ENERGY CONSUPTION, DESTRUCTION OF EXERGY AND BOIL OFF DURING THE PROCESS OF LIQUEFACTION, TRANSPORT AND REGASIFICATION OF LIQUEFIED NATURAL GAS

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Abstract. *A supply chain of Liquefied Natural Gas (LNG) is composed by several processes like extraction, purification, liquefaction, storage, transport, regasification and distribution. In all these stages, processes need of energy. The main objective of this work is to quantify the energy consumption, mass loss and exergy destruction occurred throughout the chain. Results show that the process of liquefaction is the largest consumer of energy. Storage and transport by ship are responsible for the bigger mass losses and regasification is the process of larger destruction of exergy. A case study is performed considering a stream of pure methane at the input of a liquefaction plant, and evaluates energy along the chain, ending up at the distribution of NG after its regasification.*

Keywords*: Liquid Natural Gas, LNG, LNG Regasification, LNG Transportation, LNG Boil Off..*

1. INTRODUCTION

Among the fossil fuels, Natural Gas (NG) has the lowest ratio of greenhouse gas emitions per electric energy production, reduction environment impact and allowing to run more efficient power generation systems. These advantages lead to a significant increase of NG consumption in recent years (Lu and Wang, 2008). Furthermore, technological developments on liquefaction of NG, together with advances in transport, caused the liquefaction costs made drop dramatically, pushing the Liquid Natural Gas (LNG) industry *(Pertusier, 2003; Acunha Júnior et al., 2008).*

The supply chain of LNG consists of a sequence of activities, also called production chain, which has basically four main stages: exploration and production of natural gas (E&P), then the process of liquefaction, transport to the terminals of import and, finally, the regasification services. During these stages, there are other minor significance, such as, purification, pumping, storage of LNG in tanks and lastly, compression of NG for distribution, which shall be treated in isolation in this study. In all these stages there is the need for energy, destruction of exergy or losses of mass, which will be study separately at each stage.

Natural gas (NG) is a nontoxic, colorless, odorless, and noncorrosive fossil fuel. It contains mainly methane (about 90%), ethane, propane, butane, and traces of nitrogen and carbon dioxide. Natural gas is the “natural” choice among fossil fuels. It is the cleanest fossil fuel with abundant proven reserves. Although it is a greenhouse gas with an effect that is 22 times greater than that of CO_2, it has the least CO_2 emission per unit energy and releases 1.9 times less CO_2 than coal.

Faced with the fast depletion of crude oil reserves, high oil prices in recent times, stringent environmental restrictions on CO_2 emissions, trends to diversify the energy supply, barriers to the development of feasible renewable energy sources, etc., countries are now moving toward NG as their major and/or alternate source of fuel to supplement energy demand and curb the over dependency on oil. In the U.S., about 10 000 companies explore, produce, transmit, and locally distribute NG, with a combined annual revenue of 100 billion USD. The investment on NG will equal to the oil (19% of the total energy investments) and the cumulative spending on NG supply infrastructure will rise by 3.9 trillion USD over the course of 2001-2030. Currently, NG is the world’s fastest growing energy commodity and the third largest primary energy source after crude oil and coa. In 2007, NG consumption was 2637.7 million tons oil equivalent, or about 23.8% of the total primary energy consumed worldwide. The usage is estimated to increase by nearly 52% between 2005 and 2030. It is also the fastest growing and second-largest energy source for electric power generation, producing 3.4 million GW in 2005 with a projection of 8.4 million GW in 2030. NG-fired combined cycle generation units have an average conversion efficiency of 57%, compared to 30-35% efficiency for coal. *(Natural Gas Production and Distribution, First Research, Inc.: Austin, TX, 2008)*

Most NG reserves are offshore and away from demand sites. The storage and transportation of NG is a critical technology and cost issue. Pipelines represent a security risk and are not always feasible or economical. They are often limited by a limited amount of NG that can be transported. Alternately, an attractive option is to liquefy NG at -163 °C at the source and then transport it as liquefied natural gas (LNG) by specially built ships or tankers that are essentially giant floating flasks. When liquefied, the volume of natural gas reduces by a factor of about 600 at room temperature, which facilitates the transport of NG. In fact, LNG is the most economical way of transporting NG over distances more than 2200 miles onshore and 700 miles offshore *(Thomas, S et. Al. 2003)*. LNG provides an excellent example of design for logistics. Because major end user markets of Asia, Europe, and North America are thousands of miles away from the major exporting countries such as Indonesia, Qatar, Trinidad, etc., LNG is becoming an increasingly global energy option and considered as the fuel for the future. In 2007, 226.41 billion m^3 of NG was transported as LNG, result a total LNG movement of about 165.3 million tons per year (mtpa). As an alternate fuel, the demand of LNG is doubling every 10 years. A growth rate of 6.5% per year is expected for LNG in the near future, which would be the fastest growth for any energy activity or product worldwide. Singapore has already recognized the value of LNG with the construction of the receiving terminal that will start operation by 2012. The major factors behind recent increase in LNG demand include tendency to diversify energy sources for better energy security, decrease in LNG supply chain costs, new technology LNG tankers, increase in spot transactions, etc. More than 90% of the feed heating value in a modern LNG plant is shipped as product LNG. With many higher throughput LNG trains being built in Qatar, Egypt, Iran, Russia, and Trinidad, global liquefaction and regasification capacity is expected to double between 2006 and 2010 *(Lee, H. L. et. al. 1993).*

The supply chain of LNG includes exploration and production of natural gas, liquefaction, marine transport, storage and regasification. Usually natural gas is produced at high pressure and then supplied to the liquefaction plant, where it is transformed into LNG. The liquefaction plant consists of several parallel processing modules called trains. Once LNG is produced, it is stored in cryogenic tanks from where it is loaded into the tankers. An LNG tanker is a ship with heavy insulation, and transports to the customer side at its boiling point of -163 °C at atmospheric pressure. On arrival at the receiving terminal, the liquid is stored and then regasified in regasification plants. Finally, it is supplied to the pipeline network for distribution among the consumers.

The supply chain of LNG is capital intensive, mainly due to cryogenic liquefaction and transportation. These represent nearly 85% of the cost of delivering LNG to the customer’s jetty. Although LNG supply chain has been considered as costly and rigid since the early days, recent improvement in liquefaction technology and cryogenic transportation is transforming LNG into an increasingly favorable energy commodity for both developed and developing countries. Moreover, LNG tanker operation is getting more and more competitive, as there is a significant increase of ownership of tankers among LNG buyers, sellers, and third-party logistics providers in recent years. An LNG tanker includes a cryogenic cargo containment system with proper tank support, double hull structure, secondary barrier, etc *(Michel, V. et. al. 2001).*

Due to its cryogenic nature, LNG is continuously vaporized and lost as boil-off gas (BOG) during storage and transportation. The amount of BOG depends on the design and operating conditions of the LNG tanks and ships. Depending on the insulation and sea conditions, a boil-off rate of about 0.1-0.15% of the full cargo content per day is typical over a 21-day voyage. While the boil-off rates vary significantly with different voyages, the amount of BOG produced in a typical voyage can be as high as 2-6% of the total cargo depending on the voyage duration. Considering the total LNG movement of 165.3 mtpa in 2007, at least 3.3 mtpa of LNG were lost due to boil-off during transportation only. This amount is close to the annual capacity of a large base-load LNG train. At the average price of 7.73 USD per million BTU in 2007, the cost of this cargo BOG loss exceeds 1.275 billion USD *(Grose, L. et. al. 2007).*

In addition to the loss during the voyage from an export to an import terminal, called the laden voyage, the return voyage of the tanker, called the ballast voyage, also incurs additional boil-off loss. During the ballast voyage, a small amount of cargo, called heel, is retained inside the cargo tanks to maintain them at their normal carrying temperature of -163 °C. The US Code of Federal Regulations (2008) defines the heel as the minimum quantity of LNG retained in an LNG ship after unloading at an LNG terminal to maintain temperature, pressure, and/or prudent operations. The heel may also be used to spray the tanks to cool them for the next loading of LNG. Without heel, the cargo tanks would get warm and excess flash boil-off would occur at the start of next loading. The boil-off losses can be 10-50% of the heel in a ballast voyage. Therefore, it is important to study the boil-off during LNG transportation.

However, all these studies are generally meant for the design of storage tanks and liquefaction of LNG. The different factors and their interplays make it complex to estimate and/or compute the boil-off beforehand for different voyages. The usual practice is to use a try-and-see approach to minimize or control boil-off from LNG tanks. However, a detailed simulation study on energy consumption, destruction of exergy and boil-off for LNG supply chain is still missing in the literature to our knowledge.

In this article, energy consumption, destruction of exergy and boil-off in LNG is estimated along the supply chain. Several factors that affect the energetic, exegetic and boil-off processes are identified and quantified, for further simulation of the entire roundtrip journey of methane in the entry of regasification process to an import terminal, takeing into account the regasification process and compression station. Work begins at the liquefaction process, after a discussion of the major factors affecting boil-off, and study of regasification process Then, a simulation of a case study is presented.

2. SUPPLY CHAIN OF LNG

The Figure 1 shows the proposed supply chain of LNG in details. Streams of mass and energy are depicted, taking into account that the supply chain begins right after the extraction pit of Natural Gas, where methane (CH_4) is separated from the other components of the mixture, and CH_4 is pressurized to be send to the liquefaction process, where it is again purified. Liquefaction is achieved at a temperature of about – 163ºC, demanding a high amount of energy, and it is labeled as Liquefied Natural Gas (LNG), although being pure methane. At that point, LNG is ready for delivery overseas. The last procedure to be considered in the proposed chain is the LNG regasification process, performed with the aid of external heat from sea water.

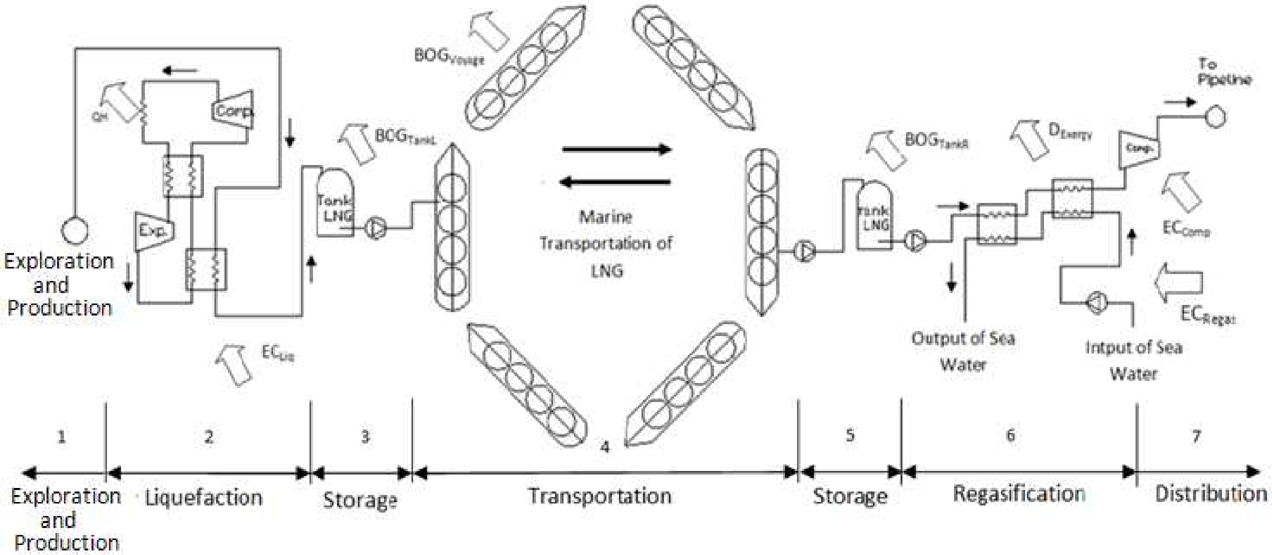

Figure 1. Supply Chain of LNG

A successive compression and expansion process is on the base of the CH_4 liquefaction, and the energy demand is indicated by EC_{Liq}. After liquefaction, CH_4 or LNG is stored in isolated tanks, with a volumetric capacity that exceeds the one of the ships. Heat gains, due to the high temperature difference between LNG and the external environment, promote a continuous evaporation called boil off (*BOG*), observed at several processes along the LNG supply chain (Fig. 1). The most significant boil off amounts occur at the liquefaction tank BOG_{TankL}, at the regasification tank BOG_{TankR}, and along the overseas transportation BOG_{Transp}. The number of ship is such that the process can be ideally considered as continuous.

At the delivery harbor, LNG is discharged to a storage tank and then regasified. This last process, although helped by the external environment conditions, needs extra energy (EC_{Regas}) to achieve high rates of phase change.

In this work, energy consumption involving both the Production and Exploration process and overseas transport are not quantified.

A case study is proposed here to assess the energy demands of the described supply chain. A prescribed input stream of 126,42 kg/s pure methane was defined as a compromise with the loading and shipping process. All the remaining processes of the supply chain were modeled after this flow rate.

The volume of any of the LNG storage tanks onshore and on the ships was 145,000 m³. In order to approximate the LNG transport to a continuous process, 6 ships must turn in a close loop of loading, transport, unloading and return. This cycle takes approximately 144 hours at the store tanks, both closed to the liquefaction and regasification processes, 720 hours on maritime transport, leading to an estimate total time of 864 hours to accomplish the complete shipping cycle. As a result, each loading and unloading of LNG will be performed within every 6 days.

Ship to tank transfer of LNG, loading or unloading, is performed by pumps taking around 61.54 hours, and an extra 10.46 hours are dedicated to the shipping maneuvers at the harbor. In its way back, a residual volume of about 5% of the original LNG load remains in tank in order to maintain the tank at low temperature, avoiding thermal stresses, and to be used as fuel supply to the trip back, generating more *BOG* during this operation.

Regasification plants are located close to harbors, composed by LNG storage tanks and a set of heat exchangers and other auxiliary equipments to promote phase change. The proposed supply chain presented here was assembled considering regasification performed exchanging heat with streams of sea water.

3. ENERGETIC AND EXERGETIC ANALYSIS

The supply chain was assessed by 1st and 2nd law balances. The physical exergy, also known as thermodynamic exergy (Bejan *et al.*, 1996; Moran and Shapiro, 2002), is defined as the maximum theoretical useful work obtainable as a system interact to equilibrium, heat transfer occurring with the environment only. For a given control volume, the physical exergy rate $\dot{E}^{PH}$, in kW, of a material stream is:

$$\dot{E}^{PH} = \dot{m}[(h-h_0)-T_0(s-s_0)] \tag{1}$$

where $\dot{m}$ is the mass flow rate, in kg/s, h is the specific enthalpy, in kJ/kg, T is the temperature, in K, and s is the specific entropy, in kJ/kg K. The sub-index "*0*" corresponds to the properties in the dead state. No chemical reactions are performed along the control volume, and therefore with no variation of chemical exergy $\dot{E}^{CH}$. In addition, the control volume is at rest and at the same cote of the reference environment.

The destroyed exergy rate $\dot{E}_D$ (kW) can be obtained throughout the exergy balance for each one of the components of the chain. At steady state, this balance is given by:

$$\sum_j \dot{E}_{q,j} - \dot{W}_{vc} + \sum_e \dot{E}_e - \sum_s \dot{E}_s - \dot{E}_D = 0 \qquad (2)$$

The first term of Eq. (2) is the exergy rate concerning with the heat transfer between the control volume and the environment; the second one is the exergy rate of mechanical energy transferred between the control volume; the third and fourth terms are the inlet and outlet exergy rate transfer across the control volume. The destroyed exergy rate $\dot{E}_D$ can also be determined according to the Gouy-Stodola theorem, where s_{gen} (kJ/kg K) is the generated specific entropy:

$$\dot{E}_D = \dot{m} T_0 s_{gen} \qquad (3)$$

The energy and exergy equations applied to the supply chain previously presented are established employing the following simplification hypotheses: 1 – The main stream is composed by pure methane, although sometimes Natural Gas NG will be used as a reference; 2- All processes are assessed in steady state; 3 – Friction losses and pressure drops through pipes, condenser, evaporator and valve are neglected; 4 – Heat exchangers are taken as adiabatics; 5 – Dead state is taken as T_0 = 25ºC and p_0 = 1 bar; 6 – Sea water temperature T_a is at 20ºC.

Methane data for several states along the supply chain are presented in Table 1.

Table 1- Operational parameters for the LNG supply chain according to Figure 1

Point	***State***	***Place***	***T [ºC]***	***P [bar]***	***ρ [kg/m³]***	***Δh$_{vap}$ [kJ/kg]***
1	G	Pipe	25	1	1,506	
2	L	Pipe	-163	0	452,00	513,5
3	L	Tank	-163	0	452,00	513,5
4	L	Tank of Ship	-163	0	452,00	513,5
5	L	Tank	-163	0	452,00	513,5
6	G	Pipe	25	8	6,78	
7	G	Pipe	25	95	72,32	

3.1 Liquefaction and storage

The liquefaction process of methane demands the highest amount of energy throughout the LNG chain. CH_4 temperature is dropped down to approximately -163ºC at the absolute pressure of 1 bar, lower than the phase change temperature at that same pressure. The gas to liquid volume ratio is of about 1/600.

Liquefaction facilities should ideally be located closed to the NG production fields and not far from the shipping harbor, in order to reduce costs due to pipeline transportation. The liquefaction process is performed in multistage refrigeration devices, starting with propane as a primary coolant, cooling down CH_4 to -30ºC, and nitrogen or other hydrocarbons as secondary coolants. CH_4 is then stored in isolated tanks. The storage capacity is based on the forecasts of shipping and production capacity of both plant and shipping terminal, carrying out the transfer of LNG.

In the present work, the modeling of the liquefaction process was performed considering a reverse Brayton cycle, using nitrogen as refrigerant fluid. According to Chang H-M et al (2008), this cycle was chosen due to its higher thermodynamic efficiency and reduced size. Its efficiency is less sensitive to flow rate changes and concentration of methane, in addition to be more flexible for the integration of different modules of purification. The reverse Brayton cycle modeled in the present work is shown in Figure 2.

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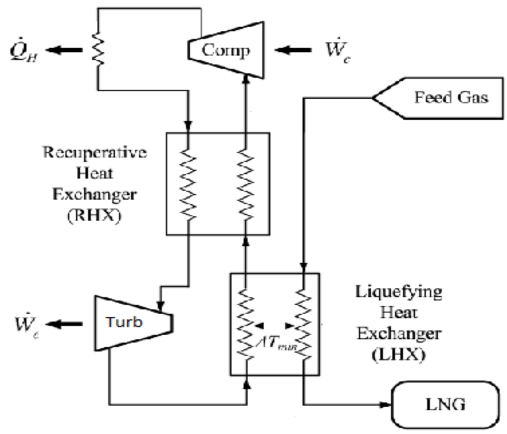

Figure 2. Diagram of the LNG refrigeration processes based on a reverse Brayton cycle.

The net compressing power of the reverse Brayton cycle $\dot{W}_{RBC}$, in W, is given by

$$\dot{W}_{RBC} = \dot{W}_C - \dot{W}_T \tag{3}$$

where $\dot{W}_C$ is the input power at the compressor and $\dot{W}_T$ the recovered expansion power at the turbine. The net compressing power can be calculated after a first law analysis of the cycle, based on many operational parameters, or alternatively using a second law efficiency or exergetic efficiency ε, defined as:

$$\varepsilon = \left[\frac{\dot{W}_{\min}}{\dot{W}_{RBC}} \right] \tag{4}$$

$\dot{W}_{\min}$ is the minimum required power for liquefaction, that takes into account that the ideal process is reversible, with no entropy generation. The combination of energy and entropy balances, for an ideal gas under the simplification hypothesis presented in the beginning of this section, leads to the expression of $\dot{W}_{\min}$ as :

$$\dot{W}_{\min} = \dot{m}_{LNG} \left[(h_{LNG} - h_0) - T_0 (s_{LNG} - s_0) \right] \tag{5}$$

where $\dot{m}$ is the mass flow rate of LNG, in kg/s, h is the specific enthalpy, in kJ/kg, T is the temperature in K and s is the specific entropy, in kJ/kg K.

The exergetic efficiency ε allows for the determination of the cycle entropy generation as:

$$\dot{W}_{RBC} - \dot{W}_{\min} = \dot{m}_{LNG} T_0 s_{gen} \tag{6}$$

Using Chang H-M et al (2008) data for liquefaction rate of 18.5 g/s of methane at T_0 = 298 K, the minimum power according to equation (5) was 19.9 kW and ε =0.263. That efficiency, together with the minimum required power for liquefaction, enables for the estimation of the net compressing power of the reverse Brayton cycle $\dot{W}_{RBC}$

The transport of LNG inside the liquefaction plant is done by pipelines, with the aid of special pumps. Heat losses during storing and transportation can be calculate with equation (7), and this same equation will be used to calculate heat gains in the storage tanks.

$$q = \frac{2\pi k (T_O - T_{LNG})}{2.3 \log(\frac{D + 2t}{D})} \tag{7}$$

k, *D*, and *L* are the thermal conductivity, inner diameter, and length of the tank or pipe, *t* is the thickness of insulation, T_O is the environment air temperature, and T_{LNG} is the LNG temperature. Knowing LNG composition (CH_4) and its latent heat H_v, together with the storage time *ST* , the boil-off in the liquefaction plant, in kg/s, is given by:

$$BOG_{Tank} = q\frac{ST}{H_v} \tag{8}$$

The mass flow rates $\dot{m}_e$ and $\dot{m}_s$ in Eq. (9) are obtained from the mass balance, performed in the control volume in all process where it occurs. With this equation is possible to know the actual mass flow rate of every process.

$$\dot{m}_e - \dot{m}_s = BOG \tag{9}$$

3.2 Shipping

Losses during the shipping process were calculated according to equation 7 and 9. A voyage time (*VT*), defined as the elapsed time between the liquefaction plant and the regasification plant, considered here as 15 days for each displacement, for the same reference conditions.

$$BOG_{Voyage} = q\frac{VT}{H_v} \tag{10}$$

3.3 Regasification

Regasification plants are composed by storage tanks of LNG and a set of heat exchanger where LNG is transformed back into gas phase for further distribution. In the proposed supply chain, the regasification process occurs by exchanging heta with sea water.

The regasification system was calculated for a rate of evaporation of LNG similar to the one chosen at the beginning of the chain. The energy required for LNG vaporization at 3 MPa is 513.5 kJ/kg. The heat exchangers system were considered as built in two distinct sections: one for evaporation of LNG and the other of its superheating.

In order to design the operational conditions of these systems, one must know or define the temperatures of the hot stream, of the input and output of the evaporator, and output at superheated conditions.

The solution of this kind of system leads to the dimensions of the heat transfer surface area, in addition to the temperature and mass flow rate at intermediate streams. With these data, and knowing that the energy consumption to operate of the system is basically composed by the pumping power W_p, given in W, as presented by equation 11.

$$\dot{W}_p = \frac{\dot{m}_{LNG}\,\Delta P}{\rho\eta_p} \tag{11}$$

$\dot{m}$ is the mass flow rate of LNG, in kg/s, ΔP the increment of pressure, in Pa, ρ is the density, in kg/m³ and η_p is the combined efficiency of pump and motor.

The proposed system must discharge cooled sea water in a deeper level then the one it was collected, making the of pumping minimum power to be dependent of such depth.

4. RESULTS

Analysis were carried out considering the total amount of energy required to perform the supply chain, the exergy contained along streams and equipments and taking into account the boil off of methane at each stage. For the exergetic analysis of the chain, was evaluated the increase or destruction of exergy at stream of methane.

Starting with the mass balance along the chain, Figure 3 displays the reduction on the mass flow rate of LNG due to the boiling off process, expressed as a nondimensional ratio of LNG mass flow rate along the chain processes to the initial LNG mass flow rate, at the input of the chain. The mass flow rate along the control volumes of the chain were corrected with the aid of equation 9, leading to a reduction of it after every boil off process.

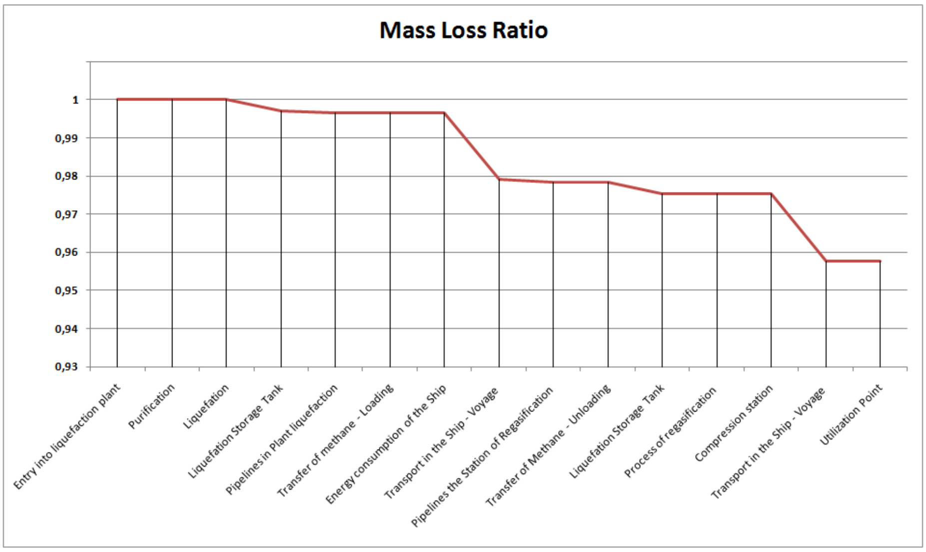

Figure 3. LNG Mass Loss Ratio.

From the initial input on the chain to the end of the liquefaction process, the total amount of methane is unchanged. LNG mass suffers a first evaporation, or boil off, from that stage on, to the liquefaction store tank. After liquefaction, the stages of storage, loading and transport some mass losses, called BOG, are identified. After the stage of regasification, it is considered that the mass remains constant until the point of use.

Losses were mainly identified in the storage tanks of the liquefaction and regasification stages, and especially in the ship tanks. This latter process exposes LNG to an important temperature difference along a long period of time. The total loss of mass in the supply chain of LNG is approximately 4.22%, the transport stage corresponding to 83.1% of it. From the total mass admitted in the chain, 95.78% is regasified after transportation.

The Figure 4 shows the energy consumption in the supply chain of LNG. Starting from zero at beginning of the process, all demanded energy per unit mass of methane is displayed on the graph.

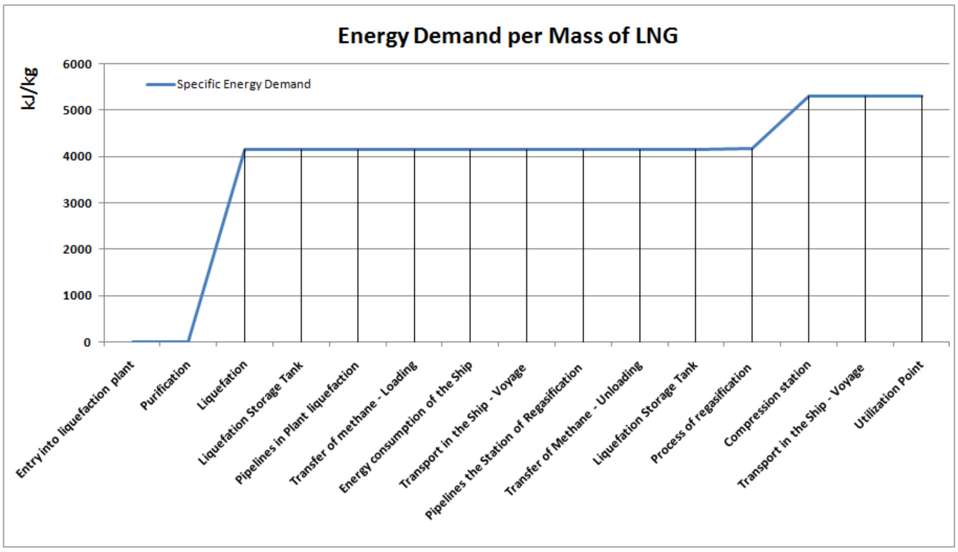

Figure 4. Energy consumption along the Supply Chain of LNG

The main energy consumers in the supply chain of LNG were identified at the liquefaction process followed by the compression of methane for its distribution. Processes as sea water pumping were less significant, but all stages are detailed on Table 2.

Figure 5 shows the exergetic along the supply chain of LNG. It starts at zero at the dead state and will suffer increases or decrease, in each stage, in accordance with the generation or destruction of exergy. The exergetic analysis was performed taking into account the stream of methane, which assess the increase or decrease of exergy in each process of LNG suffers, not being considered the destruction of exergy in cycles isolates as in the purification, refrigeration, transportation and others, because already evaluated the loss of mass and energy consumption in each step.

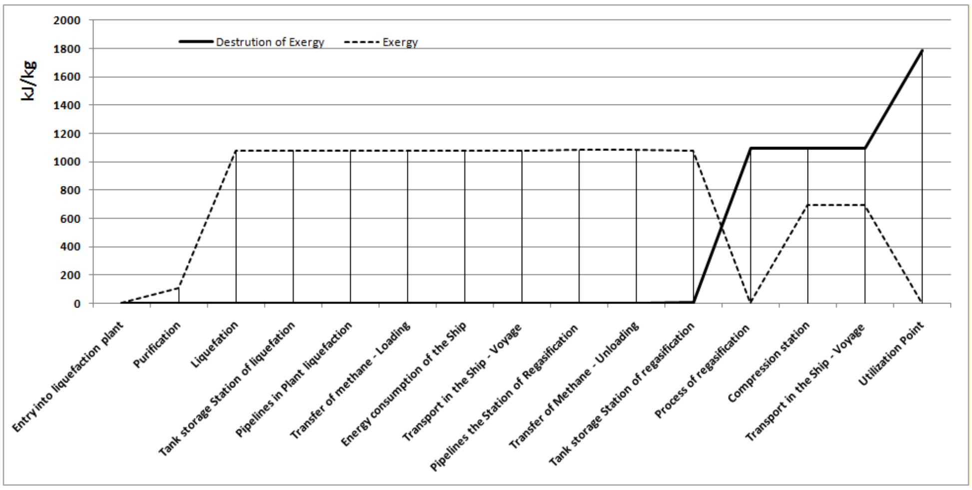

Figure 4. Exergy and exergy destruction along the Supply Chain of LNG

The substantial increment of exergy in the stream takes place at the liquefaction process and pressurization of methane, and its destruction is occurs at the regasification process and point of utilization. There are other process of generated and destruction of exergy, but of small importance as can be seen in Table 2.

Table 2 displays a detailed map of the energy consumption, loss of mass and exergy variation for each stage. It shows the individual and total results in units per kg of methane.

Table 2. Detailed results of all process along the Supply Chain of LNG

Energy and mass losses and destruction of exergy in the Supply Chain of LNG																	
	Entry into liquefaction plant	Purification	Liquefation	Liquefation Storage Tank	Pipelines in Plant liquefaction	Transfer of methane - Loading	Energy consumption of the Ship	Transport in the Ship - Voyage	Pipelines the Station of Regasification	Transfer of Methane - Unloading	Liquefation Storage Tank	Process of regasification	Compression station	Transport in the Ship - Voyage	Utilization Point	% of Losses	% Total Loss
Energy (kJ/kg)	0	0	4150	0	0	4,093	0	0	0	5,117	0	23,92	1112	0	0	10,59%	14,81%
	0	0	4150	4150	4150	4154,093	4154,093	4154,093	4154,093	4159,21	4159,21	4183,13	5295,13	5295,13	5295,13		
Mass (kg/kg)	0	0	0	0,002995	0,0004297	0	0	0,01754	0,0007162	0	0,002999	0	0	0,01754	0	4,22%	
	1	1	1	0,997005	0,9965753	0,9965753	0,9965753	0,9790353	0,9783191	0,9783191	0,9753201	0,9753201	0,9753201	0,9577801	0,9577801		
Exergy (kJ/kg)	0,09431	104,9	1080	1080	1080	1078	1078	1080	1084	1084	1080	2,156	697,4	697,4	0		
Destrution of Exergy	0	0	0	0	0	2	0	0	0	0	6	1089,844	1089,844	1089,844	1787,244		

With a transport capacity overseas of 65.540 Tons of LNG, there were approximately 9.706 Tons lost or consumed along the chain, considering a elapse time of 36 days. Figure 5 shows an integrated mass and energy overview of the process.

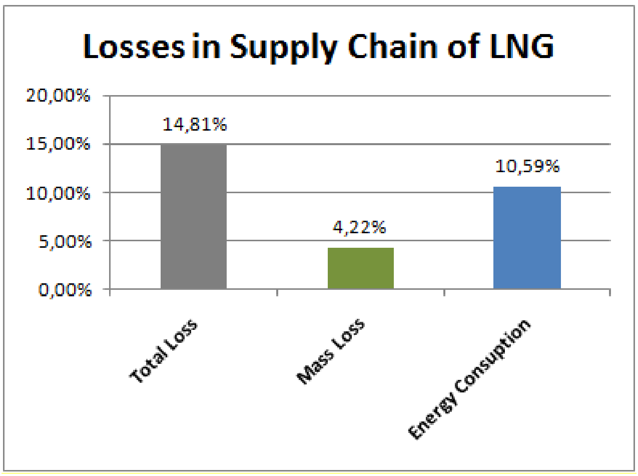

Figure 5. Losses along the Supply Chain of LNG

5. CONCLUSION

The present study proposed an integrated study of a supply chain of LNG, after the identification of realistic data from literature. It shows the main points of energy consumption, destruction of exergy and boiling off of fuel. The variables that interfere directly in losses for the chain are the ambient temperature, thickness of the insulation and time of storage in liquefaction and regasification facilities, and the overseas shipping time of transportation.

The ambient temperature influences directly the refrigeration plant for liquefaction and on the heat gains during all storage processes, impacting on the energy consumption and mass loss. The sea water temperature affects the reevaporating process, as well as the losses in mass during overseas transportation, on both ways. Results show that, even for a typical long one-way trip of 15 days, there is a 14.81% lost in mass and energy. Liquefaction facility and overseas transport are the responsible for such loss.

The destruction of exergy occurs mainly on two points, the first and most significant is the regasification plant, destroying 1078 kJ/kg of methane, due to heat exchange be made with sea water, and the second point is the change in pressure throughout valves next to the points of use.

6. ACKNOWLEDGEMENTS

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