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Development and analysis of a natural gas reliquefaction plant for small gas carriers

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ABSTRACT

A small-scale reliquefaction plant for natural gas boil-off gas from gas tankers has been developed, analysed and experimentally tested in laboratory and in full-scale. The reliquefaction plant is installed onboard a 10 000 m^3 gas carrier intended for transport of LNG between export and receiving terminals, initially in Scandinavia and in the Baltic Sea. Typical production capacity of a full-scale plant is 20 tonnes of LNG per day. Standard refrigeration components, easily available as off the shelf products, are used in the system design. Copper brazed plate heat exchangers are among the key components. The combination of using a lubricant injected screw compressor and a mixed component refrigerant contributes to achieve relatively high energy efficiency. The gas carrier is also designed to carry other gases such as ethylene, LPG and VCM, and is therefore equipped with a newly developed ordinary cascade refrigeration plant. When the vessel is in LNG service the capacity of the cascade plant is used for precooling of LNG boil-off as well as for precooling of the mixed component refrigerant. A theoretical analysis of the plant shows a specific power consumption of 0.49 kWh/kg LNG, corresponding to an exergy efficiency of 34%. The specific suction volume is 1.8 m^3/kg LNG with the current mixed refrigerant composition. The loss analysis shows several possible improvement possibilities. Successful full-scale tests have been performed, verifying the liquefaction capacity and operation of the plant.

1. Introduction

In the near future small LNG carriers will be used to distribute LNG to areas where natural gas is not available today. The gas will be used by industrial customers and within the transport sector. These gas carriers will with its technology reliquefy LNG boil-off gas (BOG) in order to be able to deliver fully refrigerated LNG to customers without product loss. A picture of the new 10 000 m^3 gas carrier, the first in a series of 6, is shown in Fig. 1.

Small-scale natural gas liquefaction units are challenged on being cost and energy efficient. It is, for the gas carrier operator, important to reduce investment and operational costs of each unit. Therefore the keywords during the design have been simplicity, efficiency and highest possible production capacity within the power supply available, within the limits of standard available components in the market.

A concept achieving a low cost and at the same time maintaining fairly high-energy efficiency has been developed. This concept is frequently referred to as the “mini-LNG” concept. The low cost and high efficiency is achieved by using standard refrigeration components in combination with advanced refrigeration techniques. The paper will describe the concept in more detail, present theoretical analysis and a comparison with experimental results achieved.

2. The small-scale liquefaction concept

The main components of the mini-LNG liquefaction unit are copper brazed plate heat exchangers, a liquid–vapour separator, a lubricant injected screw compressor, cryogenic valves and tubing. These are mostly standard refrigeration components easily available at relatively low cost. The selection contributes to shorter manufacturing time of each unit contrary to when using more tailor made components which tend to make things more complex and costly.

In order to obtain high-energy efficiency, a mixed component refrigerant in combination with a lubricant injected screw compressor is used. Process losses are reduced to a minimum by optimising the refrigerant composition to the operating conditions. Natural gas composition, pressure and temperature need to be

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Fig 1. The multigas carrier with the reliquefaction plant located mid-ship on the top deck.

considered. The mixed component refrigerant enables small temperature differences in the heat exchangers by adapting the temperature glides of the two streams, even with a relatively simple system design. An energy efficient concept is thereby obtained without using more sophisticated system layouts commonly used for large-scale plants, cascade systems or gas processes requiring at least one expander.

By using a standard lubricant injected compressor the need of a very good lubricant handling system had to be introduced Even smaller amounts of lubricant brought down to the lowest temperatures may cause clogging of the heat exchangers as well as smaller flow channels in other components. The concept developed ensures all lubricant to be kept at the higher temperature levels.

2.1. Process description

Fig. 2 shows a flow diagram of the simplified one-separator mini-LNG concept, also described in Brendeng and Nekså (2006), as implemented for the reliquefaction plant. The concept is a further development and simplification compared to the two-separator

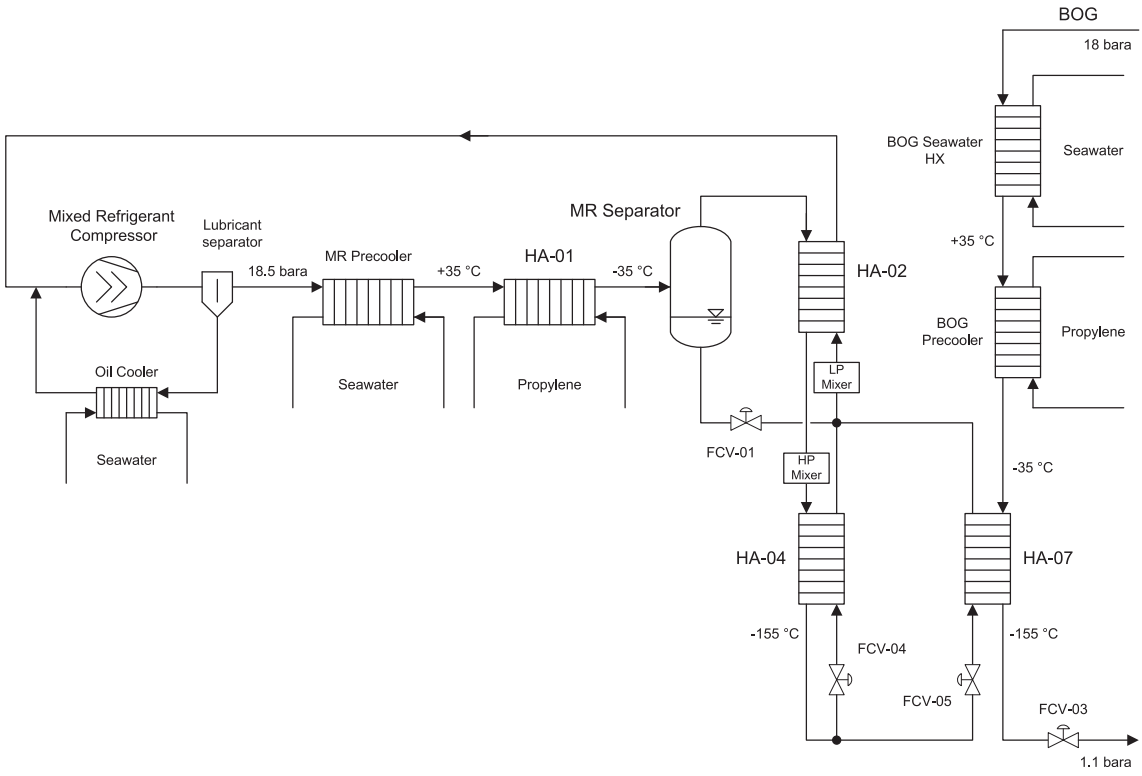

Fig. 2. Flow diagram of the small-scale reliquefaction plant using the mini-LNG concept.