Bulk Filling Losses Reduction topics in trucks for cryogenic liquids in horizontal tanks

Alan Alberto Ramírez Guevara

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***Abstract*– In this paper was studied different process variables in the cryogenic liquids filling in trucks with the intention to avoid wasted product caused by a high flow rate of the purge valve to depressurize the vehicle tank during the cryogenic liquid filling process. The analyzed variables were a bad filling operation mainly venting open valves for the trucks, possible lack of maintenance by the trucks and the initial filling pressure for the truck as well as the quantity of product loaded.**

The study begins by solving initial problems that prevent having a correct quantification of the losses which is the bad dimensioning of the tank levels due to an inconsistency in the density and conditions of liquid content.

The results for this work was an increase on the reliability in the measurement of the levels in horizontal cryogenic tanks of two plants producing cryogenic liquids, the reduction of 50% of the losses in the transfer of liquid argon in a cryogenic plant as well the complete reduction of liquid , nitrogen and liquid oxygen wasted (30 tons / month for each product) which brings about the disappearance of dangerous atmospheres for operators and people on site due to excessive venting of the purge valve on the truck during its transfer. After different statistical analysis, was concluded with 95% certainty that the amount of cryogenic liquid loaded is a significant variable in the waste of the loading process.

Keywords-- Cryogenic liquid, Road tanker filling, NPSH, Horizontal tanks, DMAIC methodology

I. Introduction

This document specifically covers the loading and unloading operations for liquid oxygen, nitrogen and argon (cryogenics liquids) in road tankers for delivery to the customers. These transfer processes apply to customers in the industrial, pharmaceuticals and food sectors, except where specific procedures are required by a customer.

A cryogenic liquid is defined as a liquid with a normal boiling point below –130°F (–90°C). The most commonly used industrial gases that are transported, handled, and stored in the liquid state at cryogenic temperatures are argon, helium, hydrogen, nitrogen, and oxygen.The vapors coming from these liquids that are released by a bad filling process are extremely cold and can produce burns. Their extremely low temperatures can produce cryogenic burns of the skin and freeze underlying tissue [1].

During the road tanker filling is possible to have different operational risks for operators, process operation and a large number of tons of liquids wasted through the venting purge valve caused by a wrong filling process. Note that the purge flow rate does not need to be high. Normally the product is filled via the top fill line into the gas space of the vehicle tank [2]. This is to re-condense the gas and lower the pressure in the tanker. Because of this, venting a tanker being filled is unnecessary as this will result in product losses which can be avoided. In order to prevent product losses is necessary to ensure that the tanker is adequately equipped with over-pressurization protection and the fill connections are suitable for the product to be filled.

A common problem to calculate the product wasted during loading and downloading for road tankers is an incorrect measurement caused by a not adequate method to calculate the level in cryogenic storage tanks. The standard method to calculate the levels in tanks is with the difference of levels. This method requires no investment except the level gauge at the storage unit. Its accuracy, at best +/- 5%, is dependent upon the accuracy of the level and a good knowledge of the geometry of the storage unit. The quantity delivered is calculated from the difference in levels through the use of conversion tables, one for the product and another for storage unit. If the method of calculating the quantities delivered involves the density of the product, the error may be significant.

Some of the different possible problems caused by a wrong measurement in cryogenic liquids in storage tanks are described below: The risks that exist for believing that there is a higher level than it really is, it is putting the pumping system at risk (if it exists) at the moment that the flow for suction is not enough to the pump operation causing cavitation problems where the concept of NPSH (Net Positive Suction Head is an important parameter in the pump circuits design that helps to know the proximity of the installation to cavitation. If the pressure at any point in the circuit is less than the vapor pressure of the liquid, it will enter cavitation jeopardizing the integrity of the equipment [3]. Therefore, it is necessary to keep in mind that a certain NPSH must be available and that it shall exceed the NPSH of the equipment to avoid cavitation problems.

Having a higher level than what you actually have results in a loss at the time that a registration and planning for new supply levels as well as logistic control is not well planned.

This article was made with the intention to inform about the different variables in the cryogenic liquid filling process that affects the amount of product wasted and the quantification of losses to prevent a large amount of product wasted in the plants and distribution centers for cryogenic liquids.

DEFINE

The main reasons to have a large number of tons wasted during road tankers filling with cryogenic liquids are listed below:

- High open venting valve during large periods
- Road tanker leaks
- Connections are not suitable for the product to be filled
- Lack of training in operators
- Net product load
- Road tanker initial pressure

In this study the last process variables were analyzed in order to understand the reason and contribution of these variables in the road tankers filling wastes. However, we had to solve typical problems in the levels quantification of the tanks because in the losses analysis quantification were found incongruity for product losses due to incorrect measurements in tank levels.

MEASURE

The waste in the trucks filling can be calculated with a mass balance, shown in equation (1) and (2).

Rate in – Rate out + Rate of production-consumption = Rate of Accumulation (1)

$$E - S + P - C = \frac{dA}{dt} \qquad (2)$$

Subsequently, the mass balance for the road tanker was solved. In the case of the tank, production is deleted since no liquid is produced inside the tank through any chemical reaction. And for the road tanker, production variables were deleted for the same reason.

The mass balance for tanks is shown below:

$$dt(E - S - C) = dA \qquad (3)$$

$$t(E - S - C) = \int_{o}^{f} A \qquad (4)$$

$$t(E - S - C) = A_f - A_o \qquad (5)$$

Where:
t = Road tanker filling time in hours
E = Production of the plant to the tank in Ton / h
S = Tank output in Ton / h
C = Liquid vaporization in Ton / h tank
A = Tank level in Ton

For the road tanker are shown in equations 6 and 7.

$$dt(E - C) = dA$$

$$\int_{t0}^{tf} dt(E - C) = \int_{o}^{f} A$$

$$tf - t0\,(E - C) = A_f - A_o$$

Where:
E and C are independent of time
t = Road tanker filling time in hours
E = Inputs from storage tank in Ton / h
C = Vaporization of liquid in road tanker or waste pipe filling in Ton / h
A = Road tanker level in Tons

Losses quantifications

The losses quantification was obtained with the previous equations for three different plants using 47 samples as is shown in the table #1.

SUMMARY				
Plant	*Count*	*Sum*	*Average*	*Variance*
Plant #3	47	-27.188	-0.578	0.371
Plant #2	47	45.091	0.959	0.273
Plant #1	47	217.020	4.617	0.178

Table #1. Losses quantification for 47 different samples of road tankers filled on the plants.

The Table #1 shows an incongruity for the losses in plant #3 and a very high percentage losses for Plant #1. The losses measurements are incorrect for plant #3 where it was necessary to calculate the tank levels for this plant. We conclude that the waste in this plant #1 is very high but we can not explain the large number of liquid argon tons lossed, so it was necessary to review the tank level curves.

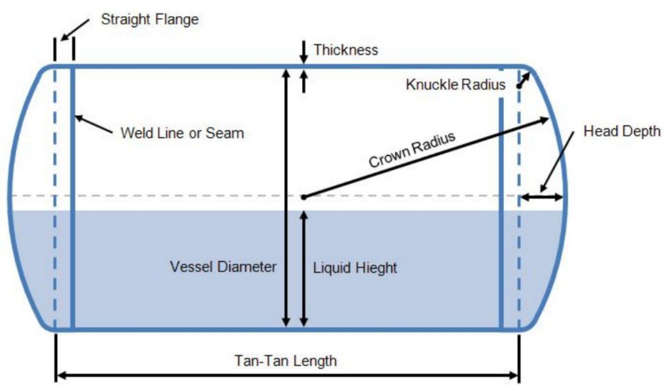
Tank level corrections for Plant #1

The first way to know a discrepancy between the level measured with the real level value was with a level measurement by the installed sensors on the tank.

The technical specifications from the tank specify a maximum level of 154.77 tons while the installed sensors measurement was higher than 165 tons.

With this value discrepancy, we concluded that we did not have correct level values.

The dimensions and measurements required to make the level calculations in horizontal tanks are those shown in the figure #1.



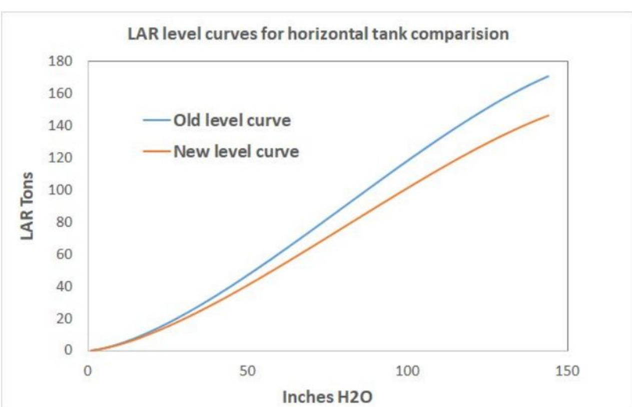
Figure#1 Design elemental parameters to calculate the tank level curve. Where the equations for the calculation of the volume of the tank as a function of its height obtained from the reference [5] are related as follows:

$$V_p = D_i^3 C \frac{\pi}{12}\left(3\left(\frac{h}{D_i}\right)^2 - 2\left(\frac{h}{D_i}\right)^3\right)$$

Where C has a value of 1 according to the ASME code, for torispherical caps following ASME design standards [6].

$$C = 0.30939 + 1.7197\frac{R_k - 0.06D_o}{D_i} - 0.16116\frac{t}{D_o} + 0.98997\left(\frac{t}{D_o}\right)^2$$

By making the corresponding corrections we were able to obtain our new level curve for the horizontal tank found in the Plant #1 as shown in the figure #2.

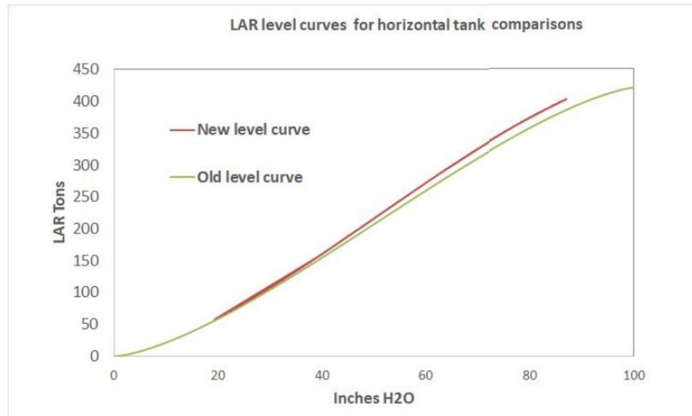


Figure#2 In this figure we can see the overestimation for the liquid contained in the tank where the difference% in weight was up to 14% approaching tank levels greater than 130 "of level water.

Tank level corrections for Plant #3

For the Plant #3 where the level was underestimated, corrections were made to the level table with justification of having a bad dimensioning of the geometry of the tank and consequently a bad calculation to obtain the real amount of tons for the product. The level curve with which it was working counted only the product contained in the body of the tank without considering the product in the caps of the tank.

In the Figure #3 we can see the comparison between the two different curves for the tank levels where we seen that the real amount is 16 tons higher than the last curve (around 4% of total capacity).



ANALIZE

In order to obtain the significant variables in the filling process for cryogenic liquids were made different calculations to obtain conclusions from the collected data for the wastes in a year.

The analyzed variables with their respective experiments are described below.

Pressurization on the road tankers

For this test, nine measurements from 3 different groups of road tankers were taken depending on their initial pressure. This test was made in order to assure if the process to depressurize the road tanker is followed, because if the road tanker is not depressurized before to make the measurement of initial weight this additional pressure can affect the weight measurement for the liquid product loaded to the supplier road tanker.

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
15 psi	9	13.641	1.51567	0.0077
20 psi	9	13.6833	1.52037	0.02663
30 psi	9	13.91	1.54555	0.01494

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.00465	2	0.00232	0.14147	0.8688	3.40283
Within Groups	0.39425	24	0.01643			
Total	0.3989	26				

With the previous results in spite of finding an ascending waste for more pressurized road tankers, we do not have enough evidence that the initial pressure of the road tanker is a variable that has an important role in the waste in the transfer of cryogenic liquids. This means that the operators depressurize the road tankers before starting the filling procedure.

Operators

With the intention of evaluate if there is indeed a significant difference in the case of the operators regarding the filling of road tankers, different tests were made considering the operator of each of the road tankers as we can see in the table below:

SUMMARY

Groups	Count	Sum	Average	Variance
	29	47.95765	1.653712	0.234543
	70	114.719	1.638843	0.408167
	35	62.18599	1.776743	0.656563
	8	12.43713	1.554641	0.279816
	22	41.90465	1.904757	0.266592
	76	122.0367	1.605747	0.319389
	80	135.0733	1.688416	0.288599
	55	91.87737	1.670498	0.562902
	103	184.6053	1.792284	0.611912
	17	30.05946	1.768204	0.845153
	13	24.16309	1.858699	0.303928

ANOVA

Source of Variatio	SS	df	MS	F	P-value	F crit
Between Group	3.615898	10	0.36159	0.811897	0.617315	1.849752
Within Groups	221.3458	497	0.445364			
Total	224.9617	507				

After performing this study in the same way, the operator is not a significant variable in the filling process. With this result we could conclude that the road tanker filling procedure is followed in the same way by all operators or not with a notable difference.

Net load filling

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
30-25	151	240.2286	1.590918	0.424033
25-20	300	512.684	1.708947	0.430326
20-15	101	183.589	1.817713	0.524532
15-10.	9	17.97803	1.997559	0.822597

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	4.01602	3	1.338673	2.967061	0.031514	2.620904
Within Groups	251.3063	557	0.451178			
Total	255.3223	560				

With the previous results we conclude with 95% certainty that filling road tankers with greater initial tons brings with it a greater waste. It can even be seen how the quantity of product to be packed decreases as the increase in tons of wasted cryogenic liquid increases.

Road tanker between suppliers

During the road tanker filling process there are different suppliers to whom the product is supplied as can be seen below where the A supplier represents 44% of the total road tankers and where the sum of the suppliers A, B and C represents more than 80% of the road tankers that are provided with service as we can see in the next Pareto diagram presented in the Figure #4.

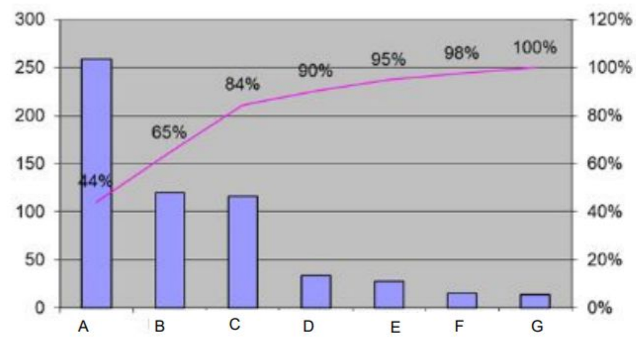


Figure #4 Pareto diagram

The supplier could represent a significant variable in the cryogenic liquids filling if they have particular road tankers that due to lack of maintenance causing leaks or in another particular cases where different valves do not work for where the gas part of the road tanker is placed and consequently its filling method becomes more robust and consequently higher waste. The above gives guidelines for a statistical study considering the road tankers in particular and not the supplier:

Anova: Single Factor

SUMMARY

Groups		Count	Sum	Average	Variance
TQ001		14.000	18.501	1.322	0.047
	6018	4.000	5.531	1.383	0.086
	1301	11.000	14.218	1.293	0.103
	1204	15.000	18.880	1.259	0.164
	1203	9.000	13.006	1.445	0.339
	1202	6.000	7.088	1.181	0.043
	1201	3.000	4.430	1.477	0.086
	1112	24.000	26.388	1.099	0.033
	380	8.000	9.828	1.229	0.053

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	1.234	8.000	0.154	1.558	0.150	2.049
Within Groups	8.414	85.000	0.099			
Total	9.648	93.000				

Although for this particular case we can observe a behavior that does not fully evidence that there is a difference in different waste by taking different road tankers. Personal experience indicates that it is a variable that must be monitored to conclude and discard the load of a road tanker that may present problems due to lack of maintenance.

IMPLEMENTATION

After evaluating the calculation of pressure and flow for the tank-pump-road tanker system and performing various operational tests for 1 month, the most efficient arrangement was obtained during filling, with the venting valve closed as long as possible.

The cryogenic product waste during road tanker filling was reduced to less than 1 ton and after making a mass balance for the plants it is concluded that with the new road tanker filling procedure reduces the liquid argon waste 40 tons per month as you see in the Figure #5:

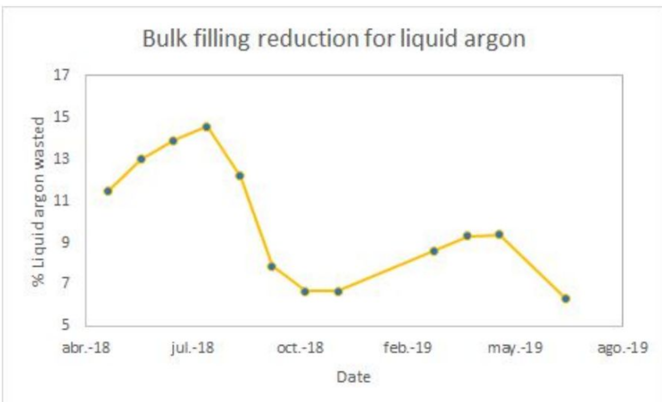


Figure #5 In this figure we can see the reduction for liquid argon wasted in the Plant #1.

CONTROL

Nowadays, the operators on the plants follow a new procedure about bulk filling for the road tankers. This procedure was made with technical support from operators, and supervisors to decrease the product wasted avoiding having opening in excess the purge venting valves on the road tankers. Considering the results from the data analysis we follow the next recommendations:

- Road tanker pressure assurance at 0 Psig
- More training for operators (with the new procedure).
- Promote the filling and the greater net load in road tankers, avoiding low net loads.
- Monitoring of supplier pipes for A and B vendors with their respective filling conditions.

CONCLUSIONS

This study was concluded with 95% certainty that the amount of cryogenic liquid to be loaded is a significant variable in the waste of the loading process as opposed to the initial pressure of the road tanker (always if the road tanker is depressurized before taking the initial measurement to calculate the total amount loaded) and operational variables such as operators and procedures.

Was very important to study the different factors to prevent having a large product waste during loading and downloading road tankers with cryogenic liquid because this can prevent drastic economic losses, avoid installation damage and assure the people's safety.

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