

CLAIMS

What is claimed is:

1. A liquefied natural gas (LNG) production system, comprising:

a main cryogenic heat exchanger;
a natural gas liquefaction subsystem; and
a refrigeration subsystem comprising:

a plurality of refrigerant compressors configured into a series arrangement and a plurality of refrigerant recompressors configured into a series arrangement, wherein the last outlet of the plurality of refrigerant compressors is coupled to the first inlet of the plurality of refrigerant recompressors so that a refrigerant is compressed in a-to-perform multi-stage compressions of a refrigerant manner when it flows through the series compressors and recompressors; and wherein the compressors are driven by gas turbine or electrical motors and the recompressors are driven by expanders,

a plurality of aftercoolers each of which being coupled to each of the plurality-pluralities of refrigerant compressors and recompressors to cool the compressed refrigerant after each stage of compression; wherein the compressed refrigerant is not expanded before leaving the last outlet of the aftercoolers,

a plurality of turboexpanders ~~coupled to the last aftercooler and~~ configured into a series configuration, wherein the first inlet of the plurality of turboexpanders is coupled with the last outlet of the aftercoolers and the first outlet of the plurality of turboexpanders is coupled with the inlet of subsequent turboexpander to perform multi-stage expansions of the compressed refrigerant, and

a plurality of refrigerant heat exchange means coupled to both the first inlet of the plurality of refrigerant compressors and the last outlet of the plurality of turboexpanders, so that all components form a close refrigeration cycle;

wherein the main cryogenic heat exchanger facilitates heat exchange between a pressurized natural gas passing through the natural gas liquefaction subsystem and a refrigerant passing through the refrigeration subsystem so that the pressurized natural gas

in the natural gas liquefaction subsystem is liquefied by the refrigerant in the refrigeration subsystem.

2. The LNG production system of claim 1, wherein the main cryogenic heat exchanger is a multi-stream heat exchanger.

3. The LNG production system of claim 1, wherein the natural gas liquefaction subsystem comprises:

- a gas treatment module for treating the pressurized natural gas so as to make it suitable for being liquefied;

- a natural gas heat exchange means fluidly/gaseously coupled with the gas treatment module and disposed within the main cryogenic heat exchanger for enabling the passing-through pressurized natural gas to exchange heat with countercurrent refrigerant flows; and

- a natural gas pressure reduction means fluidly/liquidusly coupled with the natural gas heat exchange means for controlling the reduction of the pressure of the cooled pressurized natural gas from the natural gas heat exchange means so as to further reduce the temperature of the pressurized liquefied natural gas, yielding LNG and flash gas.

4. The LNG production system of claim 3, wherein the natural gas pressure reduction means is Joule-Thomson (J-T) valve, two-phase expander or liquid expander.

5. The LNG production system of claim 1, wherein the refrigeration subsystem comprises:

- a first refrigerant compressor;

- a first refrigerant aftercooler coupled to the first refrigerant compressor;

- a second refrigerant compressor coupled to the first refrigerant aftercooler;

- a second refrigerant aftercooler coupled to the second refrigerant compressor;

- a first refrigerant recompressor coupled to the second refrigerant aftercooler;

- a third refrigerant aftercooler coupled to the first refrigerant recompressor;

- a second refrigerant recompressor coupled to the third refrigerant aftercooler;

- a fourth refrigerant aftercooler coupled to the second refrigerant recompressor;

a first refrigerant heat exchange means disposed within the main cryogenic heat exchanger and coupled to the fourth refrigerant aftercooler to intermediate cool the compressed refrigerant;

a first turboexpander coupled to first refrigerant heat exchange means to first expand the compressed refrigerant;

a second turboexpander coupled to the first turboexpander to second expand the first expanded refrigerant; and

a second refrigerant heat exchange means disposed within the main cryogenic heat exchanger and coupled to the second turboexpander and the first refrigerant compressor.

6. The LNG production system of claim 5, wherein the refrigeration subsystem further comprises a third refrigerant heat exchange means disposed within the main cryogenic heat exchanger, wherein the upstream inlet of the third refrigerant heat exchange means is coupled to one downstream outlet of the first turboexpander while the downstream outlet of the third refrigerant heat exchange means is coupled to one upstream inlet of the second refrigerant compressor; and wherein during operation, the refrigerant after the expansion by the first turboexpander is split into two streams with a ratio of 30/70 to 60/40, one stream (30-60% of full stream) being introduced into the third refrigerant heat exchange means to serve as a cold stream in the main cryogenic heat exchanger, and the other stream (40-70% of full stream) being further expanded by the second turboexpander and then being introduced into the second refrigerant heat exchange means to serve as the coldest stream for the sub-cooling of the liquefied natural gas.

7. The LNG production system of claim 5, wherein the refrigeration subsystem further comprises an inter-cooler disposed within the main cryogenic heat exchanger and between the first and second turboexpanders.

8. The LNG production system of claim 6, wherein the refrigeration subsystem further comprises an inter-cooler disposed within the main cryogenic heat exchanger and between one stream from the first turboexpander and the second turboexpander.

9. The LNG production system of claim 7, wherein the refrigerant subsystem further comprises a third expansion device and a second intercooler, both being disposed between the second turboexpander and second refrigerant heat exchange means, and the second turboexpander provides one stream to the third expansion device via the second intercooler.

10. The LNG production system of claim 7, wherein the refrigerant subsystem further comprises a third expansion device and a second intercooler, both being disposed between the second turboexpander and second refrigerant heat exchange means, and the second turboexpander provides two split refrigerant streams, one feeding back to a fifth refrigerant heat exchange means disposed within the main cryogenic heat exchanger and the other to the third expansion device via the second intercooler.

11. The LNG production system of claim 8, wherein the refrigerant subsystem further comprises a third expansion device and a second intercooler, both being disposed between the second turboexpander and second refrigerant heat exchange means, and the second turboexpander provides two split refrigerant streams, one feeding back to a fifth refrigerant heat exchange means disposed within the main cryogenic heat exchanger and the other to the third expansion device via the second intercooler.

12. A method for producing liquefied natural gas by means of a single phase gaseous refrigerant in a close loop, comprising

providing a main cryogenic heat exchanger in which heat exchange occurs;

providing a pressurized natural gas stream that flows through the main cryogenic heat exchanger to get liquefied; and

providing cold energy to the main cryogenic heat exchanger by a refrigeration device; wherein the refrigeration device comprises:

a plurality of refrigerant compressors configured into a series arrangement and a plurality of refrigerant recompressors configured into a series arrangement, wherein the last outlet of the plurality of refrigerant compressors is coupled to the first inlet of the plurality of refrigerant recompressors so that a refrigerant is

compressed in a-to-perform multi-stage compressions of a refrigerant manner when it flows through the series compressors and recompressors,

a plurality of aftercoolers each of which being coupled to each of the plurality-pluralities of refrigerant compressors and recompressors to cool the compressed refrigerant after each stage of compression; wherein the compressed refrigerant is not expanded before leaving the last outlet of the aftercoolers,

a plurality of turboexpanders coupled to the last aftercooler and configured into a series configuration, wherein the first inlet of the plurality of turboexpanders is coupled with the last outlet of the aftercoolers and the first outlet of the plurality of turboexpanders is coupled with the inlet of subsequent turboexpander to perform multi-stage expansions of the compressed refrigerant, and

a plurality of refrigerant heat exchange means coupled to both the first inlet of the plurality of refrigerant compressors and the last outlet of the plurality of turboexpanders, so that all components form a close refrigeration cycle.

13. The method of claim 12, wherein the refrigeration device comprises:

a first refrigerant compressor;

a first refrigerant aftercooler coupled to the first refrigerant compressor;

a second refrigerant compressor coupled to the first refrigerant aftercooler;

a second refrigerant aftercooler coupled to the second refrigerant compressor;

a first refrigerant recompressor coupled to the second refrigerant aftercooler;

a third refrigerant aftercooler coupled to the first refrigerant recompressor;

a second refrigerant recompressor coupled to the third refrigerant aftercooler;

a fourth refrigerant aftercooler coupled to the second refrigerant recompressor;

a first refrigerant heat exchange means disposed within the main cryogenic heat exchanger and coupled to the fourth refrigerant aftercooler to intermediate cool the compressed refrigerant;

a first turboexpander coupled to first refrigerant heat exchange means to first expand the compressed refrigerant;

a second turboexpander coupled to the first turboexpander to second expand the first expanded refrigerant; and

a second refrigerant heat exchange means disposed within the main cryogenic heat exchanger and coupled to the second turboexpander and the first refrigerant compressor.

14. The method of claim 13, wherein the refrigeration device further comprises a third refrigerant heat exchange means disposed within the main cryogenic heat exchanger, wherein the upstream inlet of the third refrigerant heat exchange means is coupled to one downstream outlet of the first turboexpander while the downstream outlet of the third refrigerant heat exchange means is coupled to one upstream inlet of the second refrigerant compressor; and wherein during operation, the refrigerant after the expansion by the first turboexpander is split into two streams with a ratio of 30/70 to 60/40, one stream (30-60% of full stream) being introduced into the third refrigerant heat exchange means to serve as a cold stream in the main cryogenic heat exchanger, and the other stream (40-70% of full stream) being further expanded by the second turboexpander and then being introduced into the second refrigerant heat exchange means to serve as the coldest stream for the sub-cooling of the liquefied natural gas.

15. The method of claim 13, wherein the refrigeration device further comprises an inter-cooler disposed within the main cryogenic heat exchanger between the first and second turboexpanders.

16. The method of claim 14, wherein the refrigeration device further comprises an inter-cooler disposed within the main cryogenic heat exchanger between one stream from the first turboexpander and the second turboexpander.

17. The method of claim 15, wherein the refrigerant device further comprises a third expansion device and a second intercooler, both being disposed between the second turboexpander and second refrigerant heat exchange means, and the second turboexpander provides one stream to the third expansion device via the second intercooler.

18. The method of claim 15, wherein the refrigerant subsystem further comprises a third expansion device and a second intercooler, both being disposed between the second turboexpander and second refrigerant heat exchange means, and the second turboexpander

provides two split refrigerant streams, one feeding back to a fifth refrigerant heat exchange means disposed within the main cryogenic heat exchanger and the other to the third expansion device via the second intercooler.

19. The method of claim 16, wherein the refrigerant subsystem further comprises a third expansion device and a second intercooler, both being disposed between the second turboexpander and second refrigerant heat exchange means, and the second turboexpander provides two split refrigerant streams, one feeding back to a fifth refrigerant heat exchange means disposed within the main cryogenic heat exchanger and the other to the third expansion device via the second intercooler.