COSTS OF ENERGY LOST DURING THE LNG REGASIFICATION AT ŚWINOUJŚCIE TERMINAL

Dr. Ewelina Zloczowska
Szczecin Maritime University, Poland

ABSTRACT

Nowadays, LNG plays an increasingly important role in the world's energy balance. The traditional natural gas supply model requires transportation via a gas network from the extraction site to the final recipient. This solution is limited by too long distance or large water reservoirs (e.g. an ocean) in between the manufacturer and the recipient. Given that the largest natural gas deposits are in: Indonesia, Malaysia, Algeria, Qatar, Trinidad and Tobago, Nigeria, Australia, Brunei, Oman and UAE, there is a need for its transportation over long distances. In such cases, the effective transport of natural gas is made possible via its liquifying, accomplished by lowering the temperature to about-161°C. However, it requires LNG export and import terminals to be built. The processes of condensing and regasification of gas are quite energetically and environmentally costly links of LNG supply chain. There are possibilities to minimize them, treating LNG not only as a fuel but also as a source of low-temperature heat. During the LNG regasification, the cold "stored" within is usually released into the environment, which causes a significant loss. The ever-increasing energy prices and environmental consciousness have resulted in the development and implementation of technical solutions effectively utilizing cold waste from the LNG regasification process in a variety of industries. This article presents a possible potential for usage of cold waste from LNG regasification process in the Świnoujście terminal and benefits associated. For this purpose, a characteristic of the currently used regasification system based on the SCV exchangers was performed, then its energetic analysis followed. A concept of regasification system, in which cold waste is used to supply a cold store, will also be presented. Not only energy aspects resulting from cold recovery from the process were accounted in the following analysis, but also a reduction of the environmental impact of the system in question. Basing on carried out research, the cost of energy lost in the LNG regasification process in the Świnoujście terminal was indicated.

Keywords: *LNG, waste cold, efficiency, regasification*

INTRODUCTION

The liquification of natural gas (NG) allows for its efficient transport over long distances since in this state its volume is about 600 times lower than in a gas state. The LNG abbreviation is commonly used for an NG in liquid state. However, to achieve and maintain NG's liquid state, significant energy inputs are necessary. The liquification of NG requires decreasing its temperature to about -162°C in a pressure of 1bar. The amount of heat extracted from NG during this process varies from 600 to 650 kJ/m^3. This value is related to quantity composition of the NG, mainly to the methane content, for which this value is 654 kJ/m^3. To accomplish the supply of liquified gas, an adequate infrastructure is necessary. Generally, at the LNG production plant the facility should provide: liquification of NG, its storage in liquid state and loading on carries. While, at the receiver, the facility should allow unloading, storage and regasification of LNG. The individual steps of the supply of natural gas from extraction to delivery to the final consignee are called the LNG supply chain. This chain remains in almost unchanged form since 1964 [1] and consists of four main cells: The production sector, which includes: mining – locating natural gas deposits, gas extraction and delivery to the export terminal; Export terminal - liquification, storage, loading LNG on carriers; Transport; Import Terminal: receiving, storage and regasification of LNG, deliver NG to final customers.

It is crucial that the individual links of the LNG supply chain have the lowest cost. This has a huge impact on the price of the final product, i.e. its competitiveness. According to the analysis presented at work [2], an average of 41% of the total costs associated with LNG delivery is the cost of its liquification. The remaining links represent 21% of LNG regasification and storage, 20% of transport and 18% of natural gas extraction. Regardless of the technology adopted, the condensing process is the most energy-intensive link in the supply chain. However, when LNG is used not only as a fuel, but also as a source of low-temperature heat (cold), there is a real opportunity to improve the efficiency of the LNG supply chain and consequently to reduce the price of the final product. Cold, which is accumulated in the gas during its liquification, in the process of regasification can be used in cold stores [3], electricity production [4] or other technological processes such as liquification of gases, desalination of water, production of ice for food purposes, etc. [5]. Unfortunatelly, there is a whole range of regasification systems in operation, where the cold accumulated in LNG remains unused e.g. terminal Świnoujście. The purpose of this article is to assess the potential for exploiting the waste cold from the LNG regasification process in the Świnoujście terminal and the benefits associated with it. The analysis covered energy, economic and environmental impacts.

ENERGY ASPECTS OF THE LNG REGASIFICATION PROCESS

The amount of heat q supplied to LNG during the regasification process equals its enthalpy increment. In the lgp-h chart, a straight line coinciding with constant pressure illustrates the transition of LNG from liquid to gas state during regasification (fig.1). As the regasification process usually occurs at supercritical pressures, it is difficult to clearly indicate the moment of transition from the liquid to the gas state. In order to simplify the analysis, LNG was treated as pure methane (CH_4). Then, using the lgp-h charts for methane, the theoretical heat demand in the regasification process was determined.

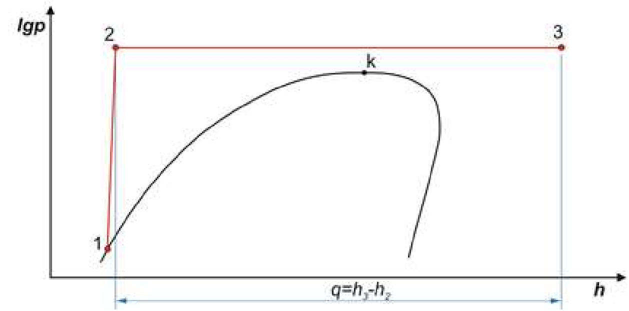

Figure 1. LNG regasification: 1-2 increasing of LNG pressure, 2-3 – regasification

The calculations were carried out assuming that the initial temperature of saturated LNG is -162 °C and the final temperature of gas, after the regasification process is 5°C. Pressure has a great impact on the amount of heat, which has to be supplied to LNG during regasification. Increasing of the LNG pressure before regasification (to one dictated by parameters of the network) is justified energetically and economically. For the gas to be compressed to pressure required by the pipeline after regasification, the required power would be very high: the ratio of the pumping power needs of NG to the needs of LNG is greater than 20 [4]. In figure 2, the heat demand in the regasification process depending on the pressure in which the process occurs is presented.

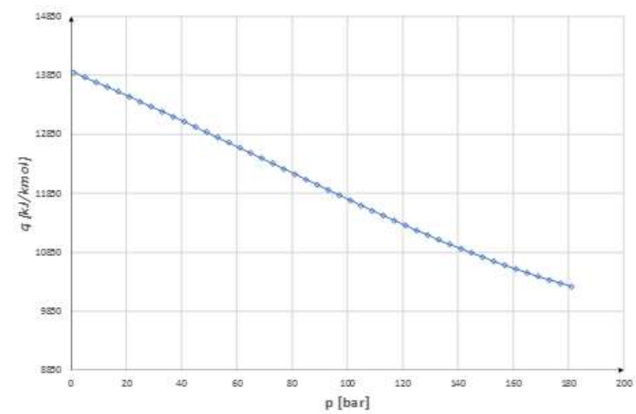

Figure 2. Specific heat supplied to LNG during regasification depending on the pressure

According to figure 2, the higher the pressure, the less heat should be supplied during the regasification process, meaning less waste cold will be available from this process. Thus, in systems where cold recovery is planned, the process should be preferably carried out at the lowest possible pressures, opposed to systems without cold recovery. For example, at a pressure of 120 bar, the heat suppled to the LNG is approximately 11350 kJ/kmol, while at a pressure of 80 bar this value is about 12176 kJ/kmol. Therefore, in the second case for each kmol of regasified gas, about 826 kJ more heat should be delivered (that is, so much more cold will be available for regasification). In a situation where heat for regasification is produced e.g. as a result of gas combustion, these are already considerable differences. Even more so, the efficiency of regasification systems is counted in billions of cubic meters. To thoroughly analyse the problem, the power of the pumps should also be considered.

When considering the thermal parameters in which the regasification process is carried out, the temperature should also be paid attention. As has been demonstrated in many times, the more heat source temperature differs from the ambient temperature the higher its usable energy potential, which can be seen introducing the concept of degree of heat value, $\frac{T-T_o}{T}$. [6], defined as:

$$\frac{T-T_o}{T} = \frac{-\Delta B_{zr}}{Q} \qquad (1)$$

Where: T-the absolute temperature of the heat source, T_o - the ambient temperature,
(-Δ B_{zr}) – The decrease of heat source Egzegy, Q – The amount of heat given by this source.

Most generally, the degree of heat value expresses an egzergia relative to the unit of heat and can be considered as a measure of the technical-economic value of heat. Figure 2 shows the graphical interpretation of this indicator in the temperature function.

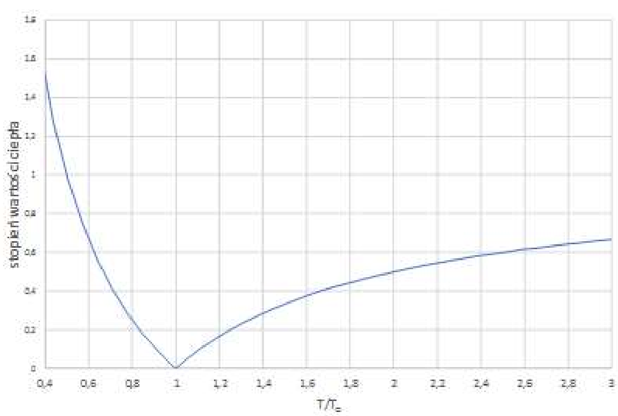

Figure 2. Degree of heat value [6]

Figure 2 shows that, as the ambient temperature approaches, the degree of heat value decreases rapidly to zero. In the temperature range of $0.67 < T/To < 2$ The degree of heat value is less than 0.5. The lower the temperature of the heat source, the degree of heat value gets higher values. Therefore, it is justified to treat LNG not only as a fuel, but also as a source of low-temperature heat. And the heat stream fed to LNG during regasification as a potential profit and not a loss.

LNG REGASIFICATION AT THE TERMINAL ŚWINOUJŚCIE

LNG terminal in Świnoujście is able to provide the efficiency of regasification at the level of 75 000 Nm^3/h up to 656 000 Nm^3/h (nominally: 570 000 Nm^3/h). Figure 3 shows the terminal blueprint.

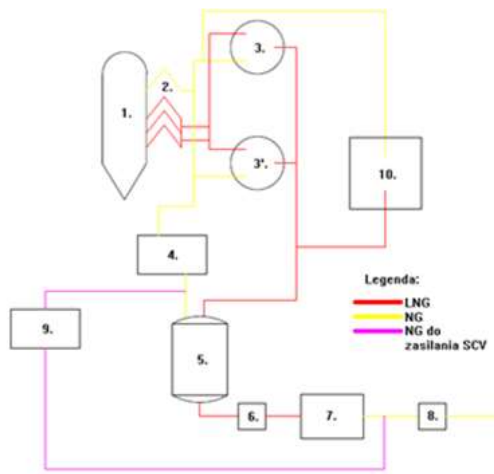

Figure 3. Terminal blueprint: 1– LNG carriers, 2– handlers, 3– storage tank nr 1, 3'– storage tank nr 2, 4– compressor BOG, 5– condenser BOG, 6 – high-pressure pump, 7– SCV heat exchangers, 8– measurement station, 9- NG station [7]

When operating at maximum regasification capacity (656 000 Nm^3/h), the LNG flow rate is 1150 m^3/h. The Pressure at pumps reaches 84 barg, which corresponds to the pressure required by the NG gas pipeline. Once the pressure is reached, LNG is routed to the evaporators. The LNG Terminal in Świnoujście has five SCV (Submerged Combustion vaporizer) type evaporators with a nominal power of 27.5 MW each. During normal operation, four SCV Evaporators are operating and one remains at ready. In SCV type evaporators, the heat necessary for regasification comes from the combustion process of the gaseous fuel, which is a specially prepared NG. NG preparation for combustion in the SCV consists in cleaning, normalizing its pressure and temperature to the required values: 5 barg and 5°C. Such prepared fuel is burned in a special compartment using the air provided by fans. At the evaporator outlet, the temperature sensor measures NG temperature and sets the corresponding fuel pump output to the evaporator torch nozzles accordingly. Gases from the combustion process heat a water bath, in which stainless steel heat exchanger tubes are immersed. In these tubes, the flowing LNG is subjected to a regasification process.

In addition, the SCV is equipped with two electric heaters, which serve to maintain the water bath temperature above 5 °C, especially during the winter. Carbon dioxide from the combustion process causes the acidification of water in the evaporator. To maintain a neutral pH of the bath, an alkalizating caustic soda is put into the water. There is no need to replenish water in the evaporator, because the steam vapor in the combustion process liquifies and replenishes resulting deficiencies. Excess water is removed by overflow pipes and routed to the treatment unit. After leaving the vaporizers, natural gas is directed to the measurement station. Here the amount of gas transmitted and its parameters is assessed.

Maximum efficiency of the regasification system in the Świnoujście terminal is 570 000 Nm^3/h. Considering the efficiency of regasification given in units of Nm3/h is for normal conditions (i.e. p_n = 1.01 bar, T_n = 273,15 K), as well by adopting the temperature and Gas pressure after regasification (i.e. T = 275,15 °C, p = 85 bar), the regasification capacity in units of m3/h can be calculated. For this purpose, the Clapeyron equation should be used, treating methane as a perfect gas:

$$\frac{p_n \dot{V}_n}{T_n} = \frac{p\dot{V}_{NG}}{T} \quad (2)$$

Hence, the LNG mass flow rate, counted at the output to the SCV:

$$\dot{m} = \dot{V}_{NG} \cdot \rho \quad (3)$$

As already mentioned, during the regasification, which takes place at a constant pressure of 85 bar, LNG is experiencing a temperature rise from about 113.15 K to 275.15 K. Using the REFPROP the enthalpy values at the beginning and end of the process was established. By introducing the mass flux of the working fluid to the equation (1), a dependence allowing to determine the heat flux brought to the LNG during the transition from the liquid state into the gas. The mass flow rate of the regasified gas is determined by the LNG volume flow rate. Table 1 shows the results of the calculation.

Table 1 Results of the calculation

$\dot{V}_{LNG}$ [m^3/h]	$\dot{V}_{NG}$ [m^3/h]	$\dot{m}$ [kg/h]	Δh [kJ/kg]	$\dot{Q}$ [MW]
1160	6 822	498 365	738,52	102

As the current form, at the Świnoujście terminal, the heat necessary for LNG regasification is produced by burning NG fuel. Basing on available data, it is possible to approximately determine the fuel stream which is burned in SVC heat exchangers. The energy balance of the heat exchanger, with certain simplification assumptions, can be saved as:

$$\dot{v}_f \cdot W_f \cdot \eta = \dot{V}_{LNG} \cdot \rho \cdot \int_{T_{in}}^{T_{out}} c_p dT \quad (4)$$

where: $\dot{v}_f$- fuel gas flux [m^3/s], W_f - calorific value of fuel gas [J/m^3], η – efficiency of SCV exchanger [-],$\dot{V}_{LNG}$- vaporization capacity of the SCV [m^3/s], ϱ – density [kg/m^3], c_p – specific heat of LNG (NG) [J/kgK], T_{in}, T_{out}– inlet and outlet temperature of LNG respectively [K].

The energy value of W_f fuel gas was assumed to be 32 MJ/m^3 and the efficiency of the SCV exchanger at the level of η = 0.95 [8]. Hence, determined by the equation (4), the estimated unit fuel consumption in the regasification process is 0.024m^3/kglng. assuming that the annual quantity of the regasified gas on the terminal is 3000000000m^3, the fuel consumed as a supply for SCV exchangers is

63 721 072 m^3/year. With the price of gas for the Polish markets at the level of 2 zł/m^3, the cost of the fuel itself to supply the SCV exchangers is 127 442 145 zł/year. Therefore, we lose not only a lot of cold but we also pay a high price.

POTENTIAL USAGE COLD

An interesting solution for waste cold from the regasification process in the LNG terminal in Świnoujście usage is a generation of electricity that could be used for internal terminal or to power external objects e.g. Container terminal. The electricity produced could, for example, serve For the supply of refrigerated containers (according to the design, the terminal will have 584 connections for refrigerated containers). Assuming that the consumption of electricity by a single container is at 6 kw, total electricity demand for refrigerated containers would be around 3.5 MW. In the literature there is a large number of publications on this issue [4], [9], [10], [11]. Nevertheless, in this article, the main attention has been driven to the use of waste cold for purposes of refrigeration, cryogenics or air conditioning. Important factor of this possibility is locating customers with direct use of waste cold in close proximity to the Regasification station, ie. up to 2 km. The Transport of cold at considerable distances would entail large losses of cold, significant energy inputs which leads to a decline in the cost-effectiveness of the process. The objects in Świnoujście area that meet the distance requirement are: fish processing plant; Fishing harbor; Meat processing and vacuum packaging company.

Assuming that in the vicinity of the terminal Świnoujście is a cold store with a nominal cooling capacity of 2 MW. The refrigeration system is a typical compressor system, with R717 as a working factor. The storage temperatures of the products in the Chambers are maintained at three levels: freezing chamber-20°C, dry chamber 0°C and positive chamber 5°C. With some approximation, it can be assumed that the cooling efficiency coefficient of such systems is approx. 2, then the electric power needed to drive the refrigeration compressors and other refrigeration equipment would be about 1000kw. Assuming that the cold store is working 365 days a year, on average 15 hours/day, the annual energy consumption would be 5 475 000 kWh, which at the price of electricity at 0.6 PLN/kwh gives the cost of Operation of 2 628 000 zł/year. Most power plants in Poland use coal as fuel. The Calorific value of hard coal is 21.34 MJ/kg. The efficiency of a coal power plant maxes at 45%. Therefore, in order to produce 1 MWh of electricity, almost 245 kg of hard coal is needed. The CO_2 emission factor for coal is 93.80 kgCO2/GJ [12]. Thus, as a result of refrigerated operation, CO_2 emissions to the atmosphere will be 1848.8 kgCO_2/year. Using cold waste from the regasification process to supply cold stores could save not money only, but above all could take care of the environment by reducing greenhouse gas emissions into the atmosphere.

The cold from the process of regasification can also be accumulated in the so-called cold-tanks (cold accumulators) made of PCM materials. This solution allows to offset the use of cold in time and space. Namely, charged accumulators (made of suitable PCM material), can be used as a source of cold for air conditioning systems in nearby hotels or pensions. The environmental cost of the air conditioning system equipped with cold accumulators will certainly be incomparably smaller than in a typical compressor refrigeration unit. Cold accumulators can be also used for an air conditioning of large-size stores or storage cooling systems. There is also a possibility of direct regasification cold usage for air conditioning purposes. Although the Hotel center is far away from the terminal and the installation of suitable installations could be difficult, still it is not impossible. Such a network would have to be treated like a district heating network then, and a terminal like a CHP, except in that case gas and usable cold would be considered as terminal products.

CONCLUSION

In case of a classical regasification station, the whole "cold" is lost: it is released into the environment. Taking the cold waste available from the regasification process into account, as well as existing solutions for the use of this cold, this potential is worth considering in construction of new terminals. LNG Terminal working with the use of waste cold from the regasification process for refrigeration or electricity production would attract entrepreneurs. They would be able to expand their investments near the LNG terminal. Due to the fact that LNG terminals operate in the immediate vicinity of seas and oceans, this would be an investment primarily from the maritime sector. For example, construction of a cold store in Swinoujscie, which would be fed by the waste-heat could result in a rebirth of Polish fishing on a large scale. The container terminal which is being built in Świnoujście could benefit from the use of electricity produced by using cold waste.

At the same time, it should be noted that the implementation of a regasification plant with the use of cold waste does not eliminate the need to equip the terminal with a classic solution. This is due to the significantly lower regasification performance of the described solutions in relation to the currently used installations. However, the cost of construction of a terminal equipped with two different branches of regasification (including the use of cold waste) would be little higher than the cost of constructing a classical terminal with the same efficiency of regasification. Any price difference could be reimbursed by the sale of "cold". The ecological and financial aspect of the regasification plant with the use of cold waste is also the reason for further development. The use of cold will result in an even lower environmental impact of the LNG by using waste energy. Electricity or cold storage would have a competitive price compared to the current classic supply solutions for these media. Further developing this branch of the LNG industry is well worthy, as natural gas is slowly pushing out oil and coal. In a couple of years, natural gas will be used not only for the supply of domestic gas installations, but it becomes even more popular as a propellant. Then re-gasification stations will have enormous regasification capacities, and the amount of cold waste available from this process will continue to grow.

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