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Advanced exergy analysis applied to the process of regasification of LNG (liquefied natural gas) integrated into an air separation process

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ABSTRACT

Natural gas is one of the most important sources of energy, the demand for which increases continuously. The LNG (liquefied natural gas) market rises currently exponentially; many countries entered this market recently. Applying an efficient regasification process for LNG is now more important than in the past. At present, mainly regasification of LNG via direct or indirect heating is used for industrial applications. Regasification of LNG can also be combined with generation of electricity. Another possibility is the integration of the regasification into a processes requiring low temperatures. A new concept dealing with the integration of regasification of LNG into a cryogenic process of air separation has recently been developed at Technische Universität Berlin. This paper evaluates two options of integrating the regasification of LNG into an air separation system. Conventional and advanced exergy analyses are used in the evaluation.

1. Introduction

The increasing demand for energy sources all over the world leads to a growing demand for natural gas. It is expected, that natural gas will provide approximately 30% of the primary energy supply in the world by 2030 [1]. In connection with natural gas also the global market for LNG (liquefied natural gas) is growing rapidly. For example, the Asian LNG market has a large effect with 75% of the global demand for LNG [1]. The use of LNG has several advantages compared to gaseous natural gas, including lower transportation costs in case of a distance longer than 2000 km [2] and flexibility to receive LNG from different countries. A disadvantage is the large cost for the complete LNG chain, which consists of liquefaction, transportation, storage and regasification. However, with improving technologies and with the increasing number of LNG plants during the last years, the total cost for the LNG chain has been decreasing [3]. At the end of 2013 there were 86 liquefaction plants in operation in 17 exporting countries [4]. Also, the number of LNG import terminals and the number of countries with LNG receiving terminals increased during the last years (104 import terminals in 29 importing countries [4]).

The regasification is mostly accomplished via direct or indirect heating. In these cases the source of thermal energy is seawater, air or combustion gases generated through the combustion of natural gas. Just few import terminals are using process integration for the regasification of LNG. Thus LNG could be implemented in a process to generate electricity in a cogeneration system [5] or a Rankine-Cycle system [6]. A further option is the implementation of the regasification of LNG in a desalination process, which lowers the power consumption [7]. Introducing LNG in a process and using the cold energy offers a great potential for improving the original process from the thermodynamic and economic points of view.

This paper deals with the integration of regasification of LNG into an air separation process. In some LNG important terminals in China, Japan, Taiwan and France similar integration technologies have already been implemented [8].

An attempt to combine the regasification of LNG with a cryogenic process has been reported in Refs. [9,10]. Here a revised version of this concept and a new developed option of integration are discussed. The systems are evaluated from the exergetic point of view. Also, the results from an advanced exergy analysis are reported for both systems. In addition, a parametric study is conducted to analyze the effect of the LNG pressure on the overall systems.

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2. Process description

The two processes (Design 1 and Design 2) consist of four main blocks: (1) air compression and purification block, (2) liquefaction of air in the MHE (main heat exchanger), (3) column block, and (4) nitrogen liquefaction block.

The heat exchangers to liquify the air (MHE and HE (heat exchanger) (in Design 2)) and the column block are embedded in a component, which is called “cold box”. The nitrogen liquefaction block could have different designs.

The column block consists of a double-column system. For the simulation of the cryogenic columns, important design parameters such as the reflux ratios and the number of stages [11] are considered. At the top of the high-pressure column almost pure nitrogen (gaseous) is leaving. The bottom product which is an oxygen rich mixture is throttled and enters the low-pressure column. Regarding this column the bottom products are liquid and gaseous oxygen and the top product is gaseous nitrogen. A by-product of the low-pressure column is a stream, which consists of non-condensable gases (purge gas). The column block is identical in both systems and was simplified compared to the single air separation plant in Ref. [9]. Here we assumed that the air is only separated into nitrogen and oxygen.

2.1. Design 1

Fig. 1 shows the conceptual flowsheet of Design 1. The air at ambient conditions is compressed to 5.6 bar [12] in a two stage compression process. Before the air enters the first compressor dust particles are removed. Between both compressors the air is cooled

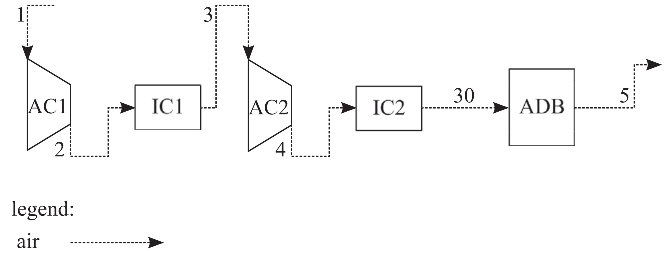

Fig. 2. Schematic of the air compression and purification block in Design 1.

down in an IC1 (interstage cooler) as shown in Fig. 2. In real air separation plants impurities such as water, carbon dioxide, hydrocarbons like acetylene and nitrous oxide have to be removed after the second compressor before the air enters the main heat exchanger. While water, carbon dioxide and nitrous oxide freeze out at low temperatures and will cause problems in operation within the downstream components, acetylene is highly flammable in combination with oxygen or oxygen enriched air. In this simulation, it is assumed that water and carbon dioxide are of particular importance and need to fulfill the following limitations [13] to prevent especially the main heat exchanger from being blocked due to the freezing of both impurities: Water vapor must be less than 0.1 ppm and carbon dioxide less than 1.0 ppm. There are several technologies to remove the impurities. In earlier times a reversing heat exchanger was used to purify the air [12]. State of the art is an adsorption process (temperature swing adsorption or pressure swing adsorption) [14]. In general the adsorption process consists of two separate beds which are working alternatively. If the air is

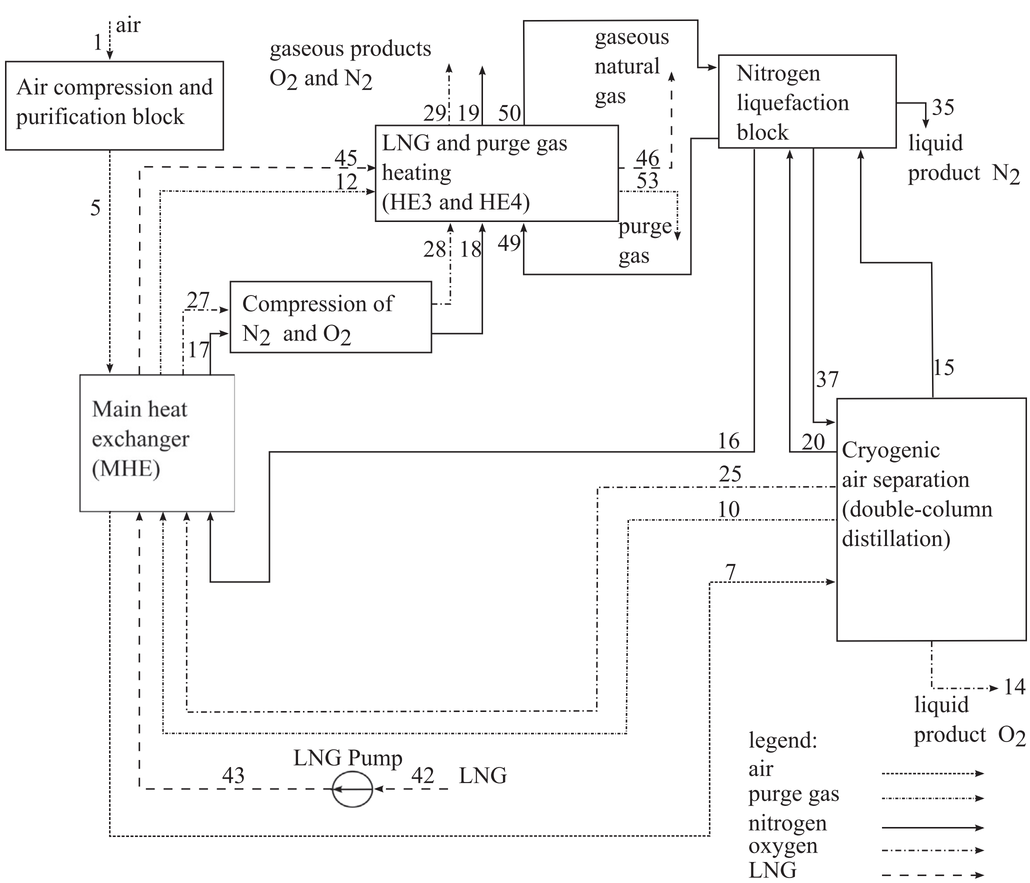

Fig. 1. Conceptual schematic of Design 1.