LECo - Feasibility study

- Analysis of cryogenic liquefaction of methane

AGERA INNOVATION OY

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1. Introduction

This feasibility study reviews the viability and efficiency of the liquefaction of methane gas by the use of nitrogen. The study is a part of the Centria University of Applied Sciences lead LECo-project.

Methane liquefaction is usually achieved by increasing the pressure of the gas to a sufficiently high level so that the gas begins to liquefy. This process requires large compressors that require much power and consume a lot of energy.

In Finland, farm based biogas production is generally low, e.g. 10 Nm3/h – of which methane accounts for about 65 %. At the moment, it is not profitable to invest in liquefaction units that are currently on the market, mainly because they are designed for higher yields.

Nevertheless, to have the methane in its liquid form would provide many benefits even for small-scale biogas producers. The long distance transportation of the substance would be a lot more cost effective, and the liquid methane could be utilized in vehicles.

Agera Innovation Ltd has presented a liquefying process that is suited for small-scale gas production. The idea is to utilize very low temperatures instead of high-pressure levels to achieve the liquefaction. However, the feasibility of the Agera liquefaction process is determined by the specific amount of liquid nitrogen required in the process.

This analysis consists of calculations that presents the yield of liquid methane in relation to the required liquid nitrogen.

2. About the LECo-project

The LECo project supports small communities in becoming self-sufficient regarding energy. The project aims at raising awareness about energy efficiency and the possibilities to use locally available renewable energy, such as wind, solar and hydropower, as well as side streams from industry, households and agricultural origin.

The project gathers test groups from Finland, Sweden, Norway and Ireland. The goal is that the test group will become self-sufficient regarding energy making the most of locally available energy source and new technologies.

3. Agera Innovation

Agera Innovation is a company made up of six farmers from the Ostrobothnia region in Finland. Agera Innovation Ltd was established in 2016, and one of the company's focus points has been to solve the unprofitability issues regarding small-scale biogas production (10-25 Nm3/h) on farms.

One of their proposed solutions is to liquefy the methane on the premises instead of only pressurizing the gas. In liquid state, the gas is in a much denser form, which in turn allows the gas to be more effectively transported. In addition, liquefied methane does not require as heavy tanks as pressurized methane for transportation and storage.

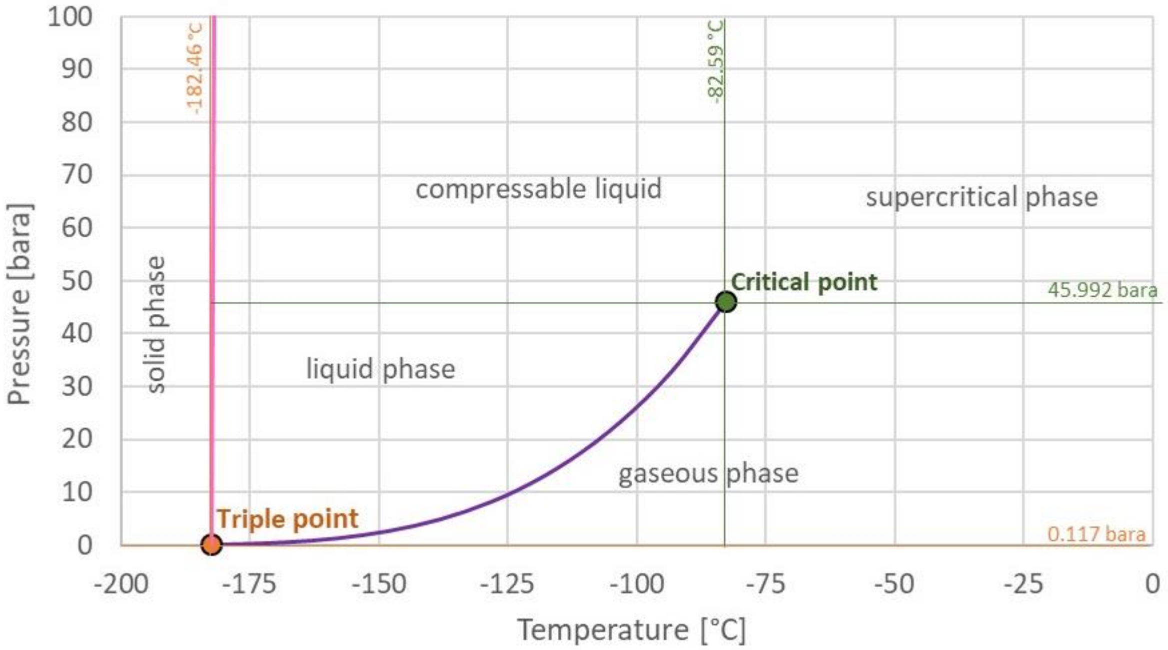
4. Cryogenic liquefaction of methane

Cryogenic liquefaction is a process by which a substance in its gaseous state is converted to its liquid state by cooling. When the temperature of a gas is decreased and enough kinetic energy has been removed from the substance, it changes from a gaseous to a liquid state.

Methane is a chemical compound with the chemical formula CH_4. Methane is the main component in biogas and natural gas. About 65 % of biogas is methane and the rest is carbon dioxide (CO_2) and small amounts of other gases. Methane's heat of combustion is 55.5 MJ/kg and it is used in a variety of applications for e.g. in the generation of electricity and heat or as fuel in vehicles. Methane has a boiling point of −164 °C at a pressure of one atmosphere.

In order to liquefy methane gas, its temperature must be lowered below the boiling point; this can be archived by utilizing liquid nitrogen as a refrigerant. Nitrogen is in its liquid state at an extremely low temperature and has a boiling point of −195.79 °C.

Methane phase diagram:



Source: Engineering toolbox (www.engineeringtoolbox.com)

5. Calculations

The calculations consists of three different theoretical ideal reviews of the consumption, and one practical simulation of the liquefaction process. The Reference Fluid Thermodynamic and Transport Properties Database 23 Version 9.1 was used to define the properties and states of the compounds, and the simulation was performed with the Aspen HYSYS-process simulation software.

Case 1:

In this case, only the latent heat from the gasification of the liquid nitrogen is utilized. The latent heat is the energy released or absorbed by a substance during its phase shift. In practice, the heat energy required for the evaporation of the liquid nitrogen flow is transferred from the methane gas with a heat exchanger, which results in the methane gas being cooled and liquified.

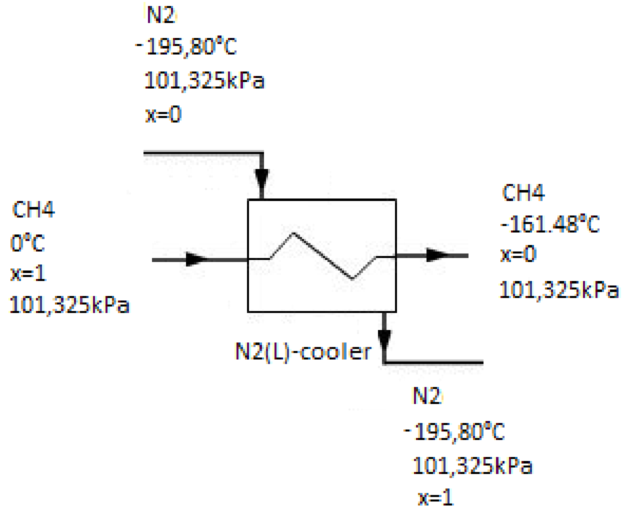


Image 1.1

Properties of the methane at the different states:

	Temperature (°C)	Pressure (kPa)	Enthalpy (kJ/kg)	Quality (kg/kg)
CH4	0	101.325	854.8	Superheated
CH4	-161.48	101.325	0	0

Table 1.1

The liquefaction of pure $CH_4(G)$ at atm-pressure occurs when the temperature is approximately -162 °C.

The specific enthalpy change required for the liquefaction:

$$\Delta h_{CH4} = h_{CH_4(G)} - h_{CH_4(L)} = (854{,}8 - 0)\frac{kJ}{kg} = 854{,}8\frac{kJ}{kg}$$

Properties of the nitrogen at the different states:

	Temperature (°C)	**Pressure (kPa)**	**Enthalpy (kJ/kg)**	**Quality (kg/kg)**
N2	-195.80	101.325	-122.0	0
N2	-195.80	101.325	77.2	1

Table 1.2

The specific enthalpy change:

$$\Delta h_{N2} = h_{N_2(L)} - h_{N_2(G)} = (-122 - 77{,}2)\frac{kJ}{kg} = 194{,}2\frac{kJ}{kg}$$

Required amount of $N_2(L)$ for $CH_4(G)$ liquefaction in Case 1:

$$kg_{N_2(L)} = \frac{\Delta h_{CH4}}{\Delta h_{N2}} = \frac{854{,}8\frac{kJ}{kg}}{194{,}2\frac{kJ}{kg}} = 4{,}40$$

The calculations shows that when utilizing only the latent heat from the liquid nitrogen the process requires 4,4 kg of nitrogen per 1 kg liquid methane yield.

Case 2:

In this case, the cooling effect of liquid nitrogen is utilized more efficiently, and the temperature of the liquid nitrogen is raised to the liquefaction temperature of the methane gas. This leads to a lower nitrogen consumption but requires a more complex heat exchanger with a greater surface area. The heat exchange is considered ideal.

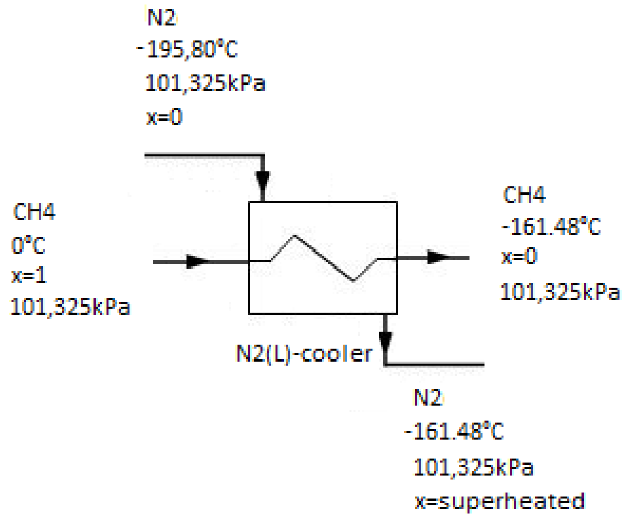


Image 2.1

Properties of the methane at the different states:

	Temperature (°C)	Pressure (kPa)	Enthalpy (kJ/kg)	Quality (kg/kg)
CH4	0	101,325	854,8	Superheated
CH4	-161.48	101,325	0	0

Table 2.1

The liquefaction of CH_4(G) at atm-pressure occurs when the temperature is approx. -162 °C.

Properties of the nitrogen at the different states:

	Temperature (°C)	Pressure (kPa)	Enthalpy (kJ/kg)	Quality (kg/kg)
N2	-195.80	101.325	-122.0	0
N2	-161,48	101.325	114,3	Superheated

Table 2.2

The specific enthalpy change:

$$\Delta h_{N2} = h_{N_2(L)} - h_{N_2(G)} = (-122 - 114{,}3)\frac{kJ}{kg} = 236{,}3\frac{kJ}{kg}$$

Required amount of N_2(L) for CH_4(G) liquefaction in Case 2:

$$kg_{N_2(L)} = \frac{\Delta h_{CH4}}{\Delta h_{N2}} = \frac{854{,}8\frac{kJ}{kg}}{236{,}3\frac{kJ}{kg}} = 3{,}62$$

The calculations shows that when the temperature of the liquid nitrogen is raised to the liquefaction temperature of the methane gas the process requires 3,6 kg of nitrogen per 1 kg liquid methane yield.

Case 3:

In this case, all the theoretical cooling energy from the liquid nitrogen is utilized. The temperature of the nitrogen is raised to the original temperature of the methane with is the theoretical maximum regarding efficiency.

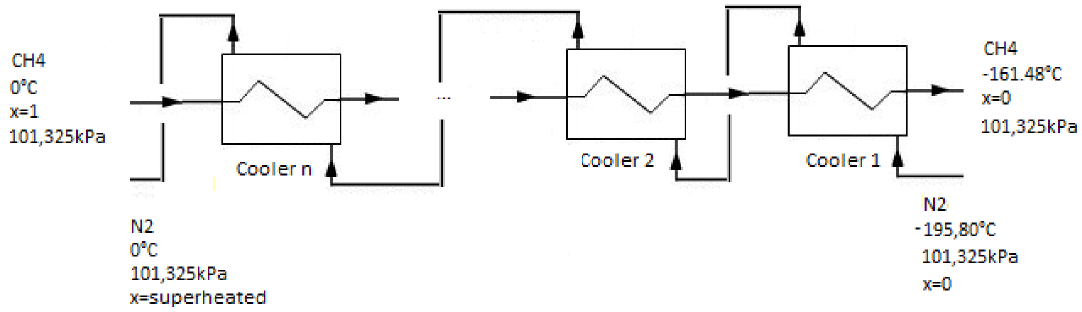


Image 3.1

Properties of the methane at the different states:

	Temperature (°C)	Pressure (kPa)	Enthalpy (kJ/kg)	Quality (kg/kg)
CH4	0	101.325	854.8	Superheated
CH4	-161.48	101.325	0	0

Table 3.1

The liquefaction of pure $CH_4(G)$ at atm-pressure occurs when the temperature is approximately -162 °C.

The specific enthalpy change required for the liquefaction:

$$\Delta h_{CH4} = h_{CH_4(G)} - h_{CH_4(L)} = (854{,}8 - 0)\frac{kJ}{kg} = 854{,}8\frac{kJ}{kg}$$

Properties of the nitrogen at the different states:

	Temperature (°C)	**Pressure (kPa)**	**Enthalpy (kJ/kg)**	**Quality (kg/kg)**
N2	-195.80	101.325	-122.0	0
N2	0	101.325	283,2	Superheated

Table 3.2

The specific enthalpy change:

$$\Delta h_{N2} = h_{N_2(L)} - h_{N_2(G)} = (-122 - 283{,}2)\frac{kJ}{kg} = 405{,}2\frac{kJ}{kg}$$

Required amount of $N_2(L)$ for $CH_4(G)$ liquefaction in Case 3:

$$kg_{N_2(L)} = \frac{\Delta h_{CH4}}{\Delta h_{N2}} = \frac{854{,}8\frac{kJ}{kg}}{405{,}2\frac{kJ}{kg}} = 2{,}1$$

The calculations shows that when the temperature of the liquid nitrogen is raised to the original temperature of the methane gas the process requires 2,1 kg of nitrogen per 1 kg liquid methane yield.

6. Results and conclusions

	$CH_4(L)$	$N_2(L)$
Case 1	1 kg	4.4 kg
Case 2	1 kg	3.6 kg
Case 3	1 kg	2.1 kg

Table 5.1

	$CH_4(L)$	$N_2(L)$
Case 1	227.3 kg	1000 kg
Case 2	277.8 kg	1000 kg
Case 3	476.2 kg	1000 kg

Table 5.2

The calculations are theoretical and do not take into account many factors like e.g. system losses. However, the calculations demonstrates the limit values; case 1 is a lightly achievable instance and case 3 is the theoretical maximum within the given conditions.

Depending on the total efficiency of the system, the actual consumption of liquid nitrogen will likely set between case 2 and 3.