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Design and analysis of a small-scale natural gas liquefaction process adopting single nitrogen expansion with carbon dioxide pre-cooling

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HIGHLIGHTS

- A novel small-scale liquefaction process used in stranded gas is designed.
- The adaptability of this process under different pressure, temperature and compositions of feed gas is studied.
- The exergy analysis of main equipment in the process is analyzed.

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ABSTRACT

With the growth of energy consumption and environmental protection concerns, it is of enormous economic and environmental values for the development of stranded gas. As a means for exploitation and transportation of stranded gas to market, a novel small-scale liquefaction process adopting single nitrogen expansion with carbon dioxide pre-cooling is put up with in this paper. Taking unit energy consumption as the target function, Aspen HYSYS is employed to simulate and optimize the process to achieve the liquefaction rate of 0.77 with unit energy consumption of 9.90 kW/kmol/h. Furthermore, the adaptability of this process under different pressure, temperature and compositions of feed gas is studied. Based on the optimization results, the exergy losses of main equipment in the process are evaluated and analyzed in details. With compact device, safety operation, simple capability, this liquefaction process proves to be suitable for the development of small gas reserves, satellite distribution fields of gas or coalbed methane fields.

1. Introduction

An expanding population and economic growth are main causes of increasing global energy demand [1]. World energy consumption increases from 524 quadrillion Btu in 2010 to 630 quadrillion Btu in 2020 and 820 quadrillion Btu in 2040, with a 30-year increase of 56 percent [2]. Among those, natural gas, an environmentally attractive fuel compared with other hydrocarbon fuels, continues to be favored due to abundant resources and robust production. To satisfy such a demand of the natural gas, a number of gas fields are under development such as scattered onshore and offshore gas fields, associated gas from oil fields, coalbed methane from coal mines, which were vented to atmosphere or flared due to the status of technologies and economic situations once upon a time, resulting in great loss of energy and damage to the environment.

Stranded gas refers to some gas resources remote from markets or pipelines, or other gas resources close to markets whose reserves are too small to be piped economically [3], in other words, the gas in discovered or identified fields that is not currently commercially producible for either physical or economic reasons [4]. Based on the data of IHS International Field File (2008a), E.D. Attanasi and P.A. Freeman [4–7] have estimated the world total recoverable stranded gas volumes both in gas and oil fields except North America (Table 1), the development of which is quite likely the most cost-effective means for quickly increasing gas production capacity.

Benefited from the technological advance of natural gas industry, there exist three options currently for stranded gas exploitation and transportation to markets. They are 1) gas to transitory medium by volume reduction such as LNG (Liquefied Natural Gas) [8–11], CNG (Compressed Natural Gas) [12], and NGH (Natural Gas Hydrate) [13,14], 2) conversion to other products (GTL)

Abbreviations: LNG, Liquefied Natural Gas; CNG, Compressed Natural Gas; NGH, Natural Gas Hydrate; GTL, gas to liquid; GTW, gas to wire; C3/MRC, mixed refrigerant cycle liquefaction process with propane pre-cooling; N_2–CH_4, N_2–CH_4 expander cycle process; N_2–CO_2, N_2 expander cycle process with CO_2 pre-cooling.

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Table 1
Volumes, in Tcf, of recoverable stranded gas in producing oil and gas fields.

Country situation	Stranded gas in gas fields	Stranded gas in oil fields	Total
South America	145	55	200
Europe	119	20	139
Middle East	304	584	888
Africa	219	100	319
South Asia	57	3	60
East Asia	171	26	197
Transcaucasia	301	44	345
Southeast Asia and Oceania	433	43	476
Russia	864	90	954
Grand total of all regions except North America	2612	966	3578

[15,16], and 3) conversion to other energy form such as electric power and transmission by subsea cable to shore (GTW) [8,16]. As a means of transporting natural gas to consumers, LNG has a history of almost 100 years. In the last decade, not only has there been a proliferation of liquefaction and regasification plants, but also a rise in LNG production and transport capacity has increased [17]. Whereby, the small-scale natural gas liquefaction process has got its rapid evolution and attracted the attentions of the investors for the development of stranded gas, with advantages of low investment, simple and compact process, start-stop convenience, strong mobility and mature progress.

Several processes have been reported for natural gas liquefaction, mainly in three types: cascade liquefaction process [18]; mixed refrigerant liquefaction process [19–21]; expander liquefaction process [22,23]. The comparison among these liquefaction processes have been conducted by lots of experts on energy consumption, exergy analysis and economic performance. Some selected mixed refrigerant process for the best choice of energy consumption consideration [24,25], while some recommended the expander cycle [23]. Nevertheless, the recent research has indicated that nitrogen expansion [26] is the most adaptive process combing energy consumption, economic performance, safety, sensitivity to motion and operability into consideration.

Adopting a pre-cooling process with propane, propylene or carbon dioxide, which is a more efficient refrigeration method in the high temperature range, can consequently reduce power consumption efficiently [27–30]. Being safe, non-toxic, environmentally friendly, and non-combusted, carbon dioxide brings great convenience for production and storage, in favor of reducing device size and capital expenditures. What's more, compared with the hydrocarbon refrigerants used for natural gas liquefaction, carbon dioxide can achieve the same cooling effect, with incomparable advantage of being easy to obtain, resulting in low price.

This paper puts forward a novel natural gas liquefaction process adopting single nitrogen expansion with carbon dioxide pre-cooling in use of small gas reserves, satellite distribution fields of gas or coalbed methane fields. Taking unit energy consumption as the major index for analysis, the optimized parameters of the liquefaction process are calculated to achieve the liquefaction rate of 0.77 with unit energy consumption of 9.90 kW/kmol/h. Based on the results, the effects of different feed gas conditions on unit

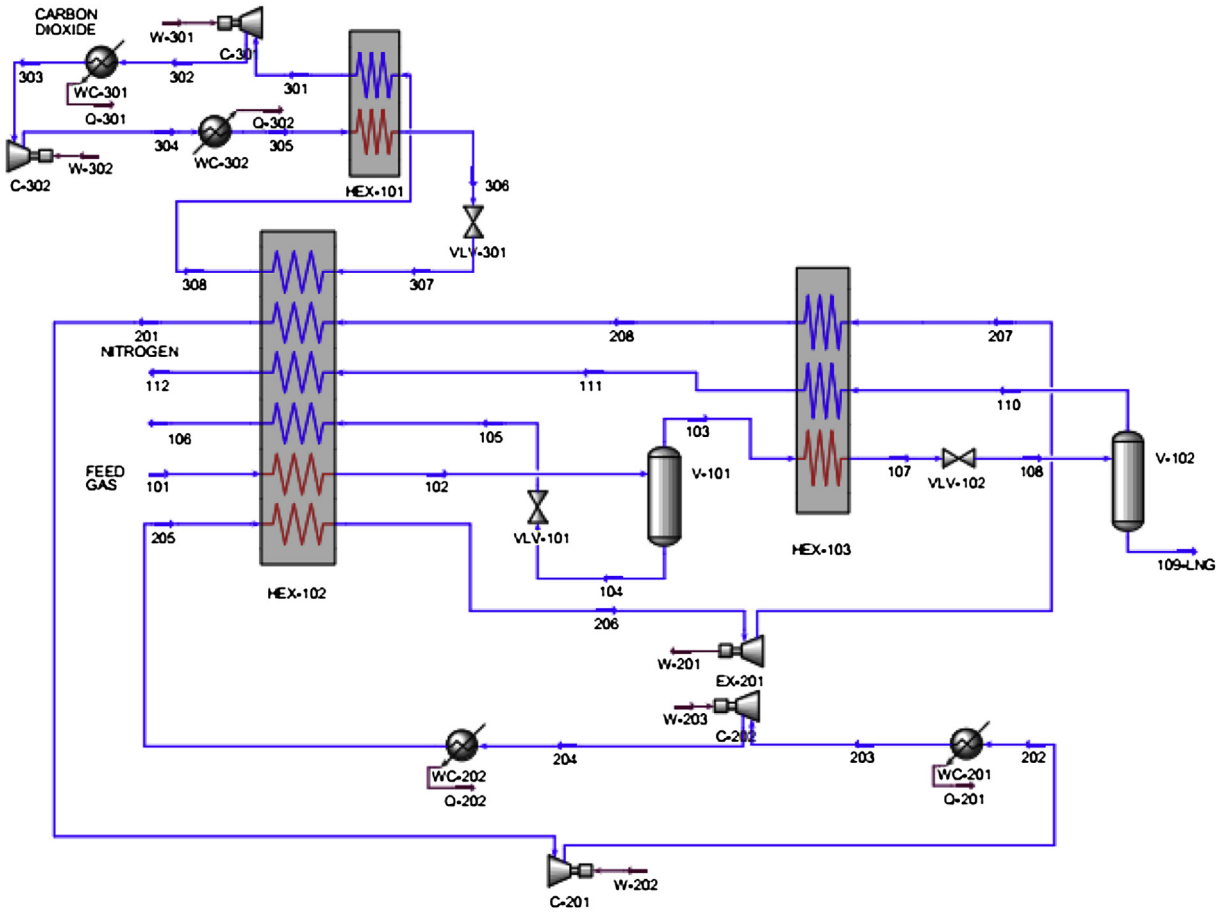

Fig. 1. The process of single nitrogen expansion with carbon dioxide pre-cooling.