shell was parallel to the shell in every case. This would play a significant role in other test detailed later in this report.

The wind speed tests provided excellent data for specific wind speeds at each fitting location on a floating roof, for different elevations of the roof, and for different size tanks. In essence, the study provided such an unexpected wealth of data and equations to estimate wind speed, it made it difficult to use in practical applications.

Due to the cumbersome nature of the equation, the CELM made a preliminary review of the research data and suggested the use of one wind speed adjustment factor. The wind testing contractor was again retained to do additional research to determine if this hypothesis was correct.

Data was collected from petroleum storage tank facilities to determine the roof heights of tanks during their normal operation. This information was combined with wind speed data at various locations and elevations on the roof. The results of this study showed that there was a single adjustment factor that could be used to simulate the wind speed. Based on this data and consultation from the US EPA, a factor of 0.7 was chosen.

TESTING OF EXISTING FITTINGS

With the preliminary statistical analysis and data from the documentation files, the CELM determined that several fittings warranted further testing due to three reasons. First, little or no testing was done on some fittings. Second, no tests were conducted at zero (still air) wind speeds. And third, no fittings were tested at different wind direction to see if there was any affect. Because of this, CELM:

- Conduct verification tests
- Tested the fittings at still air conditions (approximately 0 MPH)
- Tested at various horizontal wind directions (0, 45, 90, 135, and 180 degrees).

VERIFICATION FITTING TESTS

As reviewed earlier in this paper, some of the fittings had very few tests or were not tested at all. Most of these fittings were retested. In cases where previous data was available, the previous emission rate was compared to the new rate. Most of the previously untested fittings did match the extrapolated data from the past. However, the emissions factors for some fittings did change at certain wind speeds. API Chapter 19.2 of the Manual of Petroleum Measurement Standards should be reviewed for specific details of these changes.

ZERO WIND SPEED FACTOR FOR FITTINGS

Although there was evaporation loss factor data for wind speeds of 5 to 15 MPH, there was limited data for zero MPH (still air). When the factors were initially developed in the 1950's and 1960's, the CELM felt that a data reduction method could be used to approximate the emissions at zero wind speed. When test were conducted in the 1990's, the data showed that the emissions were higher than expected for some fittings at still air conditions (approximately zero MPH).

This had a slight to moderate impact on some facilities that have low ambient wind speeds. Locations with winds above these speeds had lass of an impact on emissions. This caused some confusion when the new factors were first released because some users were stating that their emissions were higher and some were stating that they were lower than before, and both were correct. It depended on the local wind speed and the type of fittings at the facility.

DIRECTIONAL WIND TESTING

From the tests it was determined that most of the fittings were not affected by the wind direction. However, a significant difference in emissions was found with the orientation of the slotted gauge pole. As it turned out, emissions were found to be more when the wind direction was perpendicular to the slots. This was contrary to the CELM's first thoughts because it was assumed that air flowing parallel with the slots would replenish the fitting with fresh unsaturated air, thereby promoting additional evaporation. As it turned out the air going around the gauge pole created a venturie effect which lowered the pressure in the gauge pole. This promoted additional vapors to be formed.

Although the gauge pole wind orientation testing was found to be intriguing, its full potential was not realized until this data was combined with the wind speed direction testing. As you remember from the wind speed discussion, the wind direction in almost ever case was parallel with the shell. So, if a tank operator orientates his slotted gauge pole with the slots parallel to the shell, the emissions would be reduced. Although this finding was significant, the orientation of most slotted gauge poles was not known. Therefore, an average factor for emissions was determined based on an even distribution of wind speed in all directions.

TESTING OF DESIGN IMPROVEMENTS TO LOWER EMISSIONS

Because the slotted gauge pole with no improvements has the potential to contributed a majority of the fitting emissions, tests were conducted with various improvements to find ways to reduce its emissions. These test proved to be very worthwhile. The first major improvement was to add a pole sleeve. The pole sleeve is a piece of pipe attached to the cover of the gauge pole that extends down into the liquid and is slightly larger than the gauge pole. This prevents vapors form traveling between the roof well of the gauge pole and the sliding cover, and then through the gauge pole slots to the atmosphere.

Another improvement to the slotted gauge pole was to add a pole wiper to the top of the sliding cover. This wiper was use to seal in as much vapors as possible. This devise was effective in reducing emissions, especially when combined with other gauge pole improvements.

The final improvement which made a large contribution to emissions reductions in slotted gauge poles was a float placed inside the gauge pole. The float was tested with and without a float wiper. The effect of the float wiper was to reduce the emissions space between the float and gauge pipe. Although it would be tempting to place a hierarchy on the benefits derived from individual fitting improvements, the total emissions from a gauge pole are more dependent on the proper combination of improvements. For example, an unslotted gauge pole with a cover seal, pole sleeve, and wiper has 96% to 95% less emissions than an unslotted gauge pole with a float. The point to be made here is that some company operations are very dependent on access to the product in the gauge pole. A float in the gauge pole has a significant impact on operations. The addition of the well gasket, wiper, and pole sleeve allows unrestricted operations and still provides a significant reduction in emissions.

Many of the simple gauge pole modification (those which can usually be installed with the tank in service) can reduce emissions much lower than an unslotted gauge pole with minimum controls. This is a key issue due to some state agencies promoting and possibly banning slotted gauge poles. The problem is that there is little difference in emissions between an unslotted gauge pole and slotted gauge pole when each of them are modified.

There is also an operations safety consideration which must be addressed with unslotted gauge poles. If a facility operates with products where there are variances in specific gravity, the heavier products will tend to remain close to the tank bottom. Since the inlet of most gauge poles are at the bottom of the tank, only the higher gravity product off the bottom of the tank will enter the gauge pole. This causes the higher specific gravity product to be trapped in the gauge pole. The lower specific gravity product remains in the rest of the tank. The differences in gavities between the two cause the level in the gauge pole to be lower than the rest of the tank. This understates the volume in the tank, which could allow a tank to be running over the top while still retaining a safe reading in the unslotted gauge pole. Differences of up to 6 feet have been experienced due to this phenomena. With slotted gauge poles, the product is allowed to mix which results in the same level in the tank and the gauge pole.

Improvements of roof legs, emergency overflow roof drains, and other fittings were also tested. Although the results were not as dramatic as the slotted gauge pole, definite emissions reductions were obtained. The improvements either covered the fitting of reduced the amount of exposed area. For example, covers, or socks, were placed over the legs. In the emergency overflow roof drain, the amount of exposed area was reduced by 90%.

DEVELOPMENT OF EPA APPROVED TEST PROTOCOL FOR IMPROVED EQUIPMENT DESIGN

Due to imposing US EPA regulations in the early 1990's restricting and/or reducing emissions, many storage tank and tank fitting manufacturers began developing new products to reduce emissions. The problem was that there were no industry or EPA approved test procedures for verifying emission loss factors or rate of emissions from these devices. For this reason, a program was initiated in CELM to develop a test protocol that could be used by an approved test facility to verify fitting loss factors for new products.

The committee developed three types of test protocol. These were the Wind Tunnel Test Method, Air Concentration Test Method, and the Weight Loss Test method. Each of these test methods cover specific types of tests and are described below.

- Wind Tunnel Test Method - used to obtain emission loss factors for deck fittings on EFRTs
- Air Concentration Test Method - used on floating roof rim seals to obtain emission loss factors
- Weight Loss Test Method - used to obtain loss factors for deck fittings on IFRTs

One important point that should be noted is that these protocols have been reviewed and approved by the EPA and their technical consultants. Therefore, when a product is tested at an approved facility, an API monogram and emission actor is provided to the manufacture.

FUTURE EMISSION RESEARCH IN FLOATING ROOF TANKS

Since we are about to begin a discussion of current developments in emission research, it should be noted that the name of the CELM has been changed to Committee on Environmental Loss Estimation (CELE).

There are several areas that CELE is currently researching to improve emission estimation. One area is tank operations. In the 1990's, operators of storage tanks started reducing the amount of inventory they maintained in their tanks. At the same time, the EPA began a program restricting the types of products sold in specific locations at difference times of the year. All of these factors are causing the tanks to be operated at levels where the roof is landed and refloated. The emissions from this type of operation is usually referred to as "turnover losses". There is a joint project between CELE and another API committee under Health, Environmental, and Safety to determine the emissions from turnover losses. Additional information on turnover losses should be available in late 1999.

Another activity just beginning under CELE is the correlation between bulk liquid temperature and liquid surface temperature. This relationship, as it pertains to floating roof tanks, is treated differently in EPA calculation methods as compared to API. The EPA emission calculations tend to be higher than API. Hopefully, the proposed research will resolve this issue.

CONCLUSION

Many aspects and ideas on floating roof storage tanks have been presented in this paper. It was the author's intent to make the reader realize that, although storage tanks and their appurtenances are fairly simple, the mechanics of evaporation loss can be very complex. That is why it is very important to the owner or operator of a tank to understand the impact of tank emissions modifications. What you think may be reducing emissions may not have any effect at all, or may actually be increasing emissions.

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