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(54) LNG REGASSIFICATION PROCESS AND SYSTEM

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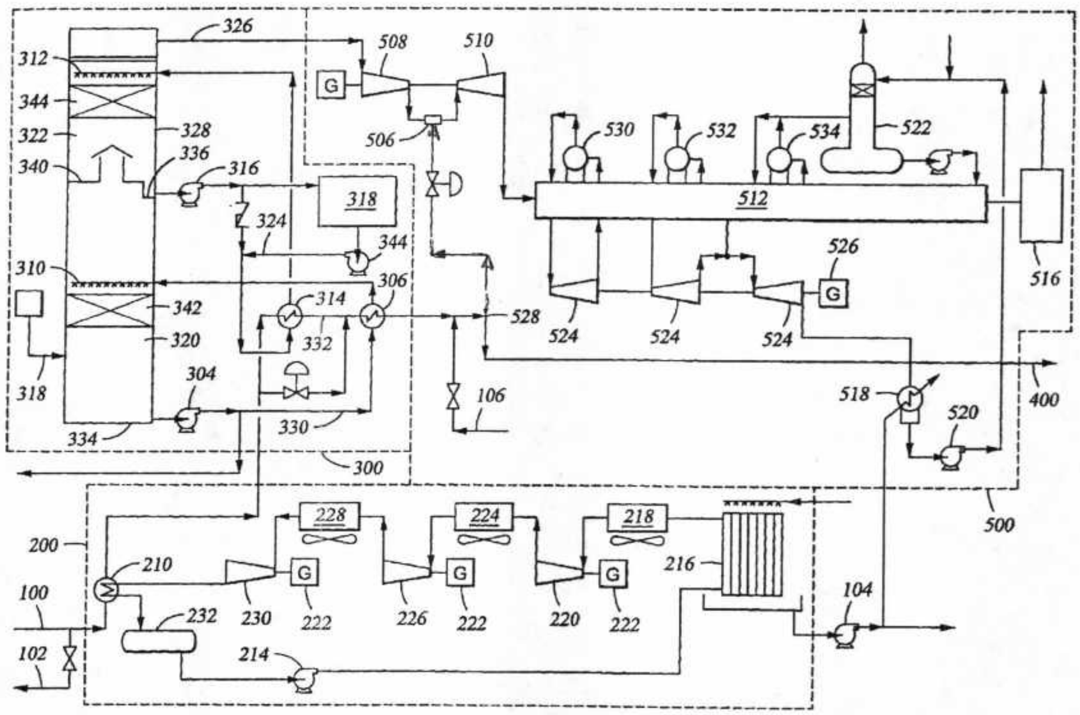
(57) **ABSTRACT**

A system for vaporizing liquefied natural gas (LNG) utilizes the residual cooling capacity of LNG to condense the working fluid of a power producing work producing cycle and chills liquids that are used in a direct-contact heat transfer system to cool air. The cold air is used to supply air to a combustion gas turbine operating in conjunction with a combined cycle power plant. Power is produced from both the work producing cycle and the combined cycle power plant and the chilling of the intake air to the gas turbine increases the output capacity of the combined cycle power plant.



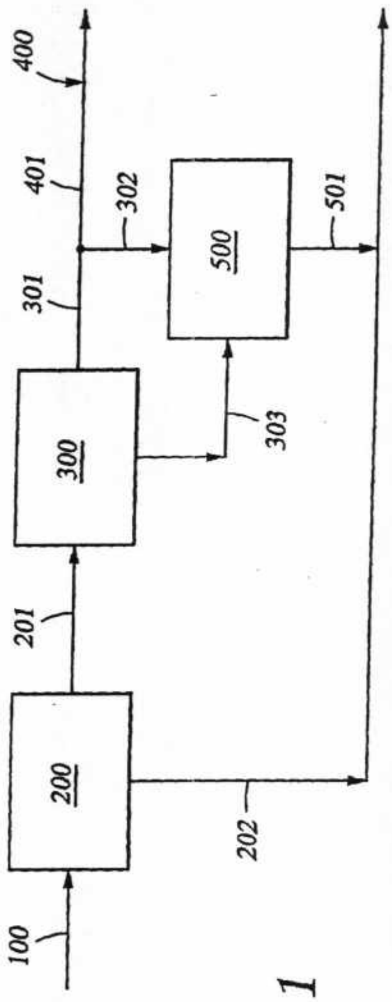


Fig. 1

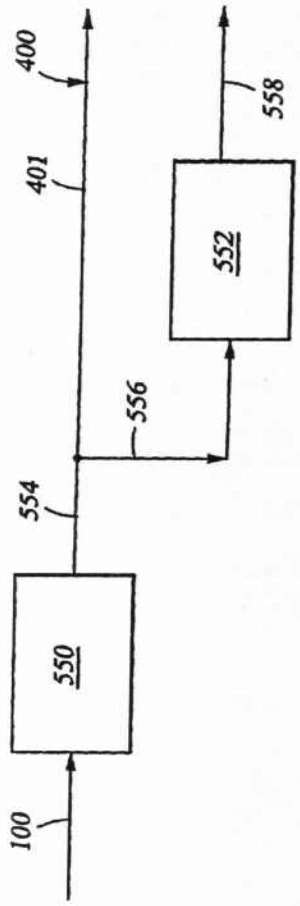


Fig. 3
(PRIOR ART)

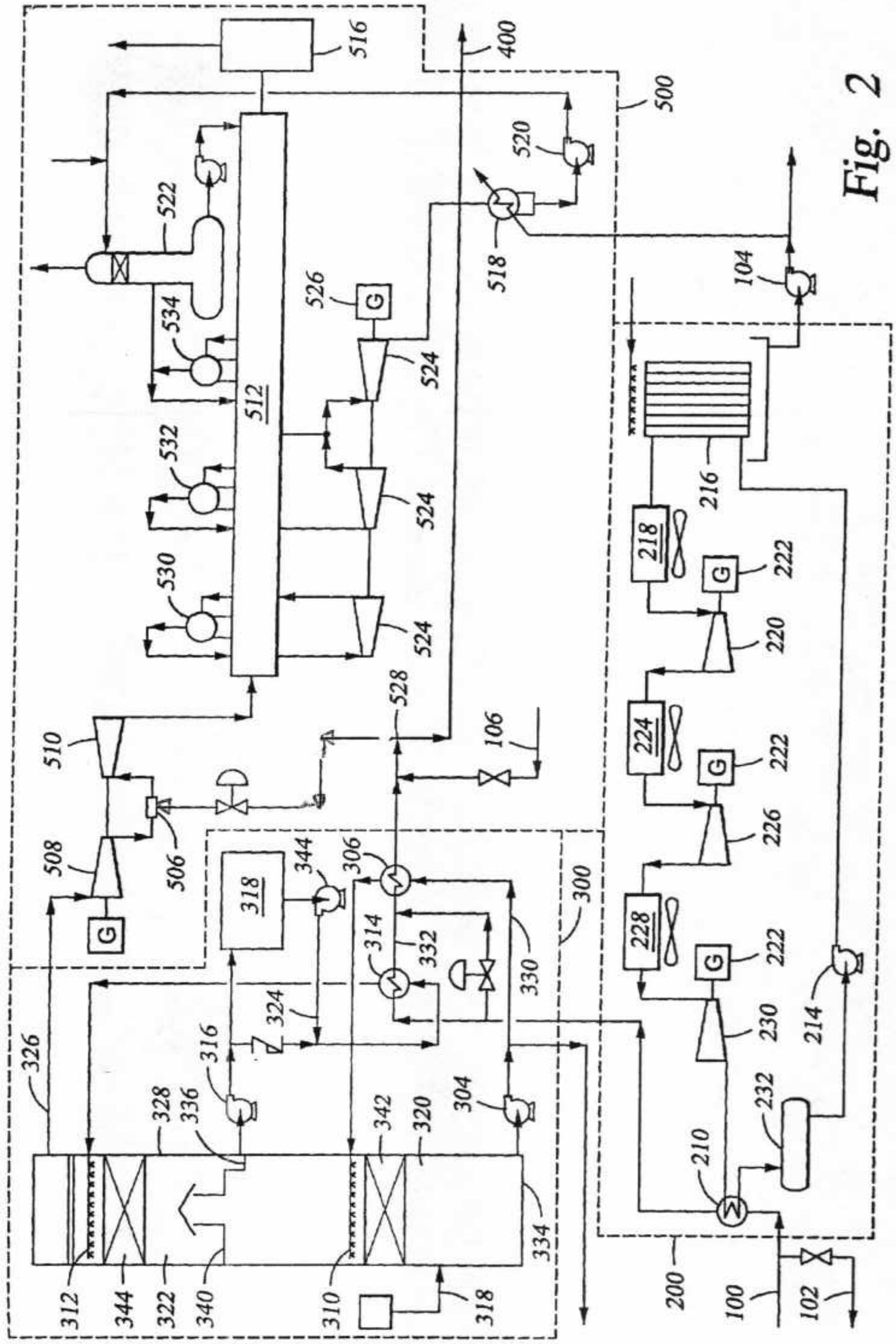


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Fig. 2

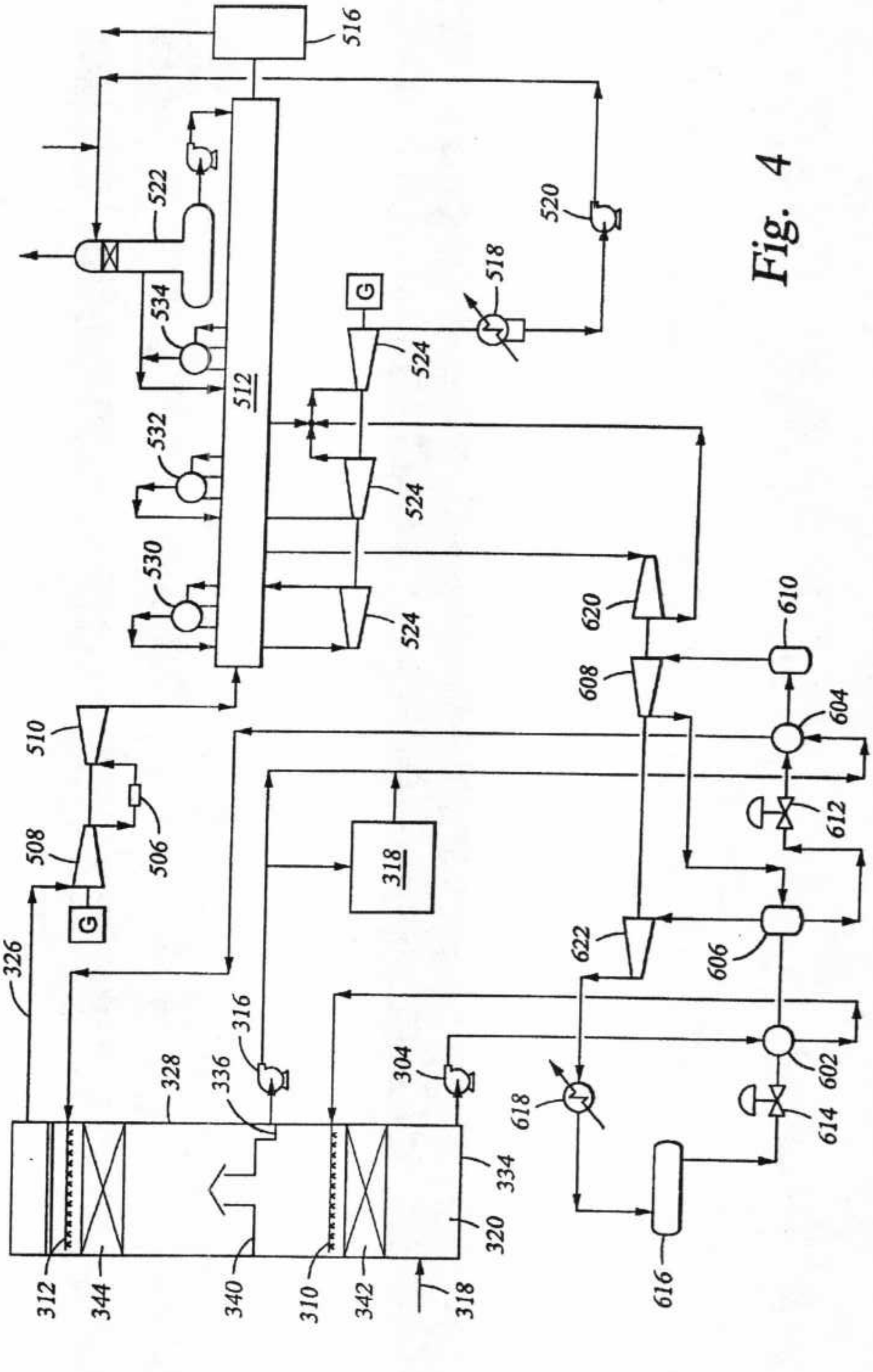
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Fig. 4

LNG REGASSIFICATION PROCESS AND SYSTEM

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] The present application claims priority to U.S. Provisional Application No. 60/294,334, incorporated herein by reference.

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

[0002] Not applicable.

BACKGROUND OF THE INVENTION

[0003] This invention relates to the regasification of liquefied natural gas. More specifically, this invention relates to an improved method and system of recovering mechanical energy in order to improve both the capacity and efficiency of a natural gas fired combined cycle power plant by taking advantage of the residual cooling capacity present in the liquefied natural gas.

[0004] Natural gas is used in many parts of the world as a principal source of fuel for the generation of electricity. Many areas also rely on natural gas as a fuel source for industrial applications as well as domestic applications such as heating and cooking. Natural gas can also be used as a fuel in internal combustion engines for automobiles and other vehicles. Natural gas is preferred as a fuel source because it is much cleaner burning compared to other fossil fuels, such as coal or oil, and it delivers a given amount of power with lower carbon dioxide emissions.

[0005] Natural gas is often produced in areas remote from the location where it is utilized. One of the most efficient methods of transporting gas from the production site to consumers is by pipeline. Pipelines are constructed of large diameter pipe either placed above or buried beneath the ground. The natural gas flows through the pipeline under pressure. The construction of pipelines is very expensive and when the length of the pipeline increases or terrain becomes difficult, the costs to build and maintain the pipeline increase dramatically. When distance and terrain make a pipeline impossible or non-economical, the gas must be transported through other means.

[0006] When pipelines can not be used, it is common to transport natural gas in its liquefied state, commonly known as liquefied natural gas (LNG). To create LNG, natural gas is cooled in a cryogenic process to a liquid at about −260° Fahrenheit. LNG must be kept cold by insulation to maintain its liquid state and to minimize evaporation. Because the LNG is denser than natural gas, a significantly greater amount of fuel energy can be transported in a LNG vessel as compared to a pressurized natural gas vessel of equal draft and displacement. LNG is often transported in specially designed vessels aboard very large ocean going ships. When the ships arrive at their final destination, the LNG is offloaded to storage tanks at a receiving terminal where the LNG then is processed back into natural gas so that it can be transported through a pipeline to consumers.

[0007] The process of vaporizing LNG into natural gas is known as regasification. Regasification is principally achieved through the transfer of heat into the LNG, usually through at least one heat exchanger. Typically, LNG regasification systems use one of two processes. One common technique is to burn a small amount of the LNG in a submerged combustion vaporizer to produce the heat needed to gasify the stream of LNG. The other common method for regasification of LNG utilizes open rack vaporizers that vaporize the LNG using heat from ambient water, such as seawater or river water. The LNG typically enters the lower section of the open rack vaporizer and leaves in gaseous form from the top section. The ambient water is fed to an external rack that allows the water to cascade down the outside of the vaporizer and the water is collected in a trough below the vaporizer prior to being returned to the water source.

[0008] In most prior art systems, little or no effort is made to utilize the residual cooling capacity in the LNG to produce power or increase efficiency. A significant amount of energy is consumed in forming LNG and it is the purpose of this invention to recover the maximum amount of energy from the regasification of LNG and to improve combined cycle power plant performance. In doing this, the present invention overcomes these and other drawbacks of the prior art.

SUMMARY OF THE INVENTION

[0009] Accordingly, there is provided herein a system for vaporizing LNG that utilizes the residual cooling capacity of the LNG to recover the maximum amount of energy from the regasification process. The residual cooling capacity of the LNG is used to condense the working fluid of a work producing cycle, such as a Rankine cycle. The cold LNG may also be used to chill liquids for use in an air chilling system to supply cold air to a combustion gas turbine operating in conjunction with a combined cycle power plant.

[0010] In preferred embodiments, the invention includes at least the following embodiments. The preferred LNG regasification process of the present invention comprises a receiving terminal having a work producing cycle, an air cooling system, and a combined cycle power plant. At the receiving terminal, liquid LNG is intermittently offloaded from transport vessels to storage tanks. From the storage tanks LNG is continuously processed into a gas using the LNG regasification process, passed through a custodial transfer station to a natural gas pipeline, and delivered through the pipeline to consumers. In summary, the LNG regasification process utilizes the residual cooling capacity of the LNG to produce as much useful work as possible and to improve combined cycle capacity.

[0011] In a preferred LNG regasification process of the present invention, a stream of LNG continuously enters the process and is vaporized in a heat exchanger that is a component of the work producing cycle. The vaporized LNG is still very cold and is used in the air-cooling system to chill liquids that are used to chill ambient air. The chilled air is fed to the air compressor section of a combustion gas turbine and a small portion of the product natural gas stream is then fired in the combustion chamber of a combustion gas turbine operating as part of a combined cycle power plant. The chilled inlet air increases the maximum power output of the gas turbine. The majority of the warm natural gas stream exits the process in a pipeline as natural gas. Power is produced from the work producing cycle and from the natural gas combined cycle power plant.

[0012] In the work producing cycle, the expansion of superheated working fluid is harnessed to run generators that produce electricity. In the cycle, the LNG passes through a first heat exchanger in heat exchange relationship with an organic working fluid that is cooled and condensed to a liquid. The working fluid is then pumped to an elevated pressure and evaporated in a second heat exchanger, such as an open rack vaporizer. The vaporized stream may be further superheated, typically against ambient air, when the air temperature is suitable. The warm working fluid is then expanded through an expander that drives a generator. The exhaust stream from the expander can then be reheated and expanded one or more times to enhance the efficiency of the system. The exhaust stream from the expansion cycles is then passed back through the first heat exchanger to condense the organic working fluid and complete the cycle.

[0013] The air cooling system chills the inlet air for the gas turbine operating as part of the combined cycle power plant. Atmospheric air is drawn into the air cooling system through a two-stage direct contact cooling process. In the first stage of the process, the air is exposed to a circulating chilled first liquid, such as water. In the second stage of the process, the air is exposed to an even colder circulating second liquid, such as methanol. The chilled air resulting from the air cooling system then passes to the compressor of a combustion gas turbine where chilled air is used to increase the output of the combustion gas turbine compared to its output operating with ambient air. The cold vaporized LNG is first used to cool the second circulating fluid and then the first circulating fluid in separate heat exchangers before the vaporized LNG's discharge as natural gas to the custody transfer station.

[0014] Once the LNG is fully vaporized it is available for transport through a gas pipeline. The majority of the natural gas stream flows into the pipeline while a relatively small portion of the natural gas product is used, possibly at a lower pressure, to supply fuel to the combustion chamber of the combustion gas turbine. This small portion of natural gas is combined with the compressed air and combusted in the gas turbine, which drives a generator that produces electricity. The cold air increases the mass flow into the gas turbine and therefore increases the capacity of the gas turbine to deliver power. The hot exhaust gases of the turbine are fed into a heat recovery steam generator and used to generate steam to drive a plurality of steam turbines. A heat recovery steam generator is well known in the art and designed to utilize the hot exhaust gases from a combustion process, in this case a gas turbine, to create steam that is used to generate electricity through one, or more, steam turbines and generators operating as part of a conventional steam cycle.

[0015] In summary, the LNG regasification process processes a stream of LNG into a gaseous product suitable for transport through a pipeline. As part of this process the LNG is first vaporized as part of a work producing cycle and the residual cooling capacity of the vaporized LNG is used to chill ambient air that is then compressed and mixed with a vaporized LNG to fuel the gas turbine component of a combined cycle power plant.

[0016] One advantage of the LNG regasification process is that energy is produced from both a work producing cycle and a natural gas combined cycle power plant.

[0017] Another advantage of the present invention is that chilling the inlet air to a combustion gas turbine increases the capacity of the turbine.

[0018] Still another advantage of the present invention is that it offers more economical production of power than prior art systems.

[0019] Thus, the LNG regasification process comprises a combination of features and advantages which enable it to overcome various problems of the prior art. The various characteristics described above, as well as other features, will be readily apparent to those skilled in the art upon reading the following detailed description of the preferred embodiments of the invention, and by referring to the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0020] For a more detailed description of the preferred embodiment of the present invention, reference will now be made to the accompanying drawings, wherein:

[0021] **FIG. 1** represents a block diagram of a preferred LNG regasification process;

[0022] **FIG. 2** represents a schematic of a preferred LNG regasification process;

[0023] **FIG. 3** represents a block diagram of a prior art LNG regasification terminal with a natural gas combined cycle power plant; and

[0024] **FIG. 4** represents schematic of an alternative system for cooling the intake air for the gas turbine.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0025] The present invention relates to processes for the regasification of liquefied natural gas and is susceptible to embodiments of different forms. The purpose of this invention is to increase the efficiency of the regasification of these liquid hydrocarbons. There are shown in the drawings, and herein will be described in detail, specific embodiments of the present invention with the understanding that the present disclosure is to be considered an exemplification of the principles of the invention, and is not intended to limit the invention to that illustrated and described herein. It is to be fully recognized that the different teachings of the embodiments discussed below may be employed separately or in any suitable combination to produce desired results.

[0026] In particular, there are many hydrocarbons that are gaseous at ambient conditions but are transported as liquids. Each different hydrocarbon mixture has a different latent heat property that may change the most preferred embodiment of the present invention. Further, the geographic location of the facility must be considered due to different ambient air conditions that also may effect the most preferred embodiment. For purposes of example only, and not by way of limiting the scope of the invention in any way, the present invention will be described as a process to regasify liquefied natural gas (LNG) that is located at a facility at sea level in a temperate environment. The temperatures and pressures stated hereinafter are for exemplary purposes.

[0027] Referring initially to **FIG. 1**, the LNG regasification process of one embodiment of the present invention comprises an inlet **100** for LNG, a work producing cycle **200**, an air cooling system **300**, a combined cycle power plant **500**, and a natural gas pipeline **400**. The system also includes a piping system, as is well known in the art, connecting these components. The LNG enters inlet **100**, preferably in a substantially continuous manner, such as from a storage tank, and passes through a heat exchanger in work producing cycle **200**. The LNG then passes through conduit **201** and one or more heat exchangers in the air cooling system **300** that is used to cool ambient air. Substantially all of the regasified LNG then passes through conduit **301, 401** to the outlet for natural gas pipeline **400** while a small portion of the vaporized LNG is fed through conduit **302** at a lower pressure to supply fuel to the combustion gas turbine of the combined cycle power plant **500**. Alternative embodiments may divide the gas in any portions between pipeline **400** and power plant **500** or supply all of the gas to one component or the other. Cold air from the air cooling system **300** passes through conduit **303** to the combustion gas turbine of the combined cycle power plant **500**. Power **202, 501** is produced both by the work producing cycle **200** and by the natural gas combined cycle power plant **500**.

[0028] Referring now to **FIG. 2**, the work producing cycle **200** is a closed loop system that circulates a working fluid, such as multi-component hydrocarbon mixture, and transforms the heat energy contained in the working fluid into useful work. Work producing cycle **200** is shown and described as a Rankine cycle, but could also be any other work producing cycle that takes advantage of the temperature of LNG as a heat sink. The hot source is preferably ambient air or water, and could also be other relatively hot sources, such as waste heat, that can be conveniently captured. The work producing cycle **200**, generally comprises a heat exchanger **210**, a pump **214**, a vaporizer **216**, a superheater **218**, at least one expander **220**, at least one generator **222**, and a piping system, well known in the art, to connect all the components. The work producing cycle preferably includes a plurality of superheaters **224, 228**, expanders **226, 230**, and generators **222**. The work producing cycle may also contain a storage vessel **232**. The vaporizer **216** is any device that allows the transfer of heat into the working fluid, such as a boiler or an open rack vaporizer.

[0029] The air cooling system **300** comprises a single direct-contact heat exchange tower **328**, which in one embodiment is partitioned into a lower section **320** and an upper section **322** by a chimney tray **340**, which is familiar to one skilled in the art. The lower section **320** and the upper section **322** are packed with typical proprietary liquid/vapor contact devices **342, 344**. Several types of packing are available from several vendors. A preferred packing to be used is known as structured packing. The specific advantage of structured packing over other types of packing is that it affords efficient gas-liquid contact with a minimal amount of pressure drop in the air as it passes through the packed sections **320, 322** of the tower **328**. Although the preferred embodiments are described as systems where air is contacted with a cooling liquid circulated counter-currently, an air cooling system may also be developed with the cooling liquid flowing co-currently with the air, such as a partitioned "void" tower. A co-current system may be used to reduce the pressure drop in the air but may tend to increase circulation rates through the air cooling system.

[0030] The lower section **320** preferably comprises a water contact circuit **330** in which water, or a water/antifreeze mixture, is circulated via a pump **304** from the lower section **320** and through the second cold natural gas heat exchanger **306**. Exchanger **306** cools the water against the cold natural gas to a temperature above the freezing point of water. The cold water is then distributed through a distributor **310** on top of the lower structured packing **342**. As the water flows down through the packing **342**, air flows up, and the direct contact of the two fluids in a counter-flow arrangement over the structured packing **342** causes a heat transfer from the air into the water.

[0031] The cold air is passed through a total trap-out chimney tray **340** into the upper section **322** of the tower **328**. The upper section **322** also contains structured packing **344** similar to the lower section packing **342** and a second fluid circulation system **324**. In the second circulating system **324**, a pump **316** draws liquid from the upper section **322** and circulates it into the first cold natural gas heat exchanger **314**. Exchanger **314** cools the circulating medium against the cold natural gas to a temperature well below the freezing point of water. The cold circulating liquid is then distributed through a distributor **312** on top of the upper structured packing **344**. As the circulating liquid flows down through the packing **344**, air flows up, and the direct contact of the two fluids in a counter-flow arrangement over the structured packing **344** causes a heat transfer from the air into the circulating fluid.

[0032] The degree of cooling in the air is largely a matter of economic trade-off. The colder the air the greater the power capacity increases from the combustion gas turbine. The offsetting factors of a decreased temperature are materials of construction used in the combustion gas turbine and where an excessive power addition will prevent the use of a standard combustion gas turbine because of additional stress on the drive shaft or other limitations realized by persons skilled in the art. Because of currently available technology, a target minimum air temperature, for purposes of the examples contained within, is −20 degrees Fahrenheit. This temperature should not be considered a limit and it is fully considered that a lower temperature will result in increased capacity of the combustion gas turbine and the natural gas combined cycle power plant.

[0033] Some of the criteria used to select a suitable second circulating fluid include: 1) a freezing point below the lowest temperature desired, 2) a fluid easily pumped at the lowest temperature, 3) a fluid with a low vapor pressure at the coldest working temperature, 4) a fluid not susceptible to explosion when mixed with air, and 5) availability and price. One of the fluids that meet these criteria is methanol. Other fluids may prove to be more or less qualified for use in the disclosed system. As the desired inlet air temperature to the combustion gas turbine changes, the parameters for selection of the circulating fluid also change. For example if a lower temperature is selected, methanol may no longer qualify because of pumpability or freezing point. If a higher temperature is selected, a methanol may evaporate at too great a rate and safety could be compromised.

[0034] In keeping with the current example, the second circulating system **324** may also comprise a fluid recovery system **318**. Considering methanol as the second fluid, amounts of water vapor still remaining in the cold air in the upper section **322** will be mostly absorbed into the methanol. With time, the circulating fluid in the upper section 322 will increase in water content and could eventually lead to the production of ice, which may decrease the effectiveness of the cooling or cause damage to the gas turbine. To separate methanol from the contaminating water, a distillation package **318** could be incorporated to remove unwanted water. Alternatively, instead of recovering the methanol by distillation, it would also be possible to purge an amount of recirculating methanol to control the amount of water contamination. The purge stream could then be added to the fuel used by the combustion gas turbine. This added methanol and water could be used to displace an amount of fuel otherwise needed by the combustion gas turbine.

[**0035**] In the natural gas combined cycle power plant **500**, the hot exhaust gases from a gas turbine are used to generate steam to drive one or more steam turbines **524**. The natural gas combined cycle power plant **500** generally comprises a combustion gas turbine, which comprises a compressor **508**, combustion chamber(s) **506**, an expansion gas turbine **510**, and a heat recovery steam generator 512. The heat recovery steam generator **512** is well known in the art and generally comprises a pump **520**, at least one heat exchanger and steam storage vessel **530**, equipment 522 to store boiler feed water and remove air, at least one steam turbine 524 to convert the steam energy into mechanical energy used to produce electricity, and an exhaust 516. The system also includes a condenser **518** to convert the steam back into liquid. The advantage of the combined cycle power plant **500** is that mechanical energy is derived from both the combustion gas turbine expander **510** and the steam turbines **524** and this energy is used to run generators 526. The preferred embodiment of the heat recovery steam generator **512** contains steam generation of a low pressure at 534, a medium pressure at **532**, and a high pressure at 530.

[**0036**] The preferred embodiment utilizes the above described components to process LNG into a gaseous product while using the latent heat of vaporization and cooling capacity of the LNG to produce mechanical energy and increase the capacity of a combined cycle power plant. To further describe the disclosed system, a preferred embodiment of the LNG regasification process at one set of operating parameters will be described. It is understood that the operating parameters and specific equipment arrangements are dependent upon many factors, such as the particular LNG being regasified and the site-specific conditions at the location of the receiving terminal. Modifications may be made without deviating from the spirit of the invention.

[**0037**] Pressurized liquefied natural gas (LNG) at about 1100 psia, and −249° F. enters the process from a storage tank located in the receiving terminal (not shown) through inlet **100** at 1317 million standard cubic feet per day (MMSCFD). The LNG flows into heat exchanger 210 of work producing cycle **200** at 1100 psia and −249° F. and is vaporized, exiting heat exchanger 210 at 1090 psia and −42° F. The stream of vaporized LNG is divided roughly in half at **342** with one half passing through heat exchanger 314 of air cooling system **300** where heat is absorbed from circulating methanol in upper liquid circulation circuit **332**, further warming the natural gas to 6° F. The natural gas stream from the first heat exchanger 332, at 6° F., is then combined with the other half of the separated stream, at −42° F., and fed through a second heat exchanger **306** in lower liquid circulation circuit 330 to chill water. The natural gas leaving the second heat exchanger **306** is now at 1070 psia and 60° F. Approximately 52 MMSCFD of natural gas is diverted at **528** to fuel the combustion chamber **506** of gas turbine in the combined cycle power plant **500**. The remainder of the natural gas, 1265 MMSCFD, is fed into the pipeline **400** for transport to consumers.

[**0038**] In the work producing cycle **200**, the expansion of a working fluid is used to create mechanical energy. The working fluid can be any substance, or mixture, with suitable thermodynamic properties over the range of conditions to be used in the work producing cycle **200**. The preferred working fluid in this example comprises 15% methane, 60% ethane, and 25% propane. A preferred working fluid has a boiling point between −350° F. and −100° F. One of ordinary skill in the art would recognize different compositions of working fluid capable of being used in this system.

[**0039**] In the work producing cycle **200**, a working fluid, of the composition stated above, at 17 psia and 7° F. enters heat exchanger **210** and is fully condensed against LNG at −249° F. The condensed fluid, now at 16 psia and −210° F. is fed into a multi-stage pump **214**. The pump **214** pressurizes the working fluid to 315 psia and feeds it into an open rack vaporizer **216**. The fluid is vaporized in vaporizer **216** and superheated in a first superheater **218** to 65° F. and 280 psia. The superheated vapor is fed into a first expander **220** that is coupled to a first generator **222**. The superheated vapor flowing through the expander **220** creates useful work in the generator **222**. The lower pressure vapor at 115 psia and 0° F. exiting the expander **220** is heated in a second superheater **224** to 65° F. and 110 psia. The reheated vapor is then fed into a second expander **226** that is coupled to a second generator **222** that produces useful work. The lower pressure vapor at 46 psia and 9° F. exiting the second expander **226** is heated in a third superheater **228** to 65° F. and 41 psia. The reheated vapor is fed into a third expander **230** coupled to a third generator **222** and back into heat exchanger **210** where the vapor, at 17 psia and 7° F., is fully condensed to complete the cycle. Those skilled in the art will recognize other arrangements of components in the work producing cycle to include multiple heat exchangers, and a different number or combination of expanders, heaters, and generators.

[**0040**] Atmospheric air is drawn into the air cooling system **300** through an inlet **318**. Atmospheric air can exist at any number of conditions depending on environment. For purposes of this description, the atmospheric air will be 90° F. and 85% relative humidity. While the preferred embodiments contemplate using air at ambient conditions, alternative embodiment may use air that has been pressurized, pre-cooled, dehumidified, or otherwise processed before entering the air cooling system **300**. Air is drawn into the first cooling chamber **320** of direct contact cooling system **324** and exposed to chilled water at about 33° F. The air is cooled through direct contact with the cold water over the lower structured packing **342**. The air is then drawn through a chimney tray **340** into a second cooling chamber **322** and exposed to a chilled liquid, in this case methanol at −22° F. The air is further cooled to about −20° F. by contact with the cold methanol as it passes through the upper structured packing 344. Excess water is purged from the bottom **334** of the first cooling chamber **320** of the cooling tower **328** via pump **304** which recirculates the water through heat exchanger **306**. In the heat exchanger **306**, the water is passed in heat exchange relationship with cold vaporized LNG. Cold water exits the heat exchanger 306 and flows through a distributor **310** that evenly places the water over the structured packing **342**.

[0041] The methanol and absorbed water buildup is removed from the bottom **336** of the second cooling chamber **322** of the direct-contact cooling system 324 by a pump **316**. A portion of the mixture may be diverted to a methanol distillation and regeneration unit **318** where excess water is removed. Methanol leaving the distillation unit 318 is pumped back into the system by pump 344. The cooled methanol exits the heat exchanger **314** and flows into a distributor **312** that evenly distributes the methanol over the upper structured packing **344**. Alternatively, the methanol regeneration unit **318** may be omitted and the make-up methanol supplied from a storage source. As a further alternative embodiment, purged (wet) methanol can be used as a fuel supplement for the combustion chamber **506** of the combustion gas turbine.

[0042] The air cooling system **300** chills atmospheric air to a low temperature prior to compression in the compressor **508** of the combustion gas turbine. Compressed air is combusted with fuel in the combustion chamber(s) 506 of the combustion gas turbine. The hot combustion gas is expanded through the expansion unit 510 of the combustion gas turbine producing hot exhaust gas that is fed into the heat recovery steam generator **512**.

[0043] The chilled air at −20° F. exiting the air cooling system **300** at **326** is compressed in the compressor 508 and combined with natural gas in the combustion chamber **506** of the combustion gas turbine. The use of cold air increases the mass flow rate of the fuel air mixture into the combustion chamber(s) **506**, which increases the power output from the expander **510** of the combustion gas turbine. The expander **510** creates mechanical energy that produces power through a generator **534**. The hot exhaust gases from the expander **510** are fed into heat recovery steam generator **512** where the exhaust gases are used to create steam that is also used to generate power in a conventional steam Rankine cycle.

[0044] Heat recovery steam generators **512** are well known in the art and are used to produce steam that is used to make additional power from the exhausts of gas turbines. In the heat recovery steam generator 512, boiler feed water is evaporated and superheated using the hot exhaust from the expander **510** of a gas turbine, cycled through a series of expanding steam turbines **524** to create mechanical energy, and condensed back to a liquid to complete the cycle. The heat recovery steam generator **512** can be any of a number of combinations of heat exchanger elements to generate steam at several pressures. A preferred heat recovery steam generator **512** for this application includes the use of steam at three pressure levels in order to produce power through steam turbines **524** connected to generators 526.

[0045] **FIG. 3** shows a standard system of the prior art that comprises an inlet **100** for LNG, a regasification plant **550**, a natural gas combined cycle power plant **552**, and a natural gas pipeline **400**. LNG is transferred from an inlet **100** into a regasification plant **550**. Substantially all of the regasified gas then passes through conduit 554, **401** to the outlet for natural gas pipeline **400** while a small portion of the vaporized LNG is fed through conduit **556** at a lower pressure to supply fuel to the combustion chamber(s) of the gas turbine of the combined cycle power plant **552**. Alternative embodiments may divide the gas in any portions between pipeline **400** and power plant **500** or supply all of the gas to one component or the other.

[0046] A comparison of the prior art system of **FIG. 3** with the new system of **FIG. 1** was performed using identical input data including inlet gas conditions, flow rates, and ambient conditions. A gas flow rate of 1317.2 MMSCFD at the inlet **100** results in 1281.76 MMSCFD of gas transferred to the pipeline **400** in the prior art system while 1265.39 MMSCFD of gas is transferred to the pipeline **400** in the new system. The decrease in gas transferred to the pipeline is a direct result of the increased capacity of the natural gas combined cycle power plant **500** caused by the use of cold inlet air for the combustion gas turbine. The power export from the system **558** increases from 222.97 MW in the prior art system to 366.14 MW in the new system. This means that for a 4% decrease in the output of natural gas, an increase of export power of 64% is realized.

[0047] The embodiments of the present invention also provide a flexible system that can easily adjust to changes in demand for electricity. For actual systems the supply of LNG may not be sufficient to run both the work producing cycle and the inlet air cooling to the combined cycle power plant at their respective peak outputs and efficiencies. In other words, the temperature increase in the LNG from the work producing cycle may raise the temperature of the LNG to a point that the air cooling system will not fully cool the air. Therefore, it may be desirable to be able to vary the amount of LNG sent to each system in order to provide an efficient overall system. During times of high demand, the supply of LNG can be diverted to ensure peak output of the combined cycle power plant by fully lowering the air temperature. In periods of less demand, where power is less expensive, the system can be tuned to operate at peak efficiency.

[0048] Table 1 was produced to evaluate different operating parameters for a 400 MW ISO combined cycle power plant when there is only 660 MMSCFD of LNG available for regasification. Case 1 is operating at standard (ISO) conditions, case 2 is operating at ambient conditions (90° F., 85% relative humidity), case 3 is at ambient conditions with the work producing cycle maximized leaving sufficient cooling capacity to partially cool the intake air, and case 4 is at ambient conditions with inlet air temperature for the power plant minimized leaving sufficient cooling capacity to operate the work cycle at less than optimal output.

TABLE 1

Case	Inlet Air Temp (° F.)	Power Plant MW	Work Cycle MW	Total Power MW	Efficiency %
1	59.0	400.0	0.0	400.0	60.0
2	90.0	365.1	0.0	365.1	59.9
3	72.8	385.1	19.0	404.1	62.9
4	−20.0	531.0	6.2	537.2	61.1

[0049] Although the operating parameters of case 3 provide efficient operation, the parameters of case 4 when demand for power increases and additional capacity is required.

[0050] Referring again to FIG. 2, as a backup to the work producing cycle 200, the system can also include a bypass 102 that would utilize conventional regasification techniques and return the natural gas to the system at a connection 106 so that fuel supply to the natural gas pipeline 400 and to the combined cycle power plant 500 can be maintained. The backup regasification system could utilize a submerged combustion vaporizer (not shown) or an open rack vaporizer. If an open rack vaporizer 216 is utilized in the work producing cycle 200, LNG flow may be diverted to take advantage of the in-place equipment if the system was designed to do so.

[0051] The system may also use some of the cold water from the trough of the work producing cycle open-rack vaporizer 216 to help condense the steam in the surface condenser in the steam Rankine cycle 512. The fluid could be collected from the lower trough of the open rack vaporizer 216 and pumped through a heat exchanger 518 by a pump 104 before being returned to the water source. Alternatively, the water may be partially or totally recirculated to the top of the open rack vaporizer.

[0052] Referring now to FIG. 4, in an alternative embodiment of the present invention, a system using a refrigeration process may be substituted for the previously described system of FIGS. 1 and 2 for cooling the intake air 300 of a gas turbine. Heat exchangers 306 and 314 of FIGS. 1 and 2 are replaced by heat exchangers 602 and 604. The refrigeration system can be any system to supply a cold medium in a heat exchange relationship to sufficiently cool the liquids flowing through the heat exchangers. One preferable type of refrigeration system is a multi-stage refrigeration system. The multi-stage refrigeration system comprises a multi-stage compressor 608, 622, vapor/liquid separators 610, 616, a heat exchanger 604, 602, and expansion valve 612, 614. A multi-stage refrigeration system is well known in the art and has many variations. Variations of the multi-stage refrigeration system as well as other refrigeration systems have applicability in the above-described process. In this example, a two-stage flooded screw compressor is depicted in which large compression ratios are achievable. A three-stage centrifugal refrigerant compressor may prove to be more appropriate to accommodate the broad air-cooling range. Alternatively, the refrigeration system may use singe effect, or multi-effect chillers that use absorption technology to provide the cold source. These chillers typically operate through lithium bromide or ammonia absorption, depending on the temperatures involved. A low grade steam may be used as the hot source for an absorption chiller.

[0053] While a preferred embodiment of the invention has been shown and described, modifications thereof can be made by one skilled in the art without departing from the spirit of the invention.

What is claimed is:

1. A system for the production of power and the vaporization of liquid hydrocarbons that uses the residual cooling capacity of the liquid hydrocarbons to improve power production efficiency, the system comprising:

a first heat exchanger passing the hydrocarbons in a heat exchange relationship with a working fluid in a power producing cycle that utilizes the working fluid to produce power, wherein at least a portion of the hydrocarbons are vaporized and at least a portion of the first fluid is condensed in said first heat exchanger;

an air cooling system wherein the hydrocarbons are used in a heat exchange relationship so that the hydrocarbons are warmed and a stream of chilled air is produced; and

an engine that uses a portion of the vaporized hydrocarbons mixed with the stream of chilled air to produce power.

2. The system of claim 1 wherein the working fluid is condensed in said first heat exchanger and the work producing cycle is a Rankine cycle that further comprises:

a second heat exchanger wherein the condensed working fluid is vaporized by being passed in a heat exchange relationship with a heat exchange medium at a higher temperature than the condensed working fluid; and

an expander that produces useful work by the expansion of the vaporized working fluid.

3. The system of claim 2 wherein the heat exchange medium is at ambient temperature.

4. The system of claim 1 wherein said working fluid has a boiling point between $-350°$ F. and $-100°$ F.

5. The system of claim 4 wherein said first fluid is an organic hydrocarbon.

6. The system of claim 1 wherein said air cooling system further comprises a second heat exchanger passing the hydrocarbons in a heat exchange relationship with a first cooling fluid, wherein the temperature of the hydrocarbons is increased and the temperature of the first cooling fluid is decreased, wherein the first cooling fluid is further used to lower the temperature of a stream of air.

7. The system of claim 6 wherein the air cooling system comprises an air cooling chamber where the stream of air is exposed to the first cooling fluid in a direct contact heat exchange relationship.

8. The system of claim 6 further comprising a third heat exchanger passing the hydrocarbons in heat exchange relationship with a second cooling fluid so that the temperature of the hydrocarbons is increased and the temperature of the second cooling fluid is decreased, wherein the second cooling fluid is further used to lower the temperature of a stream of air..

9. The system of claim 8 wherein the air cooling system further comprises a first cooling chamber where an air flow is exposed in a direct contact heat exchange relationship with the first cooling fluid, and a second cooling chamber where the air flow is exposed in a direct contact heat exchange relationship with the second cooling fluid.

10. The system of claim 9 wherein at least one of said first or second cooling fluids has a freezing temperature lower than the freezing temperature of water.

11. The system of claim 6 wherein said first cooling fluid is circulated counter-currently to the air stream.

12. The system of claim 10 wherein the air is cooled to a temperature of at least $-20°$ Fahrenheit.

13. The system of claim 1 wherein said engine is a gas turbine.

14. The system of claim 13 further comprising a heat recovery steam generator that uses the exhaust gases from the gas turbine to create work.

15. A method for producing power from the vaporization and use of a liquid hydrocarbon product, the method comprising:

vaporizing at least a portion of the liquid hydrocarbon produce by circulating the product in a heat exchange relationship with a working fluid so as to condense the working fluid, wherein the working fluid is used in a work producing cycle; and

circulating the hydrocarbon product in a heat exchange relationship in an air cooling system so that the temperature of the product increases and a stream of chilled air is produced.

16. The method of claim 15 further comprising:

mixing at least a portion of the hydrocarbon product with the chilled air stream; and

burning the hydrocarbon and air mixture in a power plant.

17. The method of claim 15 further comprising:

vaporizing the working fluid by exposure in a heat exchange relationship to a heat exchange medium;

expanding the working fluid through an expander that is coupled to a generator.

18. The method of claim 17 wherein the heat exchange is at ambient conditions.

19. The method of claim 15 wherein the chilled air stream is produced by:

exposing the stream of air in a direct contact heat exchange relationship to a first cooling liquid that is cooled in a heat exchange relationship with the hydrocarbon product; and

exposing the stream of air in a direct contact heat exchange relationship to a second cooling liquid that is cooled in a heat exchange relationship with the hydrocarbon product.

20. The method of claim 19 wherein the first cooling liquid is chilled to a temperature above the freezing point of water and the second cooling liquid is chilled to a temperature below the freezing point of water.

21. The method of claim 15 further comprising:

mixing the chilled air stream and at least a portion of the vaporized hydrocarbon product in the combustion chamber of a gas turbine; and

burning the air and hydrocarbon mixture to produce power through the gas turbine.

22. The method of claim 21 further comprising exhausting hot exhaust gases from the gas turbine to a heat recovery steam generator that uses the heat of the exhaust gases to generate power.

23. A system for the vaporization of hydrocarbons comprising:

a first exchanger passing the hydrocarbons in a heat exchange relationship with a first fluid in a work producing cycle;

a second heat exchanger passing the hydrocarbons in heat exchange relationship with a second fluid in an air cooling system to produce a chilled air stream; and

an engine that burns a mixture of the hydrocarbons and chilled air stream to produce power.

24. The system of claim 23 wherein the work producing cycle produces power.

25. The system of claim 23 further comprising a third exchanger passing the liquid hydrocarbons in heat exchange relationship with a third working fluid in said air cooling system.

26. The system of claim 23 wherein said first fluid is condensed in said first exchanger and the work producing cycle is a Rankine cycle that further comprises:

a third heat exchanger to vaporize the first fluid; and

an expander to convert the energy of the vaporized first fluid into useful energy by using a generator.

27. The system of claim 26 wherein the third heat exchanger passes the first fluid in heat exchange relationship with a compound at ambient temperature.

28. The system of claim 23 wherein the air cooling system comprises an air cooling chamber where a flow of air is exposed to the second fluid in a direct contact heat exchange relationship.

29. The system of claim 23 further comprising a fourth heat exchanger passing the hydrocarbons in heat exchange relationship with a third fluid, and wherein the air cooling system further comprises a first cooling chamber where an air flow is exposed in a direct contact heat exchange relationship with the third fluid at a temperature above the freezing point of water, and a second cooling chamber where an air flow is exposed in a direct contact heat exchange relationship with the second fluid below the freezing point of water.

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