Summary

Simulation of techniques to reduce vapour emissions from atmospheric storage tanks

Introduction

Hydrocarbon vapour emissions from refineries, chemical plants and loading terminals are not only a source of atmospheric pollution, but also a substantial loss of valuable products. If hydrocarbon vapours are not emitted to atmosphere, there is an obvious direct environmental benefit in reduced emissions. Governments worldwide are making major efforts to reduce emissions of CO_2 and other greenhouse gases, in line with the Kyoto agreements.
At present, there are various techniques available to reduce vapour emission from storage tanks, however these are not always applied in the most effective manner.

Vapour emissions from different storage tanks are analysed in this report. Common used tank types are fixed roof tanks: FRT, external floating roof tanks: EFRT and internal floating roof tanks: IFRT, which exist in different dimensions, varying from small tanks to very large tanks of more than 100,000 m^3. Emission losses that occur in these tanks could be split up in:

- Breathing losses, which are caused by changing weather conditions.
  - The liquid and the gas volume in the tank will expand and expelled from the tank.
  - Wind draws the vapours trough the seals and fittings of a floating roof tank.
- Working losses, which are caused when the tank is filled or emptied.
  - The vapour makes place for the liquid and is expelled from the tank.
  - At floating roof tanks these losses appear only if the roof is landed.
- Pumping losses, which are caused at lowering the liquid level in a floating roof tank.
  - Liquid sticks to the wall (these losses are relatively small).

Worldwide accepted calculation models to describe these vapour emission from storage tanks are the 'U.S. Environmental Protection Agency' (EPA) models made by the "American Petroleum Institute" (API) in 1991. They are based on average year or day values as input and describe the emissions that appear in different types of tanks under various operational conditions (e.g. ambient temperature, solar irradiance or cloudiness, wind speed and ambient pressure) including all sorts of reduction techniques (e.g. floating roofs tanks, rim seals, deck fittings and tank dimensions). Translation of this model to shorter time (hourly) input intervals result in a better insight on hourly emissions and gives a more realistic emission loss prediction of the reality because more (extreme) weather conditions are now taken into account.

Methods

Verification of the new hourly based method with the current EPA method should give the same results for similar (uniform distributed) input data over a certain time interval (e.g. 24 hours). It is checked if the new model implements the translated relations correctly and to ensure that it works as it is intended to do. The resulting sum of 24 hourly based breathing losses is exactly the same with the current model (daily average based) for all tank types, which proves that the model is correct.

Interpolation of daily data is recommended if hourly input data is not available at the KNMI (or other institutes). An analysis is made if data interpolation is accurate enough to represent the hourly input data. Temperature interpolation results in an increase of emission losses of maximum 2.5% compared with real hourly data, cloudiness in a decrease of maximum 2.9% and wind speed in a decrease of maximum 27.2% emission losses. Using the interpolation method should take this accuracy into account for the different losses. Purchasing the actual hourly data from the KNMI will improve the accuracy of the model results and is recommended for wind speed. If the solar irradiance is not available it could be predicted with the help of sunrise and sundown times of a location in combination with the cloudiness and the total yearly energy received on $1m^2$ earth surface. The development of the throughput of the liquid and corresponding liquid level is also important to calculate emission losses. The throughput generator in the model generates an input and output batch of '0' or '500' m^3 liquid every hour, based on the yearly turnover of liquid and the tank volume.

Before implementation of the model in Delphi, the used calculations are divided in procedures and described in a pseudo code to make it usable for more design tools. All results from the procedures are used in a calculation procedure where the variable input is read from a table to determine the different emission losses. The calculation procedure calculates the emission losses for both models. Firstly the sum of 24 loose hour (new model) calculations is made; secondly the calculation for the current model (daily average) is made. This is done with the average of the hourly input data, to compare adequately.

Input variables which are used in the Delphi tool to make it better usable and understandable are:

- Form input (for: tank type, dimensions, vent settings, etc.), redundant input is disabled
- Access coupled database input (for: wall factor, tank colour, liquid type, seal type, fitting types, etc.) It is possible to introduce a new liquid, seal or fitting type without changing the Delphi code. Expanding the database in access should now be easy for users.
- Input from a file (KNMI data: hour, temperature, cloudiness, pressure and wind speed). The input file is a list with hourly data from a certain location in the world. If hourly data is not available or not available for free, daily based data could be used in the input file.

The new model can calculate past emission losses and simulate future emission losses based on data generation. The model is build with help of the tool Delphi. For simulation applications the tool TOMAS is used to implement different random streams, which are necessary for the random input generators. Random streams in TOMAS can be made regenerative using 'seeds', from which different simulation could be compared adequately for different operational conditions. The model is constructed in such a way that it is relatively easy to use and expand with more variables in the future. The results from experiments with the new emission model are presented for three different types of tanks and include:

- The total yearly emission losses for the new hourly based model and an output file with all hourly individual losses.
- A graphical presentation of the difference in emission losses (kg) between the current and the new model.
- A graphical cumulative development of the amount of emission over a year (kg)
- The emission losses split up in breathing, working and pumping losses
- The emission losses are presented in Euros (with a variable crude oil price set on 0.40 €/litre)

The simulation makes use of input data of the year 2006, because this year is most close to the average calculated emission losses of the years 2000 to 2006. This input data is modified by the generator which implements a modification based on a sample of a normal distributed random stream. Sensitivity tests for different magnitudes of the modification to the emission results are made to analyze which input variables are relatively important. Changing the temperature and the wind speed will relatively have the most influence to the emission results. Changing the percentage of clouds and the ambient pressure will have relatively less influence.

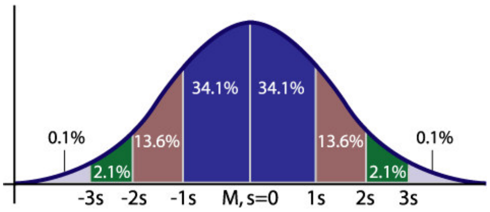
The performed experiments with the model are based on hourly data without interpolation. All experiments are performed for FRT, EFRT and IFRT with a volume of 5000 m^3, by changing:

• Tank dimensions:	10 meter (Height) and 25.23 meter (Diameter)
	16 meter (Height) and 19.95 meter (Diameter)
	20 meter (Height) and 17.84 meter (Diameter)
	30 meter (Height) and 14.57 meter (Diameter)
• The liquid type:	Crude oil (RVP5) or gasoline
• The turnover factor	6 or 36 tanks per year
• The colour of the tank	white or aluminium
• The shape of the roof	dome or cone shaped
• The vent on the roof	free vented or a (+20 & -6 mbar) vent
• Seal types	(vapour, shoe or liquid mounted)
	(tight or average)
	(primary or secondary)

Results

Simulation of future losses will result in a small increase of emission losses compared to a calculated year. All simulation results must be interpreted within this increase and the stochastic conditions below (average increase and standard deviation of increase). E.g. for FRT breathing losses this average increase is 1,9% with a standard deviation of 0,4%.

NEW MODEL Hourly based			
FRT Br	FRT Wo	EFRT Br	IFRT Br
Average			
1.9%	0.0%	0.4%	0.6%
Standard deviation for 68.2% range			
0.4%	0.1%	0.1%	0.1%



"Stochastic conditions for the increase in emission losses at simulation"

Difference between the current and the new model.

- The maximum increase in emission losses for FRT from the new model compared with the current model is 22% (and 64,9%, specified to breathing losses)
- The maximum increase in emission losses for EFRT is 61.1%
- The maximum increase in emission losses for IFRT is 4.1%

These results must be interpret within the stochastic conditions above.

Reduction techniques applied to the new model.

- Breathing losses are reduced by implementing techniques like a pressure vent, a light tank colour, a higher tank and a cone shaped fixed roof. Implementing these techniques is technically the best to reduce emissions, but economically not always the most efficient. Reduction techniques like raising the FRT height from 10m to 30m represent maximum 63% of breathing loss reduction. Changing the colour of the tank from aluminium to white represent maximum 48% of breathing losses for a FRT.

- Reduction techniques like raising a floating roof tank height from 10m to 30m represent maximum 11% of breathing loss reduction for floating roof tanks. Pumping losses could be reduced almost 100%.
- Reduction techniques like changing the colour of a floating roof tank from aluminium to white represent maximum 13% of breathing loss reduction for floating roof tanks. Pumping losses are not reduced.

- Floating roof breathing losses (or wind losses) are reduced by implementing better seals. It was already known which seal types (liquid, shoe or vapour mounted), (primary or secondary) and (tight or average) have the best reduction properties. Now the relative differences for the new model are described. Implementing a secondary liquid mounted seal is technically the best to reduce emissions, but economically not always the most efficient and even not necessary.

A low liquid level in a tank will result in less breathing losses:

- In FRT the vapour in the top is less saturated than directly above the liquid level.
- In EFRT the wind will have less influence because the distance between the top of the wall and the floating roof is bigger.

Discussion

- By means of a new hourly simulation model it is possible to predict the emission losses more realistic than the current daily average based model. With the model it is should be easy for users to change input variables and techniques, which determine the emission losses for each type and dimension of tanks under various operational and weather conditions. Unlimited analysis could be made from which only a selection is presented.
- When calculating emission losses with the new model, the use of real hourly data input is recommended to obtain more realistic emission losses. Interpolation of wind data compared with real hourly wind data could result in a maximum underestimation of 27.2% in emission losses.
- If hourly input data is used, the temperature and wind speed are very sensitive to modifications with respect to the emission losses.