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# Cold recovery during regasification of LNG part two: Applications in an Agro Food Industry and a Hypermarket

Vincenzo La Rocca*

DREAM – Dipartimento di Ricerche Energetiche ed Ambientali, University of Palermo, Viale delle Scienze, Ed. 9, 90128 Palermo, Italy

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ABSTRACT

The paper deals with the cold energy available during LNG regasification, which can be recovered and utilized both inside the LNG regasification area and at a distance, such as in deep freezing agro food industry facilities and for space conditioning in the commercial and residential sector (e.g. Supermarkets and Hypermarkets). The feasibility study of this kind of application has been carried out at DREAM, Palermo University, within the framework of a research program.

The results of a feasibility study of the kind of venture proposed, starting from its conceptual design and with a thorough thermodynamic and economic analysis, demonstrated the suitability and the profitability of the applications proposed. They seem very attractive due to expected wide future exploitation of LNG regasification in the World.



## 1. Introduction

A previous Author's paper deals with the main results of a feasibility study pertaining to the possibility of cold recovery during LNG regasification [1], a modular LNG regasification unit having the regasification capacity of 2 BCM[1]/year of gas is proposed and is based on the use of a Power Cycle working on Ethane: this unit allows the operation of cold energy transfer, contained in LNG to be regasified in a range of temperatures suitable for a multipurpose use of the cold by reducing the regasification process irreversibility.

The recovery of the physical exergy of cold available during the regasification of LNG in a Regasification Plant is of capital interest. The cold contained in LNG has a large environmental impact, usually on the sea near the regasification site. Some studies [2,3,10] have been carried out on the possibility of cold energy recovery in cold technology application facilities (e.g. air liquefaction producing Nitrogen, Oxygen, Argon, deep freeze warehouses, cold storage warehouses and the freezing process of foods etc.). This kind of application has limitations as usually the demand for cold near the site suitable for the regasification is low. Another suitable option could also be the production of electric energy recovering the cold energy available by using the cryogenic stream of LNG during regasification as the cold source in an improved CHP Plant [4–7].

In previous papers [1,3], the main problems arising from the feasibility study of a total venture have been analyzed and a thorough thermodynamic analysis for the Regasification Plant was presented. The research developed includes both cryogenic applications and the industrial use of cold at very low temperatures inside the regasification site and cold utilization by end users far from the regasification site in deep freezing facilities and for space conditioning in the commercial sector (e.g.: Supermarkets and Hypermarkets).

This paper deals mainly with some particular problems pertaining to two kinds of applications, suitable for cold recovery during LNG regasification, which can be utilized outside of the LNG regasification area and at a distance from the site, such as in deep freezing agro food industry facilities and for space conditioning in the commercial and residential sector (e.g. Supermarkets and Hypermarkets). The transfer of cold from the regasification facility to the clusters of Agro Food Industries and the Hypermarkets takes place by means of two pipelines into which carbon dioxide travels [1,3]: in the feeding pipeline the carbon dioxide is in the liquid phase and in the return pipeline, it is in the gaseous phase. Carbon dioxide is liquefied in the regasification facility [3] recovering the cold available in the regasification process. This secondary fluid is pumped in the liquid phase, this selected option allows a considerable saving of pumping power [11] (e.g. for the gaseous phase, it would

* Tel.: +39 091 238 61935; fax: +39 0 91 484425.
*E-mail address:* larocca@unipa.it.

[1] Billion cubic metres.

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be more than 30 times higher in the of the Agro Food Industries Case Study). Carbon dioxide in the liquid phase goes to the clusters of users and feeds the evaporators of cold utilities, the gaseous phase returns back to the regasification facility where it is liquefied and then pumped into the feeding pipeline.

The main problems pertaining to the pipeline systems for the transfer of cold away from the regasification area and their conceptual design have been reported in the previous paper [1], a detailed feasibility analysis of the systems for distribution of liquid carbon dioxide in the users area is presented here. The analysis covers both the thermodynamic and economic analysis of the venture proposed. Moreover, an economic analysis has been made starting from some "scenario" forecasting case-study options, relevant to the occurrence of plant management, considering performance at partial load and its effect both on energy efficiency and on some significant economic performance parameters. This kind of economic analysis was made for both the total regasification modular unit and for each one of the two applications that are at a distance from the regasification area and which have been analyzed. The two cluster areas analyzed have an average distance of 2 km from the regasification site.

## 2. The conceptual design of the carbon dioxide distribution network in the end users area

The possible applications in refrigerating facilities, for recovery and utilization of the physical exergy of LNG during regasification away from the regasification area here analyzed, are of two kinds: one pertains to a cluster of end users made up of Agro Food Industries, where cold is needed for the freezing process of foods and to maintain them at a low temperature; another pertains to users such as Supermarkets and Hypermarkets where cold is needed for space air conditioning, for the refrigeration of display cases and cabinets in the sales area and for the preparation of foodstuffs and their cold storage in cold storage rooms.

Both kinds of applications require a cluster of facilities lying at a distance from the regasification terminal requiring cold, while bearing in mind that an LNG facility design needs to maintain suitable distances, so as to separate land-based facilities from communities and other public areas.

Such problems are of vital importance due to a lack of suitable secondary fluids to transfer the cold from the regasification site to the end users. The reason is that if a common secondary fluid (such as an aqueous solution of organic compounds: alcohols or glycols) is selected to transfer the cold any distance from the regasification site a large mass flow rate of liquid has to be circulated giving rise to special problems in the low temperature range where high viscosity increases the pumping power needed and the fluids can freeze. Recently, nanofluids and ice slurries have also been proposed, but these do not seem to be suitable for this kind of application analysis. A reliable solution could indeed be based on the use of natural fluids such as Hydrocarbons (flammable) or Carbon dioxide. The feasibility study performed for this work indicates that the use of Carbon dioxide is suitable, moreover it is a natural and inflammable fluid.

The mean single regasification capacity in the regasification sites planned throughout the world is $8 \times 10^9$ $Stm^3/y$, a regasification facility such as that proposed in Ref. [1] has a regasification capacity of $2 \times 10^9$ $Stm^3/y$ and it has a potential capacity of recovery of the entire cold power available of more than 50 MW and can produce 3 MW of electric power.

The power required by a cluster including Agro Food Industries amounts to 9 MW of cold delivered at a mean temperature of −43 °C. The end use in the Hypermarket pertains mainly to the process of space air conditioning and a quantity of cold is required

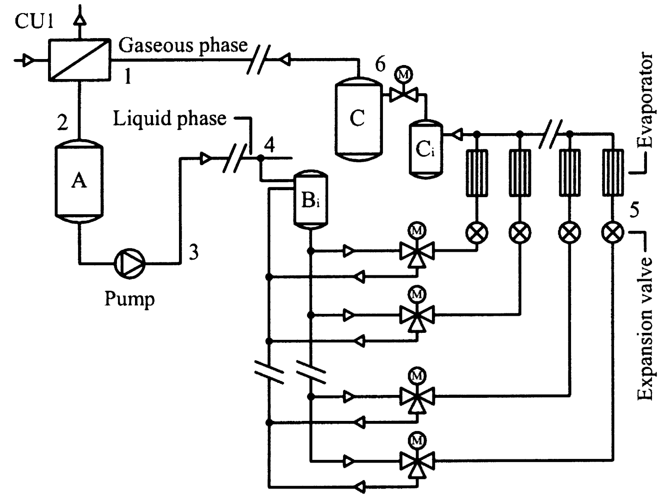


**Fig. 1.** System for transfer and utilization of cold in Agro Food Industries.

in the refrigeration utilities. The total amount of power required is of 7.5 MW: 7.0 MW for space conditioning and 0.5 MW of cold, of which 150 kW is delivered as cold at −35 °C and the remaining part delivered as cold at −15 °C.

The transfer of cold between the regasification facility and the clusters of Agro Food Industries and the Hypermarket takes place by means of two pipelines into which carbon dioxide travels: in the liquid phase in the feeding pipeline and in the gaseous phase in the return pipeline. Carbon dioxide is liquefied in the regasification facility recovering the cold available in the regasification process [1,3]. This secondary fluid is pumped in the liquid phase, the selected option allows a considerable saving of pumping power (e.g. for the gaseous phase it will be more than 30 times higher in the Agro Food Industries' Case Study).

Carbon dioxide in the liquid phase goes to the clusters of users and feeds evaporators of cold utilities, in the gaseous phase it returns back to the regasification facility where it is liquefied and then pumped into the feeding pipeline.

### 2.1. Agro Food Industries

Fig. 1 shows a process sheet of the condensation facility and of the liquid carbon dioxide pumping station lying in the regasification site[2] (exchanger CU1, receiver A and carbon dioxide liquid Pump). In the same figure a schematic sheet of some end uses and the storage system ($B_i$) of the liquid carbon dioxide installed ahead of the end uses in each Industry is shown. The gaseous phase returning from the evaporators of an Industry comes into the receiver ($C_i$) which collects all the gaseous carbon dioxide returning from the Industry. From this device gaseous carbon dioxide goes (almost dry) into a common receiver (C installed in the cluster area) and then it goes into the return pipeline which collects all the gaseous carbon dioxide returning back from the total Cluster of Industries.

In Ref. [1] the process which takes place in the secondary line (the carbon dioxide pipeline) has been analyzed. In Fig. 1, the numbers 1–2 make reference to the condensation process (at a mean pressure of 7 bar) of the gaseous phase returning from the cluster users. The evaporation process takes place in the evaporators in the Industries. From $B_i$ to $C_i$ there is a distribution and utility line of a given Industry. The 6–1 line indicates the return common

[2] see Ref. [1] Fig. 1, heat exchanger CU1.