# AN INNOVATIVE WAY OF REDUCING BOG ON EXISTING OR NEWBUILT LNG STORAGE TANKS

Damien Féger
New Generation Natural Gas Natural Growth
D.feger.NG3@gmail.com
www.ng3.eu

## ABSTRACT

Present, state of the art, LNG storage tank use expanded silica and glass wool as insulation materials on, respectively, the tank side and ceiling. When the tank is in operation, these insulations volumes are filled with the natural gas vapors coming from the LNG, at the same pressure as the LNG.

This paper presents an innovative solution to improve the thermal performance of this insulation by filling these insulation volumes with argon gas, which has a much lower (40 %) thermal conductivity, with minimal changes in the tank design, as argon, much heavier than natural gas vapors, is simply trapped in these volumes by gravity. The required design changes are respectively negligible (to inject argon in the side insulation spaces using the existing dry nitrogen injection piping) to minute (modification of the suspended ceiling to trap argon gas), making this innovation possible as a retrofit action.

Beyond the immediate operational gains linked to the reduction of BOG rate, this innovation can generate significant capital expanse savings by reducing the requirements on the BOG recompression systems.

It describes how this change can be implemented on existing and on new built tanks with:

- a review of the technical requirements and operational constraints;
- a description of the argon supply system;
- an assessment of the corresponding economical and environmental benefits both for a liquefaction plant and a regas terminal;
- an analysis of the corresponding impacts and benefits on safety and on terminal operations;
- a detailed case study on a new built and an existing tank.

## INTRODUCTION

**State of the art**

The typical configuration of LNG land based storage tanks is given in Figure 1. The LNG is contained in a open cryogenic grade nickel steel alloy circular tank.

- The bottom of the tank is supported by a layer of pressure resistant insulationmade of cellular glass blocks;
- The Side of the tank is surrounded by a layer of glass wool and a volume filled with expanded glass foam (expanded silica)
- The top of the tank is covered with a suspended roof which is insulated by a layer of glass wool
- The whole system is surrounded with a gas tight reinforced concrete envelope.

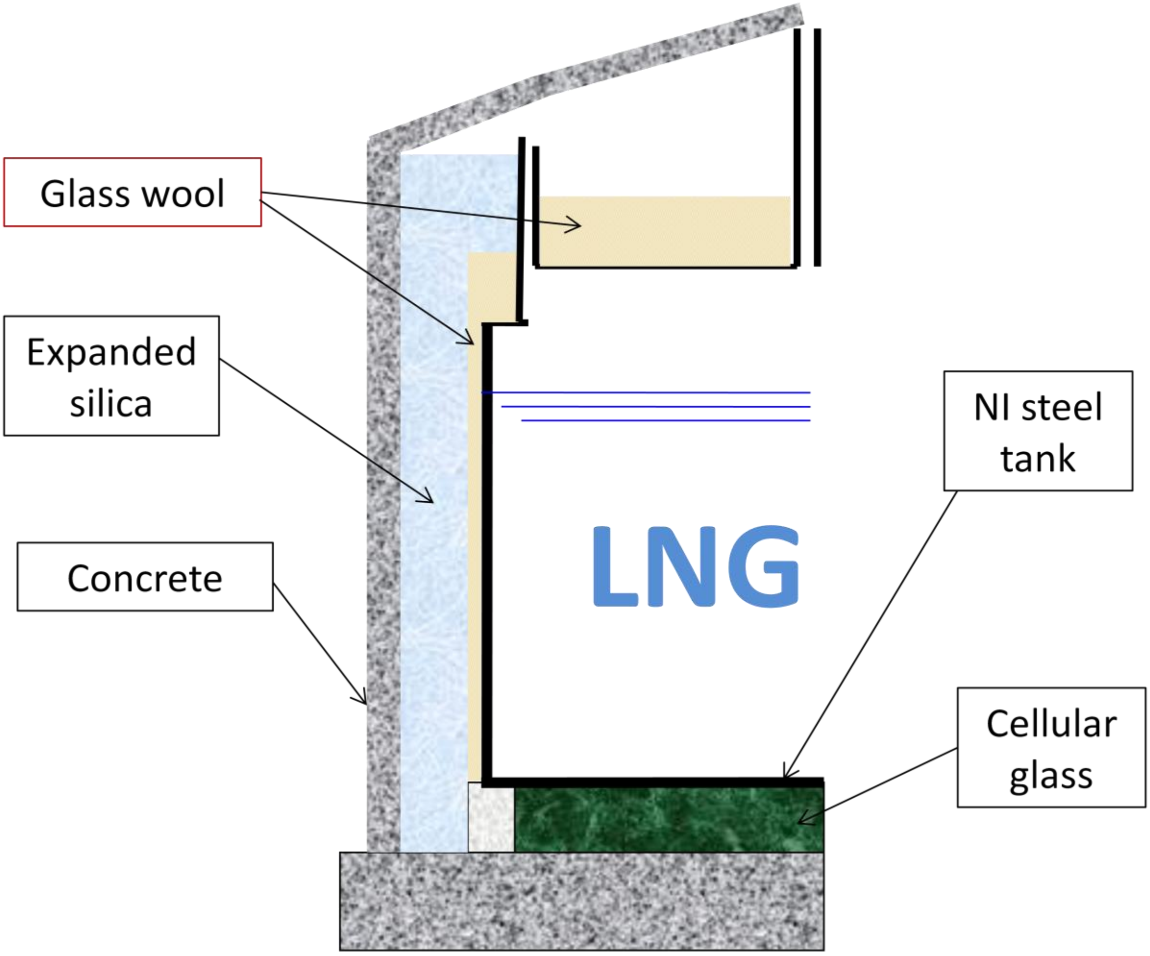


**Figure 1: Typical LNG storage tank configuration**

When the tank is in operation, the side and upper insulation volumes are filled up with the natural gas vapors and the corresponding heat transfer can be considered to be limited to the thermal conductivity of methane gas, convective and radiant thermal exchange being blocked by the glass wool and the expanded silica. Based on this design approach, the typical heat entries into the cargo are split in three equal parts:

- 1/3 through the roof insulation
- 1/3 through the side wall  insulation
- 1/3 through the tank bottom insulation

Depending on tank size, contract requirements and detailed design strategy, resulting  typical boil off rate is 0,05 % /day. Although this has been considered as acceptable  by the industry so far, there are, nevertheless, significant environmental and economical benefits to reduce it further and the purpose of the .present paper is to present an innovative solution to achieve it, by filling the side and top insulation volumes of the tank with argon instead of natural gas vapors.

- **PROPOSED INNOVATION**

**What is argon?**

Argon is the most common "rare" gas and constitute 0,94%  of ambient air composition. As such, it is a widely available industrial commodity, produced as a by-product of air separation plants, which are usually mostly aimed at nitrogen or oxygen production. It can be delivered in compressed or liquefied, bulk, form.

It is mainly used in numerous industries on a routine basis for its inert and thermal properties, such as the filling of the insulation spaces in double glazed windows.

Figure 2 illustrates the main reason of interest of argon in the present case, showing the difference of thermal conductivity of argon compared to methane and nitrogen gas.

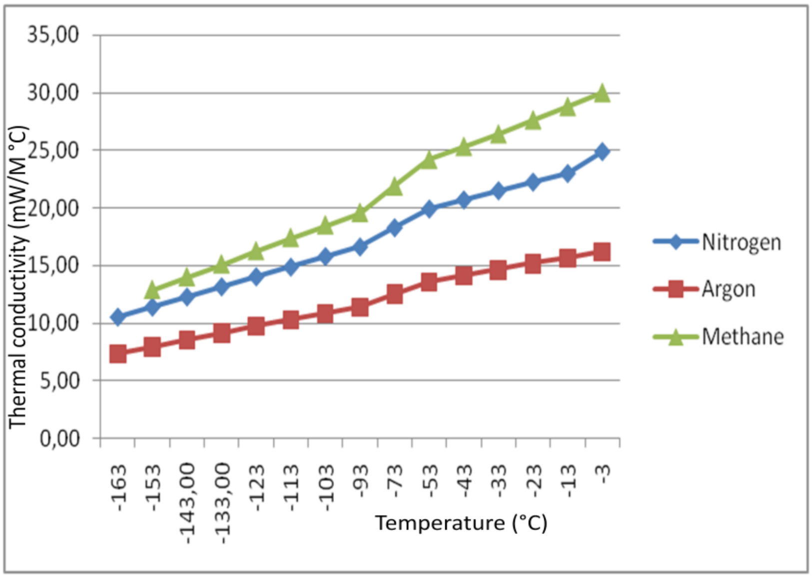


**Figure 2 : Nitrogen, Methane and nitrogen thermal conductivity**

Other argon properties of interest for this application are :

- like nitrogen, it is an inert  gas;
- its liquefaction point (- 185 °C ) is well below LNG temperature (-160°C);

- its molecular weight (39,95 g/mole) is much heavier than the one of methane (16,04 g/mole) of nitrogen (28,01 g/mole)

Therefore, replacing natural gas vapors by argon in the side and top tank insulation volumes is possible and shall reduce their thermal conductivity by around 40 %.

Implementation

Figure 3 shows a typical way of filling an LNG storage tank top and side insulation spaces with argon, taking benefits that argon is much heavier than natural gas vapors to trap it in these volumes by gravity effect, while, at the same time, providing an open communication between all these volumes and the tank dome, so that pressure differences remain minimal during tank operations.

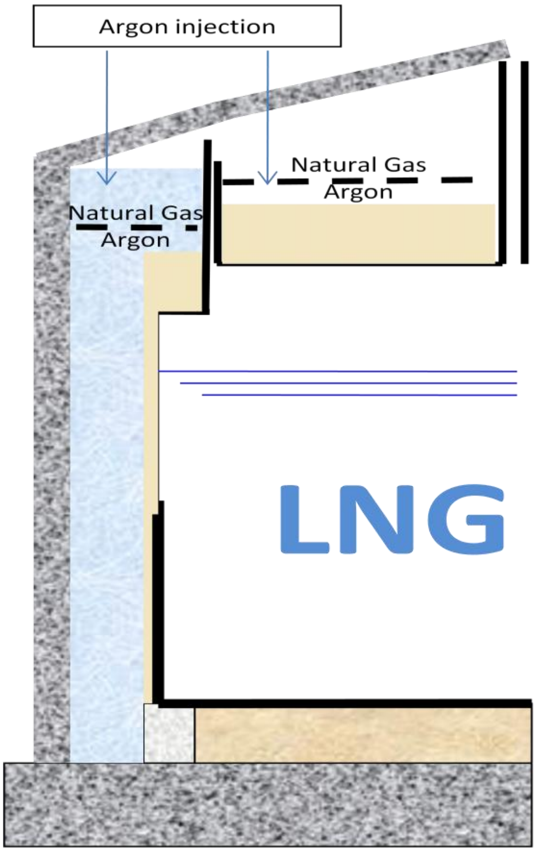


**Figure 3 : Typical LNG storage tank argon insulation implementation**

One will note that the required tank design changes are minimal, if any:

- without any design changes side wall volume will trap argon by gravity , and existing pipes, such as the one used to flush expanded silica with dry nitrogen, prior first tank filling with LNG, could be used to inject argon in these volumes. By gravity effect, the much heavier argon will displace the natural gas vapors out of the expanded silica and glass wool volumes and remain trapped between the side concrete and the NI steel tank side walls. One will note that as no operation is needed inside the tank, this argon replacement can be performed as a retrofit action, without even interfering with tank routine operations.

- for the suspended deck insulation volume, the only design changes will be to make the suspended deck gas tight so that , here gain, the argon gas will remain trapped by gravity effect inside the glass wool volume. Such modification are expected to be straightforward for a new built case. Here again any existing pipe through the roof can be used to inject argon gas above the suspended deck.

During tank operations, the pressure in the gas dome and the temperature in the insulation spaces is expected to fluctuate, so the argon trapped in the insulations volumes will either contract or expand accordingly. The frontier between the volumes filled with argon and the natural gas vapor dome will therefore move up and down (or “breathe”), the upper part of the insulation volumes acting as buffer volumes.

One will note that if too much argon is injected, the excess argon, once the side and top insulation volume have been filled up, will just overflow into the gas dome and will be either vented with the BOG flow or will fall and get dissolved into the LNG contained in the open top NI steel tank, without any significant consequences as these quantities will remain negligible compared to the LNG tonnage.

**Assessment of economical and environmental gains**

If natural gas vapors are replaced by argon in the the top and side insulation volumes of a given storage tank, the resulting reduced heat entries can be estimated the following way compared to the initial conditions :

- 33 % ➔ 20 % though the roof insulation
- 33 % ➔ 20 % through the side wall insulation
- 33 % unchanged through the tank bottom insulation

The resulting BOG rate can therefore be estimated to be reduced to around 75 % of the initial one (one will note that, in the case of a retrofit case, were only the side wall insulation spaces are filled with argon, the BOG expected reduction would be down to 85 %, which is already quite significant) .

In the case of a liquefaction plant, storage tank BOG is a direct loss in the overall efficiency of the plant, as this BOG, will be, usually, recycled as fuel gas rather than being delivered as export cargo to the LNG carriers.

As illustrated in figure 4, this 25 % new built storage tank BOG reduction opportunity can be used in, at least, two different ways, considering an initial 0,4 % storage tank BOG.

- Either keeping the same LNG output , it allows to reduce feed gas flow , by around 0,1%
- Either, increasing by 0,1 % the feed gas flow, to match the BOG reduction flow which cannot be used as fuel, it allows to increase the export quantities by 0,1%

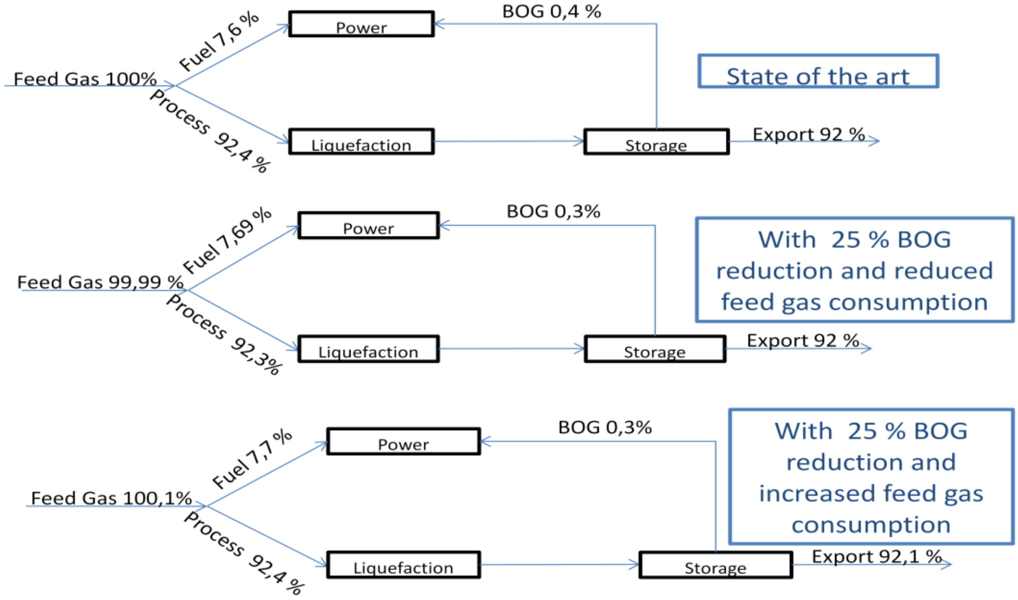


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**Figure 4 : Benefit for liquefaction plant process flow**

In both case, emissions per tons of export LNG are reduced. The second solution being , if increasing the feed gas flow is technically possible, the most attractive solution as it allows to increase the export quantities and directly monetize the gain brought by the BOG reduction.

For regas terminals, the gains are more limited, as the BOG is usually re liquefied at low pressure by mixing it with the LNG emitted towards the network…as long as the terminal BOG compressors can match the terminal BOG flow which may fluctuate a lot during transient operations, such as LNG piping cool down or LNGCs cargo unloading operations;;;to avoid any flaring.

Gains have therefore to be assessed more on a case by case basis, depending on the terminal operating profile and BOG compressors capability. In case of a new terminal, storage tank BOG reduction could allow, as well, to reduce the sizing of these compressors and drive down the corresponding investment…

Another potential benefit that we did not investigate by lack of operational data, would come from the reduced heat entries into the cargo which will slow down the “aging “ of the LNG cargo during long storage periods…

**Impact on safety and operations**

From safety point of view, main risk brought by argon is the risk of anoxia, but as argon presence is only expected either in open space or inside the tank itself, this risk is expected to be very remote.

Argon filling, monitoring and top up operations are very similar to the one required, for example, for inerting operations using nitrogen, so the application of the corresponding safety procedures to argon operations, should lead to a very low level risks.

On the other side, filling the side wall insulation volume of LNG storage tank with argon inert gas brings a safety benefit to the installation with regard to the risk of creation of explosive atmosphere in case of leakage through the outer wall side concrete envelope.

In the same way, the reduce heat entries will reduce the risk of turn over, which may cause dame, among others ,to the suspended deck.

Typically the initial argon charge can be delivered by one or two truck of liquefied argon in bulk. Filling operations would take, typically a week, depending, among other things, on the diameter and distributin of the pipes available for injection and the time required to displace the natural gas vapors out of the expanded silica and glass wool volumes.

During tank nominal operations, argon losses may occur, for example due to leaks through the outer concrete wall, the suspended roof or by entrainment with the NG BOG. To compensate this, argon refilling may be necessary either by a site small liquefied argon storage tank or by a set of high pressure cylinders…

Monitoring of the argon level in the insulation volumes can be done by sampling tubes which combined with a gas analyzer can be used y the terminal operator to assess on, typically, a monthly basis, the extra “top up” argon quantities required.

Due to the order of magnitude of the total argon and LNG quantities (typically around 40 tons of argon for a 70 000 tons storage tank!) entrainment of argon into the storage BOG flow or dissolution with the LNG , if it occurs will not significantly affect the cargo composition.

**Case study and conclusion**

Table 1 gives a summary of the estimated environmental and economical gain to be expected in the case of a liquefaction plant 175 000 $m^3$ new built LNG storage tank, assuming typical Capital and Operational expenses (including royalties to have access to this innovation) as well as, among other things, LNG and feed gas values.

It shows that return on investment can be extremely fast, typically less than a year, even without considering potential added value provided by CO2 emissions permits.

In this case, an extra capacity of 3610 tons of LNG production per year would be generated for a capital expense of 330 000 USD.

This brings the TPA /CapEx ratio to 91 USD per ton per annum, while typical value for present liquefaction project are as high as 600 USD per ton per annum…making the proposed solution an attractive, safe, and profitable solution with a very short return on investment.

Table 2 gives similar estimate for the retrofit case, were only the side wall insulation is filled with argon. Although the TPA/ CapEx ratio is slightly higher, up to 120 USD USD per ton per annum, it is still very competitive… as illustrated by a return on investment of just above one year…

In both cases, the proposed innovation can therefore be considered as attractive both for new built and retrofit cases, from environmental and economical point of view. Not a big surprise when one consider that argon filled insulation is used on a routine and profitable basis for double glazed windows where the difference of inside and outside temperature is up to 10 times lower than in LNG storage tanks!

To meet the general requirement of reducing by 40 % $CO_2$ emissions in the coming decades, the LNG industry, like all mature industry will have to implement numerous emissions abatement solutions such as :

- increased energy efficiency
- alternate power sources
- $CO_2$ sequestration
- Buying emissions permits…

No doubt that, in this context such BOG reduction opportunity, which is both environmental friendly and cost effective, should be considered as one of the lowest hanging fruit to grab!

**Table 1. Case study for a new built 175 000 $m^3$ liquefaction plant storage tank**

| | | | | | |
|---|---|---|---|---|---|
| **Hypothesis** | | | | | |
| LNG Storage tank | | | capacity | 175 840 | m3 |
| | | | density | 450 | kg/m3 |
| Insulation volume : | | | | | |
| | Side wall | | | | |
| | | Height | | 35 | m |
| | | Inner Diameter | | 80 | m |
| | | Outer diameter | | 82 | m |
| | | Volume | | 8 792 | m3 |
| | Roof | | | | |
| | | Surface | | 5 024 | m2 |
| | | Thickness | | 0 | m |
| | | Volume | | 2 010 | m3 |
| total insulation volume | | | | 10 802 | m3 |
| Average side insulation temperature | | | | 200 | K |
| Average roof insulation temperature | | | | 200 | K |
| Average Argon vapor density | | | | 3,50 | kg/m3 |
| Average Methane vapor density | | | | 0,33 | kg/m3 |
| Quantity of required argon | | | | 37 806 | kg |
| Quantity of displaced methane | | | | 3 601 | kg |
| Argon cost : | | | | 800 | USD/ton |
| Methane value : | | | | 200 | USD/ton |
| **CAPEX** | | | | | |
| Argon unit CapEX | | | | $100 000 | |
| Argon instrumentation | | | | $100 000 | |
| Engineering | | | | $50 000 | |
| Royalties | | | | $50 000 | |
| Argoncost | | | | $30 244 | |
| CH4Saving | | | | -$720 | |
| | | **TOTAL CAPEX** | | **$329 524** | |
| **OPEX** | | | | | |
| Maintenance | (5% of CapEX) | | | $16 476 | |
| Royalties | | | | $50 000 | |
| | | **TOTAL OPEX** | | $66 476 | |
| **Gains** | | | | | |
| Initial BOG | | | | 0,050% | /day |
| BOG reduction | | | | 25% | |
| New BOG | | | | 0,038% | /day |
| Reduced BOG per Year | | | | 3 610 | tons/year |
| Feed Gas value | | | | 50 | USD/ton |
| LNG Value | | | | 200 | USD/ton |
| Extra Value of Exported LNG | | | | $541 532 | /year |
| Net Value | | | | $475 056 | /year |
| | | | **ROI** | **8,3** | **months** |

**Table 2. Case study for a retrofit 175 000 m$^3$ liquefaction plant storage tank**

| | | | | | |
|---|---|---|---|---|---|
| **Hypothesis** | | | | | |
| LNG Storage tank | | | capacity | 175 840 | m3 |
| | | | density | 450 | kg/m3 |
| Insulation volume : | | | | | |
| | Side wall | | | | |
| | | Height | | 35 | m |
| | | Inner Diameter | | 80 | m |
| | | Outer diameter | | 82 | m |
| | | Volume | | 8 792 | m3 |
| | Roof | | | | |
| | | Surface | | 0 | m2 |
| | | Thickness | | 0 | m |
| | | Volume | | 0 | m3 |
| total insulation volume | | | | 8 792 | m3 |
| Average side insulation temperature | | | | 200 | K |
| Average roof insulation temperature | | | | 200 | K |
| Average Argon vapor density | | | | 3,50 | kg/m3 |
| Average Methane vapor density | | | | 0,33 | kg/m3 |
| Quantity of required argon | | | | 30 772 | kg |
| Quantity of displaced methane | | | | 2 931 | kg |
| Argon cost : | | | | 800 | USD/ton |
| Methane value : | | | | 200 | USD/ton |
| **CAPEX** | | | | | |
| Argon unit CapEX | | | | $80 000 | |
| Argon instrumentation | | | | $80 000 | |
| Engineering | | | | $30 000 | |
| Royalties | | | | $50 000 | |
| Argoncost | | | | $24 618 | |
| CH4Saving | | | | -$586 | |
| | | **TOTAL CAPEX** | | **$264 031** | |
| **OPEX** | | | | | |
| Maintenance | (5% of CapEX) | | | $13 202 | |
| Royalties | | | | $50 000 | |
| | | **TOTAL OPEX** | | $63 202 | |
| **Gains** | | | | | |
| Initial BOG | | | | 0,050% | /day |
| BOG reduction | | | | 15% | |
| New BOG | | | | 0,043% | /day |
| Reduced BOG per Year | | | | 2 166 | tons/year |
| Feed Gas value | | | | 50 | USD/ton |
| LNG Value | | | | 200 | USD/ton |
| Extra Value of Exported LNG | | | | $324 919 | /year |
| Net Value | | | | $261 718 | /year |
| | | | **ROI** | **12,1** | **months** |