BENEATH THE WAVES

Environmental Protection

Natural Gas Regasification Technologies

Efficient, environmentally friendly LNG vaporization methods.

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Natural gas is odorless, colorless, nontoxic, and noncorrosive, and, when supercooled to minus 260 degrees Fahrenheit, turns into liquefied natural gas (LNG). Liquefying natural gas reduces its volume by more than 600 times, which makes it more efficient and practical to store and transport.

At present, three percent of the United States' natural gas needs are imported from foreign sources in special-purpose LNG tankers.[1] When the LNG cargo reaches its destination, the liquefied natural gas is revaporized back into a gas, which is then linked to pipelines that transport the gas for use. This revaporization (or regasification) activity is significant in terms of operating costs and possible impact on the environment.

Offshore facilities, also known as deepwater ports, face unique challenges in structural design and siting. However, the opportunity to build deepwater ports for LNG importation has also opened doors for new and unique methods to bring natural gas into the United States. Newer technologies utilize engine cooling technology and waste heat recovery from generators, boilers, or a combination of heat sources to warm the LNG, thus improving the efficiency of regasifying and reducing impact on the environment.

Best Available Commercial Technologies

The three sources of thermal energy typically used to warm LNG from a liquid to a gaseous state are ambient air, natural gas (heat from combustion), and seawater. The basic types of vaporization systems that utilize these sources of thermal energy include:

- intermediate fluid vaporizers,
- ambient air vaporizers,
- open rack vaporizers,
- shell and tube vaporizers,
- submerged combustion vaporizers.

VAPORIZATION SYSTEMS AS THEY RELATE TO THERMAL ENERGY

VAPORIZATION SYSTEM	DIRECT OR INDIRECT HEAT	THERMAL ENERGY SOURCE: Ambient Air	Natural Gas (Combustion)	Seawater
Intermediate Fluid Vaporizer (IFV) propane or refrigerant	indirect heat[a]	x		x
Intermediate Fluid Vaporizer (IFV) water/glycol	indirect heat	x	x	x
Ambient Air Vaporizer (AAV) or indirect heat	direct heat[b]	x		
Open Rack Vaporizer (ORV)	direct heat			x
Shell and Tube Vaporizer (STV)	direct heat			x
Submerged Combustion Vaporizer (SCV)	indirect heat		x	

a. Indirect heat is defined as when the thermal energy source (ambient air, natural gas, or seawater) is used to warm a secondary heating medium that re-vaporizes the LNG.
b. Direct heat is defined as when the thermal energy source (ambient air, natural gas, or seawater) directly warms and re-vaporizes the LNG.

Each system uses a vaporization process that passes the liquefied natural gas through pipes that are surrounded by a heating medium to transfer heat into the LNG. "Direct" heat is when the heating medium directly warms the LNG. "Indirect" heat is when the heating medium is used to warm an intermediate (or secondary) medium that transfers the heat to the LNG.

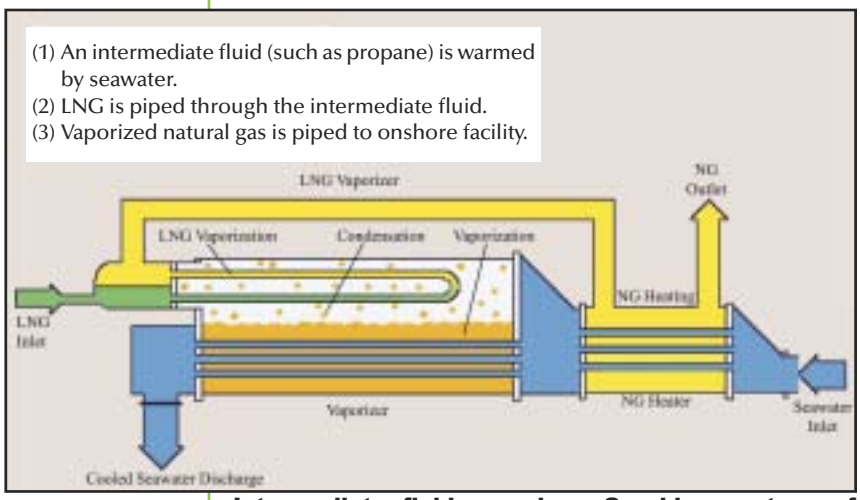
Lastly, each vaporization system can be set up as an "open-loop" or "closed-loop" system. Using seawater to heat the LNG is referred to as open-loop vaporization, while using natural gas combustion is closed-loop vaporization.

Intermediate Fluid Vaporizers

An intermediate fluid vaporizer (IFV) uses an intermediate heat transfer fluid to revaporize LNG. IFV technology can be configured to operate in a closed-loop, open-loop, or combination system. The most common intermediate fluid vaporizers use propane, refrigerant, or a water/glycol mixture as an intermediate fluid. Although propane and refrigerant have low flash points that are ideal for heat transfer, the operational risks are much higher when handling these types of fluids, and these fluids are very costly. The water/glycol mixture has a high flash point, requiring a larger heat transfer area, which results in a larger system than the propane or refrigerant systems. However, the water/glycol fluid system is more cost effective and the associated operational risks are relatively low.

An IFV typically uses a "shell and tube" heat exchanger (more about this system later), where LNG flows through the tubes with the intermediate heating medium circulating inside the shell and around the tubes. There are two stages to heating the LNG with an intermediate fluid vaporizer. First the liquefied natural gas is heated by an intermediate fluid in a heat exchanger, in which the LNG becomes a gas. The intermediate fluid flows through tubes in separate heating equipment (such as a propulsion boiler) to absorb heat. Then the vaporized natural gas is circulated through a second shell and tube heat exchanger, with seawater as the heating medium used to bring the gas to the temperature required to send it out through pipelines for use.[2]

The open-loop IFV technology requires seawater intake. Therefore, environmental issues include adverse effects (and assumed mortality) to marine life from entrainment in the intake, as well as exposure to seawater discharged back into the ocean at a temperature lower than the surrounding water. If an intermediate fluid vaporizer system operates with propane or refrigerant as the intermediate fluid, then these fluids add a potentially hazardous material to the facility operations. An IFV system that uses the water/glycol mixture is considered a safer way to operate. Lastly, depending on the combustion process used to heat the intermediate fluid, air emissions are also an environmental concern, unless the system uses waste heat recovery.



Intermediate fluid vaporizer. Graphic courtesy of KOGAS LNG Technology Research Center.

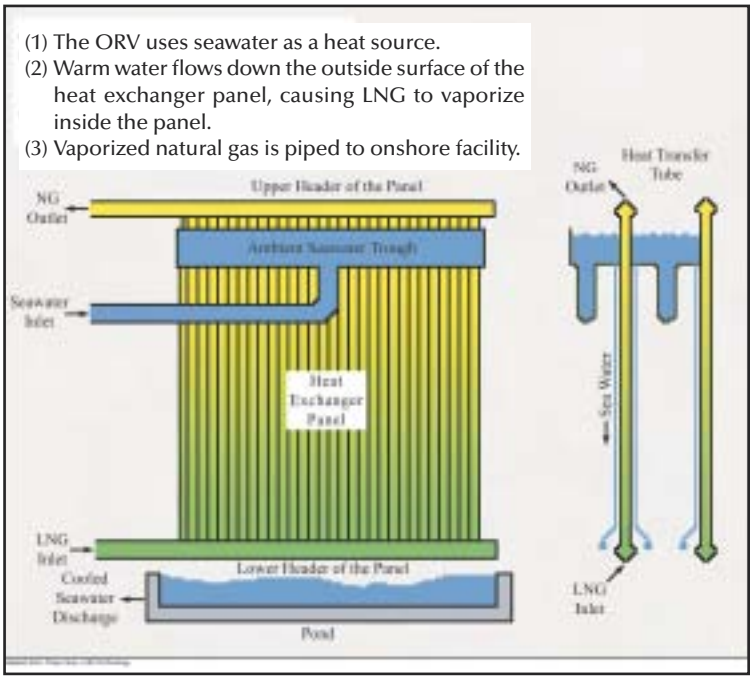
Ambient Air Vaporizers

Ambient air vaporization (AAV) technology uses ambient air as the thermal energy source to vaporize the liquefied natural gas. The LNG is distributed through a series of surface heat exchangers where the air travels down and out the bottom of the vaporizer. The air flow is controlled on the outside of the exchanger through natural buoyancy of the cooled, dense air, or by installing forced-draft air fans.

This process can be set up as either a direct heat or indirect heat system. AAV technology is best suited for areas with warmer ambient temperatures. In cooler climates, a supplemental heat system would be necessary to maintain effective use during colder weather conditions. Frost forming on the vaporizer is an issue because the LNG is vaporized directly against the air (direct heat system) and the water vapor in the air condenses and freezes. Frost build-up reduces performance and heat transfer. To maintain continual operation,

additional units are typically installed to provide the required throughput. The ambient air vaporization system requires a significant amount of space to prevent ambient air recirculation and to maintain the vaporizer capacity.

There is no seawater intake associated with this system. However, cooling ambient, moist air (which condenses into fresh water) necessitates treatment to prevent biofouling in the freshwater discharge piping. Discharging the treated freshwater back into the ocean could potentially have an adverse impact on the sea water. Also, depending on geographical locations (such as areas with high dew points) cooling the ambient air can generate a "fog bank." This is essentially benign, but you must consider siting issues.[3] Since the AAV technology typically burns natural gas only for supplemental heating during colder months, air emissions overall are relatively low compared to the other vaporization technologies.



Open rack vaporizer. Graphic courtesy of Tokyo Gas.

Open Rack Vaporizers

Open rack vaporizers (ORV) use seawater as the thermal energy source in a direct heat system to vaporize the LNG. To control algae growth within the system, sodium hypochlorite (chlorine) is injected on the intake side of the system. The treated seawater is then pumped to the top of the water box and travels down along the outer surface of the tube heat exchanger panels, while LNG flows upward through these tubes and is vaporized.[4] The cooled seawater collects in a basin under the open rack vaporizer and is discharged through the water outfall, while the vaporized natural gas is removed from the top header of the system. Because this technology relies on seawater as the primary heat source, it is only effective where seawater temperatures exceed approximately 63 degrees Fahrenheit.

The ORV technology does not require combustion and this process poses no new ignition sources. There are several environmental issues, including seawater intake, seawater outfall, and air emissions. Open rack vaporizer technology requires large volumes of water, which could adversely affect marine life. Further, the cooled and treated seawater that is returned to the ocean could potentially affect marine life and water quality. Although the ORVs do not directly produce air pollution emissions, powering the seawater pumps does.

Shell and Tube Vaporizers

Shell and tube vaporizers (STV) also use seawater as the thermal energy source. In an open-loop STV system, LNG enters the bottom of the STV, which is mounted vertically to optimize vaporization efficiency. The liquefied natural gas passes through multiple tubes while seawater enters a shell surrounding the tubes.

A closed-loop system uses an intermediate fluid (such as propane or a water/glycol mixture) to transfer heat. The intermediate fluid flows through tubes in separate heating equipment (such as a propulsion boiler) to absorb heat, then the fluid passes through the STV unit to re-gasify the LNG. Since there are two heat exchangers, this requires a large amount of space.

The open-loop technology reduces air emissions, since there is no combustion. Further, these STVs are generally small. Conversely, since the open-loop system uses seawater as the thermal energy source, there are environmental issues similar to the ORV system.[5]

Submerged Combustion Vaporizers

Submerged combustion vaporizers (SCV) do not use seawater for LNG vaporization. Instead, the LNG is warmed by flowing through tube bundles that are submerged in a water bath, which is heated by natural gas combustion. The submerged combustion burner emits hot exhaust gas that directly heats the water bath by bubbling through the water to an exhaust stack.

Since the thermal capacity of the water bath is high, it is possible to maintain a stable operation even for sudden start-ups/shutdowns and rapid load fluctuations.[6]

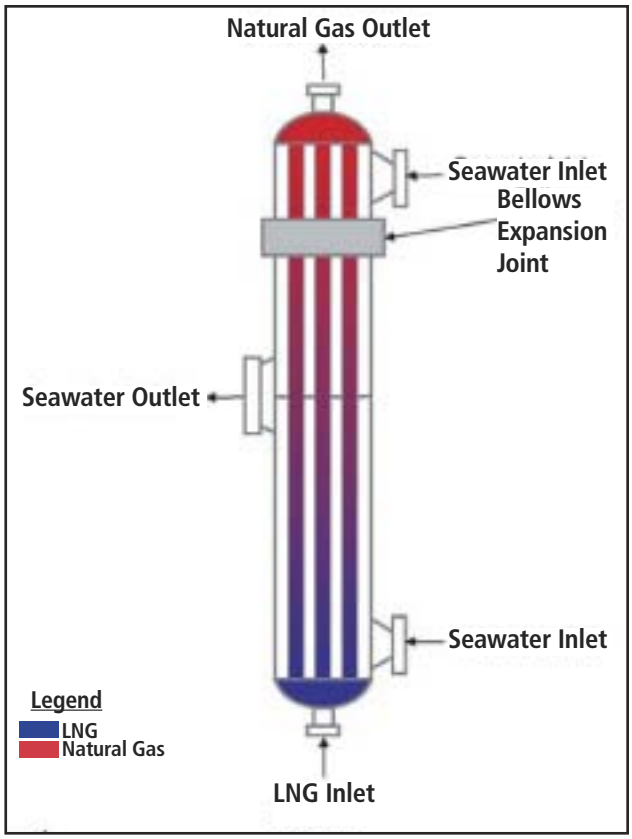
Thus, they provide great flexibility to quickly respond to changing demand requirements.[7] Since the SCV has such a huge reserve heat bank, even when the combustion process fails, surges can be mitigated with the heat just from the water bath.

During operation, SCVs consume anywhere from 1.5 to 2.0 percent of the LNG cargo to fuel the combustion burner, which is a significant operating cost.[8] In addition, the bathwater becomes acidic as the combustion products are absorbed during the heating process. It's necessary to add chemicals to the water bath, which results in excess combustion water that must be neutralized before being discharged. Lastly, the submerged combustion vaporizer system produces large quantities of air emissions from the flue gas. This can be reduced through exhaust gas control technology, but adds significant operating costs to the SCV system.

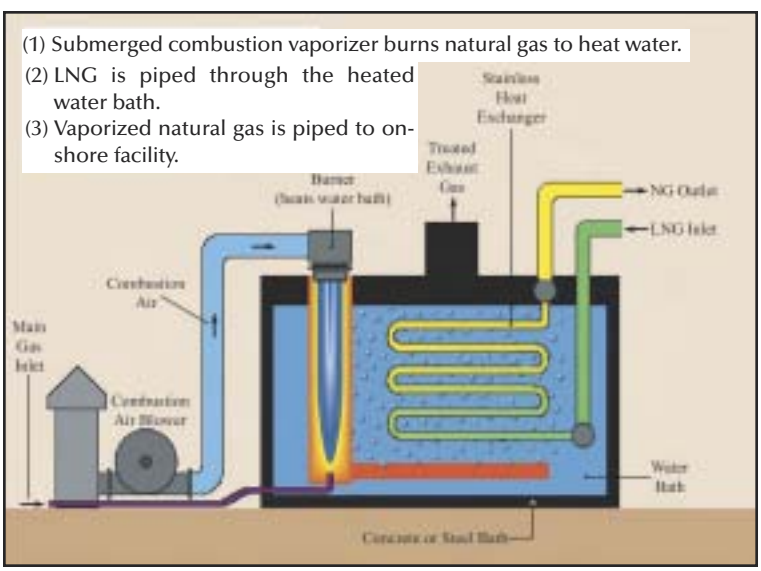
Waste Heat Recovery and Engine Cooling Technology

Deepwater ports can use regasification vessels (which are equipped with revaporization systems onboard) to vaporize the LNG to natural gas. Waste heat recovery and engine cooling technologies have been incorporated as part of the revaporization system to improve the efficiency (and reduce the emissions) of these regasification vessels.

Additionally, using engine cooling technology reduces the amount of seawater intake because, instead of cooling the engines solely with seawater, cooled water from the LNG vaporization process is used to cool the engines. Additionally, any cooling systems can be tied into the intermediate fluid, such as the heating, ventilating, and air conditioning systems.



Shell and tube vaporizer.



Submerged combustion vaporizer. Graphic courtesy of Sumitomo Precision Products.

About the author:

LT Hannah Kawamoto has served in the U.S. Coast Guard for five years and became a qualified marine inspector at Sector San Francisco prior to transferring to Coast Guard headquarters. LT Kawamoto is a graduate of the U.S. Merchant Marine Academy, with a B.S. in marine transportation and a third mate unlimited tonnage deck officer license.

Endnotes:

1. National Petroleum Council statistic.
2. U.S. Coast Guard (USCG) and Maritime Administration (MARAD). Draft Environmental Impact Statement for the TORP Bienville Offshore Energy Terminal Deepwater Port License Application (Docket No. USCG-2006-24644), July 6, 2007.
3. M. J. Rosetta, B. C. Price, and L. Himmelberger, "Optimize Energy Consumption for LNG Vaporization: New Methods Maximize Heat Transfer to Re-gasify Natural Gas with Minimum Environmental Impacts," Black & Veatch—Reports & Studies, 2006.
4. Ibid.
5. U.S. Coast Guard (USCG) and Maritime Administration (MARAD). Draft Environmental Impact Statement for the TORP Bienville Offshore Energy Terminal Deepwater Port License Application (Docket No. USCG-2006-24644), July 6, 2007.
6. U.S. Coast Guard (USCG) and Maritime Administration (MARAD). Final Environmental Impact Statement / Final Environmental Impact Report for the Cabrillo Port Liquefied Natural Gas Deepwater Port License Application (Docket No. USCG-2004-16877), March 16, 2007.
7. C. C. Yang and Z. Huang, "Lower Emission LNG Vaporization," LNG Journal, 2004.
8. U.S. Coast Guard (USCG) and Maritime Administration (MARAD). Final Environmental Impact Statement / Final Environmental Impact Report for the Northeast Gateway Deepwater Port License Application (Docket No. USCG-2005-22219), October 27, 2006.