SMALL-SCALE PRODUCTION OF LNG FROM LOW-PRESSURE PIPELINE GAS BY AN INNOVATIVE METHANE EXPANSION CYCLE (PATENT PENDING)

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ABSTRACT

This paper outlines a method for the liquefaction of low-pressure Natural Gas, using an innovative variant of the Methane Expansion Cycles (MEC). The proposed technology will allow commercially viable small-scale LNG plants by way of low capital costs and high-efficiency. The single-fluid MEC will yield more than 80 units of product for every 100 units of feed stream, with less than 20 units used as fuel.

INTRODUCTION

Small scale natural gas liquefaction plants have a growing interest for a number of different applications. In this paper it is considered a method for the on site production of vehicle-grade Liquid Natural Gas (LNG) from low-pressure natural gas pipelines. The resultant LNG has to fall within a cost framework so that it can compete with diesel fuel on a cost per BTU basis, where both fuels seek bus or truck fleets as customers.

There are no such commercially viable Small-Scale LNG production facilities anywhere in the world, where by “Small-Scale” we mean less than 10,000 gallons/day (40-50 tones of LNG per day). There is, however, a much higher upper limit on the range of LNG vehicle fuel and peak shaving applications up to 100,000 GPD. Thus, any existing LNG-fuelled fleet must depend on deliveries by tanker truck from larger-scale LNG plants or from LNG import terminals. That condition increases the cost of the LNG to the end user, because the delivered price must include the substantial cost of transporting the LNG from the production or import location to the customer. Those transportation costs tend to outweigh the lower production costs of large-scale LNG manufacture, where there is a large distance between the LNG source and the customer.

The customer must also maintain a large LNG storage tank so that deliveries can be spread out in time. Such tanks produce "boil off" which is generally vented to the atmosphere, causing methane emissions and loss of product, further increasing the net cost of the LNG. Heat gain to the storage tank, in the absence of on-site liquefaction, results in an LNG product that is not the ideal density for the vehicle's fuel tank. Re-liquefaction to avoid boil-off or to increase the product's density is not an option without an on-site LNG plant.

The alternative that is commonly used is on-site Compressed Natural Gas (CNG) production, using the local natural gas pipeline as the feed source. However, such CNG systems have severe limitations, including that the on-vehicle storage of CNG is limited by the need for heavy, high-pressure CNG tanks that store relatively little product, compared to the much denser LNG, and thus limit the travel range of the CNG vehicle.

The abovementioned MEC yields cost-effective (low-capital cost), and highly-efficient on-site Small-Scale LNG plants that allow natural gas fuelled fleets to produce, store, and dispense LNG at precisely their daily need, without depending on tanker-delivered LNG of varying quality, and without the need to opt for the less storable and less dense CNG.

1. THE SMALL SCALE LNG PLANT CONCEPT

1.1 Methane Expansion Cycle main features

This innovative MEC is a major advance in LNG production, because the only LNG plants that use methane cycles are letdown plants. Letdown plants, by definition, rely on high-pressure feed gas, and have the opportunity to send out large quantities of low-pressure natural gas. Instead this small-scale MEC achieves a good degree of the efficiency available to turbo-expander LNG plants, but at much lower capital costs, and without the need for a high-pressure pipeline or a low-pressure outflow “sink”.

This MEC assumes that a low-pressure natural gas pipeline is available adjacent to the fleet that will use the LNG and that the natural gas is delivered at a pressure of 60 psia (4 bar) or greater; at a temperature of approximately 50 - 70°F. The low-pressure pipeline stream is separated into a fuel stream that provides fuel to a natural gas fired internal combustion engine and into a product stream to be compressed and liquefied.

The process is composed of two main parts, called from now on Front End and Back End (Figure 1). In the Front End the pipeline gas is compressed up to the cycle operating pressure and it is partially precooled. In the Back End the compressed gas is refrigerated and liquified by the combined action of a Joule Thompson valve and a turbo-expander. The Front End and the Back End interacts between them by two counter corrent streams: the compressed feed gas stream and the recycle stream The feed gas stream from the Front End to the Back End that is liquified, is sent to the cryogenic tank. The non-liquified portion of this product stream is sent back to the Front End. A cold recovery from the recycle stream is performed in order to increase the overall cycle efficiency.

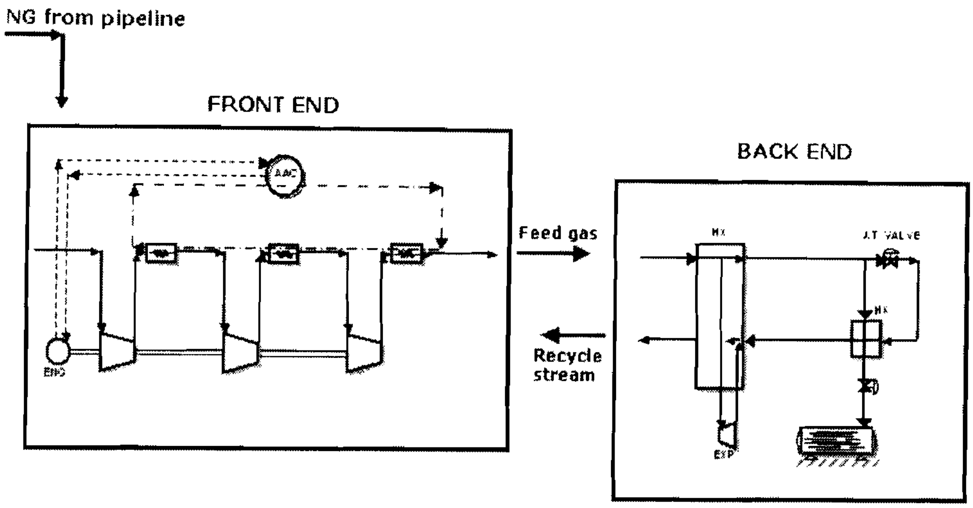

Figure 1: *MEC diagram*

1.2 Front End

The first innovation in the small-scale MEC is the use of a CNG station and/or standard CNG equipment to produce LNG. The feed gas to the LNG plant is compressed, in stages, from 4 bar to approximately 30 bar (58 – 435 psia). That choice is an essential feature of the cycle, yielding a good balance between compressor work in the Front End and refrigeration output at the Back End of the cycle. In fact operating a CNG compressor at lower pressures reduces the compressor's workload and reduces the "heat of compression" that is absorbed by the natural gas. On the contrary, selecting a pressure range much lower than 30 bar (435 psia) yields less potential refrigeration input from JT valves or expanders, later on in the cycle.

The single CNG compressor performs two functions. It is both the feed gas compressor and the recycle compressor. This is possible because the MEC is an "all methane" cycle, where the working fluid and the feed stream are both methane.

The CNG compressor's inter-coolers and after-cooler are integrated with refrigeration sources. One refrigeration source is cold recovery from the low-pressure recycle stream that leaves the Back-End at –30 °F. The other refrigeration source is an absorption chiller powered by waste heat from the prime mover. The absorption chiller uses water-ammonia as working pair and cools the CNG stream in the after-cooler down to as cold as –30 °C.

The pre-cooled CNG (at about 435 psia) is sent to the Back End into a heat exchanger where it is further cooled, condensed, and is liquefied and sub-cooled to produce LNG.

1.3 Back End

Known refrigeration "producers", such as Joule Thompson valves and turbo-expanders are integrated at the "Back-End" to convert the cold CNG produced in the front into LNG.

The first refrigeration source is a Joule Thompson (JT) valve. The pre-cooled CNG at about 435 psia and –22 °F is sent through the single heat exchanger where it is cooled to –170°F by the other streams within the exchanger. That combination of pressure and temperature allows for the use of a "plate fin" heat exchanger, rather than a more-expensive coil wound unit, and yields a worthwhile amount of JT refrigeration. In fact a portion of the -170 °F stream, at about 435 psia is sent through the JT valve, which by Joule Thompson Effect yields –252°F vapor and liquid at a pressure of only 19 psia. That cold vapor and liquid stream is used to sub-cool the portion of the stream that is still at –170 °F and 435 psia, cooling it to –157°C. The sub-cooled product is dropped in pressure to 3 bar; forming LNG at –250°F in the storage tank, without any "flash" (vapor) formation. The low-pressure stream that cooled the main product stream in the sub-cooler is sent back toward the beginning of the process as part of the recycle stream. This is an important aspect of the cycle: the balanced use of a cold, low pressure recycle stream to achieve fairly deep cooling of the "moderate" pressure main stream.

The second source of refrigeration, the turbo expander, is needed because the JT effect alone is not efficient enough. The cryogenic methane expander converts cold CNG to colder, lower-pressure natural gas. The expander work can be recovered and can be applied toward the re-compression of the recycle stream, further reducing the workload of the CNG compressor and the need to fuel the prime mover. The methane expander receives that portion of the main stream from the heat exchanger that did not travel toward the JT valve. That second stream is expanded to about 3 bar, and thus cooled to approximately –220°F and sent back to the heat exchanger for cooling the other streams in the heat exchanger. It exits the heat exchanger at 1.2 bar and –32°F and returns to the compressor in the Front End, but not before cooling down the inter-coolers of the compressor.

1.4 Performance

The ability to economically produce vehicle-grade LNG is achieved by two aspects of the small-scale MEC: low capital costs and high-efficiency.

The MEC has been simulated with Hysys by AspenTech [1] using PRSV equation of state [2]. This LNG production cycle yields approximately 80% LNG out of every unit of natural gas that is delivered to the plant from the local low-pressure pipeline, with only 20% of the natural gas used as fuel for the prime mover.

The high efficiency is achieved by energy recovery in the process in different ways, mainly by the use of an absorption chiller and by cold recovery from the recycle stream.

Natural gas liquefaction capacity	260 Lb/h
Engine power	113.8 kW
Power consumption of compressor	108 kW
Power Output of expander	16 kW

Water cooling duty	88 kW
Refrigeration load of absorption chiller	43.7 kW
Plant production ratio (LNG produced by mass/NG inlet by mass)	0.80
Specific energy consumption	0.44 kWh/Lb LNG

Figure 2: *Results of liquefaction process simulation*

In fact the chiller is powered by the waste heat from the prime mover, recovering a significant portion of the approximately 67% of the energy content of the fuel used by the engine that is normally "wasted" by the engine's exhaust and water jacket. That recovered heat will increase the 33% thermal efficiency of the engine to a practical efficiency of approximately 43%, through the refrigeration output from the absorption chiller.

Moreover the cooling of the compressor inlet streams results in approximately a 10% reduction in compressor power usage. This feature alone increases the efficiency of the prime mover from 33% to 36.5%, or approximately 10 kW. At the scale of the cycle, and with pipeline gas as the feed source, that power reduction is important.

It has been evaluated that such a plant with a production of less than 10,000-liters/day of LNG can be constructed for less than 1,000,000 euros.

CONCLUSIONS

The described method to liquefy natural gas is an innovative variant of the Methane Expansion Cycle. It allows commercially viable small-scale LNG plants to produce vehicle-grade LNG by way of low capital costs and high-efficiency. Process description shows how existing CNG compressors and other "off-the-shelf" equipment can be integrated into small-scale LNG production, where the heat of compression is mitigated and the natural gas is pre-cooled by an absorption chiller, which is powered by waste heat from the prime mover. The MEC uses moderate-pressure CNG as both the working fluid and the product stream, liquefying a significant portion of the CNG stream and returning a low-pressure recycle stream for re-compression, but only after several cold recovery steps. The single-fluid MEC yields more than 80 units of product for every 100 units of feed stream, with less than 20 units used as fuel. Process optimizations and industrialization improvement have been studying in order to achieve a 90/10 ratio of product to fuel use.

REFERENCES

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