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

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***Abstract–** This study was made in order to identify the significant process variables in cryogenic liquids trucks filling with the intention to avoid product losses caused by a high vent valve flow to depressurize the truck tank during the cryogenic liquid filling process. The analyzed variables were an incorrect filling operation process including a high flow rate in purge vent valve, the initial truck pressure as well as the quantity of product loaded. The study begins by solving the initial problem that is to have an incorrect measurement caused by a not adequate method to calculate the level in cryogenic storage tanks. The results of this work were a measurement reliability improvement for the levels in horizontal cryogenic tanks of two plants, a reduction of 50% of the losses in trucks filling with liquid argon as well a total reduction for liquids of nitrogen and oxygen wasted (30 tons / month for each product). The total reduction for N_2 and O_2 liquids allows to avoid hazardous atmospheres (Levels below 19.5% are considered oxygen-deficient) for the operators and people on site due to avoid a complete reduction from venting valve flow to the atmosphere. After different statistical analysis, It can be 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*

INTRODUCTION

This document specifically covers the loading and unloading operations for liquid oxygen, nitrogen and argon (cryogenic 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 to 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 truck trailer is adequately equipped with over-pressurization protection and the fill connections are suitable for the product to be filled.

A common problem with the product wasted calculation 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 the storage unit. If the method of calculating the quantities delivered involves the density of the product, the error may be significant.

Any of the different typical problems caused by a wrong measurement in cryogenic liquids in storage tanks are the risks that exist to believing that there is a higher level than it really is, it is putting the pumping system at risk (if any exists) at the moment that the suction flow 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 show the significant variables in the cryogenic liquid filling process that affect the amount of product wasted using ANOVA. Traditionally, ANOVA is the statistical analysis approach employed to test research hypotheses [7].

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 their contribution in the road tankers filling waste. However, it is necessary to solve typical problems on the tank levels quantification. Because in the losses analysis quantification could be found incongruities for product losses due to an incorrect tank levels measurement.

MEASURE

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

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

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

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

The mass balance for tanks is presented below:

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

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

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

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.

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

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

$$tf - t0\,(E - C) = A_f - A_o \quad \textbf{(6 and 7)}$$

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

Quantification of losses

The losses quantifications were obtained with the previous equations for three different plants using a sample of 47 measurements as is shown in table #1.

Summary

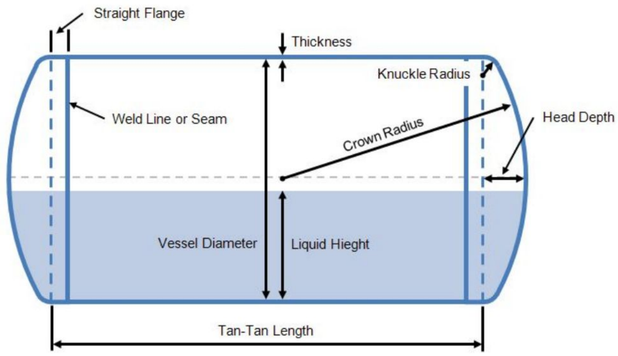
Plant	Count	Sum	Average	Variance
Plant #1	47	-27.188	-0.578	0.371
Plant #2	47	45.091	0.959	0.273
Plant #3	47	217.02	4.617	0.178

Table #1. Losses quantification for 47 different samples of road tankers filled in three different plants.

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

Tank level measurement corrections for Plant #1

The first method to know a possible discrepancy between the level measured with the real level value is comparing the tank specifications with a level measurement by the installed tank sensors. The technical tank specifications specify a maximum level of 154.77 tons while the installed sensor measurement is 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 shown in figure #1.



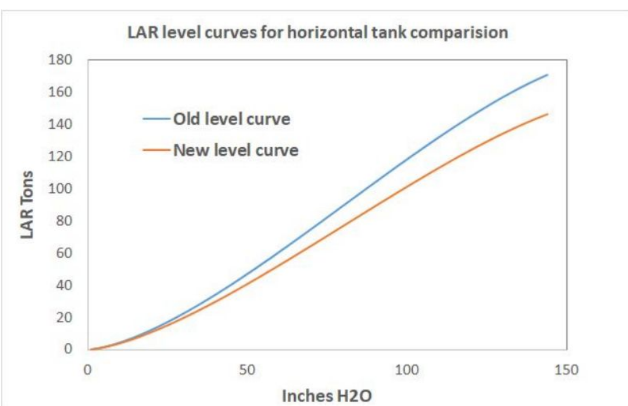
Figure#1 Design elemental parameters to calculate the tank level curve. Where the equations for the calculation of the volume of the tank as a function of its height obtained from the reference [5] are related as follows:

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

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 horizontal tank level curve as is shown in figure #2.

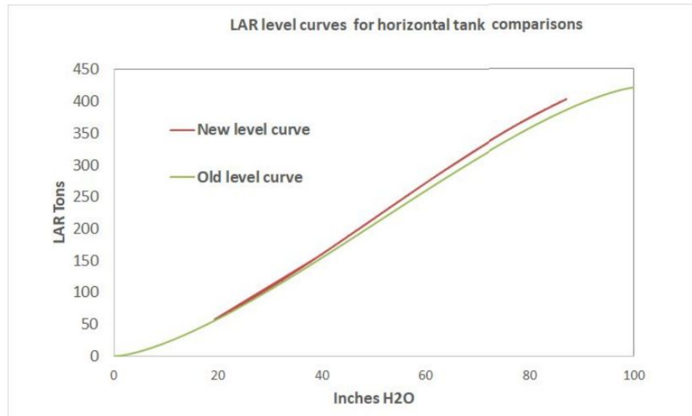


Figure#2 In this figure is shown the overestimation for the liquid contained in the tank where the difference% in weight was up to 14% approaching tank levels greater than 130 "of level water.

Tank level measurement corrections for Plant #3

In Plant #3 The curve level was underestimated, corrections were done to the tank level tables due to an incorrect geometry dimensioning to the tank and consequently a wrong calculation to obtain the real amount for product losses. The incorrect level curve has taken into account only the product contained in the tank body without considering the product in the tank caps.

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



ANALIZE

In order to obtain the significant variables to make the filling process for cryogenic liquids, different calculations were made to obtain conclusions from the data collections to calculate 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 ensure if the road tanker depressurization procedure is followed correctly, because if the road tanker is not depressurized before to make the measurement of initial weight this additional pressure can affect the weight measurement to the liquid product loaded to the customer.

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 to have 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.

Plant Operators

With the intention to evaluate if there is indeed a significant difference in the operators case 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:

Anova: Single Factor

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 it can be concluded 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.

Customer's road tanker

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

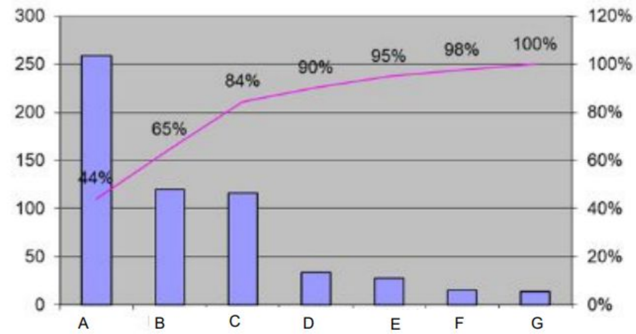


Figure #4 Pareto diagram

The customer's tank trailer can represent a significant variable in the cryogenic liquids filling due to lack of maintenance. The maintenance missing can generate leaks or failure in different isolation valves. The above gives guidelines to have a statistical study considering the customer's tank trailers as is shown below.

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				

In this particular case the customer's road tankers do not show strong evidence to be a significant variable to the cryogenic liquid filling losses. However, personal experiences indicate that a truck tanker is a variable that shall be monitored to reduce the losses on the road tanker loading.

IMPLEMENTATION

Lastly, a flow and pressure calculation were made to the pump-road tanker system and performing different operational changes during 1 month where the venting purge was closed as long as possible and obtaining a reduction to less than 1 ton per filling process. It was concluded that the new road tanker filling procedure reduces the liquid argon waste 40 tons per month as is shown in Figure #5:

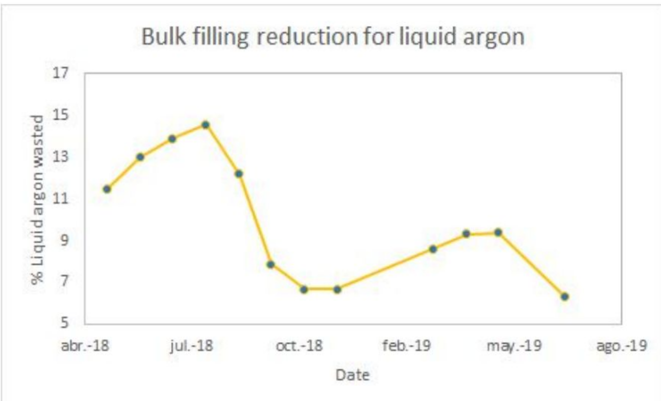


Figure #5 In this figure is shown the reduction for liquid argon wasted in the Plant #1.

CONTROL

Nowadays, the plant operators follow a new procedure to the road tankers filling. This procedure was made with technical support from operators and supervisors in order to decrease the cryogenic liquid losses avoiding an excessive opening in depressurization purge venting in road tanker valves. Considering the results from the data analysis we follow the next recommendations:

- Road tanker pressure assurance at 0 Psig
- More plant operators training (using the new procedure).
- Promote the filling and the greater net load in road tankers, avoiding low net loads.
- Customer's road tankers monitor in order to identify the complete equipment including isolation valves and liquid and gas enterings to road tankers.

CONCLUSIONS

This study was concluded with 95% certainty that the amount of cryogenic liquid to be loaded is a significant contributor in the cryogenic liquids process filling losses as opposed to the road tanker initial pressure (considering an adequate depressurization method done before to measure the initial weight to the road tanker) and operating variables such as operators and clear procedures.

Was very important to study the different variables in order to avoid large tons of cryogenic liquids losses during loading and downloading road tankers because this prevents drastic economic losses, avoid installation and equipment damage and ensure the people's safety.

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