CNG TRANSPORTATION UTILIZING COMPOSITE PRESSURE VESSELS

Steven Campbell, Trans Ocean Gas Inc.

INTRODUCTION

The following paper describes an innovative method of CNG transportation. The method utilizes composite pressure vessels which are derived from the national defense/aerospace, and natural gas vehicle industries. The method overcomes all of the deficiencies anticipated from other proposed methods of CNG transportation that propose to use steel based gas containment systems.

Existing container ships may be optimized through the use of the cassette gas containment system. The cassette system also isolates composite gas pressure vessels from ship-induced forces. Being modular, installation and removal of cassettes would be relatively easy. The cassette storage system will provide significant economic advantage over potential competitors commencing with a pilot project.

This paper will conclude that The Trans Ocean Gas CNG Transportation Method offers a high level of safety, reliability, and economic feasibility.

BACKGROUND

The first Compressed Natural Gas (CNG) pilot project using steel pressure vessels mounted on the deck of a ship was conducted off the coast of New Jersey in 1966. It was concluded as not being feasible since the weight of steel pressure vessels required would be too heavy for the host ship to carry. CNG development then stagnated for thirty years.

Over the past decade, the increased lucrative potential of CNG has renewed interest and spawned several innovative concepts. All but one proposed method use steel containment systems, which still have issues of safety, corrosion, excessive weight, and cost. All of the proposed methods using steel containment systems are requesting factors of safety less than that of the ASME code.

In 1999, author, Mr. Steven Campbell developed a method of CNG transportation that overcomes all of these deficiencies. This method, licensed exclusively to Trans Ocean Gas Inc. of St. John’s Newfoundland, proposes to use composite pressure vessels (CPVs) to safely and cost effectively transport up to 1.7 Bcf of natural gas by ship.

CPVs have been successfully used in the national defence/aerospace industry since the early 1970’s. About 10 years ago, the natural gas vehicle industry started using CPVs for buses, fleet vehicles, and automobiles. CPVs are also used as accumulator bottles for riser tensioning systems on oil and gas TLPs. The CPVs proposed for a ship-based CNG transportation method are similar, but larger than those currently used for natural gas driven buses. Since CPVs have been successfully used to store natural gas for fuel on public busses, they are well justified for use in a ship-based CNG transportation system.

The major advantages of using composite pressure vessels over conventional steel pressure vessels for a CNG transportation system are:

1. The rupture characteristics of CPVs far exceed those of steel pressure vessels. When a composite pressure vessel is punctured, the puncture does not propagate. The pressure vessel maintains its structural integrity and form. This test is documented on video with consistent results. When a steel pressure vessel ruptures it does so violently similar to a grenade. If such steel pressure vessels were nested together, the potential would exist for a domino catastrophic failure. Where factors of safety less than that of the ASME Code are applied, the potential risk is increased.
2. Since the materials used to fabricate a CPV are corrosion resistant, the CPV is also corrosion resistant. Because the liner of a composite pressure vessel is made from HDPE, raw natural gas that is often highly corrosive can be stored without a concern. Conversely, steel pressure vessels are susceptible to galvanic corrosion, especially in a salt air environment.

3. Composite pressure vessels are much lighter than comparable steel ones. Depending on the proportional amount of carbon and glass filament fibers used to manufacture a CPV, it will weigh between 1/6 to 1/3 that of a comparable high-strength steel pressure vessel. Being relatively lightweight will allow for the use of a container ship hull form, whereas all other proposed methods have to use a tanker or bulk carrier hull form. Container ship hull forms are designed for speed, resulting in fewer CNG carriers required for a particular CNG project. All other methods will have a difficult time finding a dry dock that can accommodate such a heavy ship with a large draft. Dry-docking will be even more problematic for steel method proponents without a reduced factor of safety from the ASME Code.

4. Composite pressure vessels have a long life expectancy. The combined allowable fatigue cycles of epoxy, HDPE, and glass and carbon fiber, exceed the expected life expectancy of several newly built ships.

In service CPVs have far surpassed their original design when exposed to extreme conditions. When Skylab fell to earth in 1979, the oxygen storage cylinder was the only recognizable item in the scattered debris. Although low, the pressure vessel was still pressurized. It now resides in the Smithsonian Institute. That composite pressure vessel was manufactured by Lincoln Composites now General Dynamics Armament and Technical Products, Lincoln Operations.

**PROPOSED COMPOSITE PRESSURE VESSEL**

The proposed CPVs for CNG transportation are modeled from those used on public busses, but significantly larger. The proposed CPV designed for the Trans Ocean Gas CNG transportation method is between 42 and 44 inches in diameter by approximately 40 feet long. The pressure rating of the proposed CPV is up to 3600 psi. The proposed CPV is well within existing design parameters and can be manufactured using available equipment.

CPVs are manufactured by winding a filament fibre over an HDPE liner. The liner complete with hemispherical end caps forms a mandrel, which is installed on a computer controlled automatic winder. The ends of the liner are equipped with a stainless steel port boss for future welding of the CPV to conventional piping. As the filament is wound over the mandrel, it is drawn through an epoxy bath at constant tension. The end result is a helically wound fiber formation set in an epoxy matrix.

The two most common filament fibres used to manufacture CPVs are carbon and glass. Carbon fibre has a very high tensile strength with relatively low ductility, and a density of approximately 1.8 g/cm³. Although relatively expensive, carbon fibre is used extensively in the aerospace industry due to its very high strength to weight ratio. Glass fibre on the other hand has high tensile strength, relatively high ductility, and is relatively cheap. Its density is approximately 2.6 g/cm³.

The code used for CPVs in the natural gas vehicle industry is NGV-2. This code is derived from FRP-3 Guidelines, which permits a CPV design to avail of both glass and carbon fibre characteristics. Under NGV-2, the accepted factor of safety for the proportional amount of glass fibre used is 3.5. The factor of safety for the proportional amount of carbon fibre is 2.25. A CPV made entirely of carbon fibre would weigh approximately one-sixth that of a comparable steel pressure vessel. A CPV made entirely of glass fibre would weigh approximately one-third that of a comparable steel pressure vessel.

The most important criteria for the aerospace industry is lightweight. The second is safety. Thus, for aerospace applications, the factor of safety for carbon fibre ranges from 1.5 to 2.0. Glass remains at 3.5.
For the natural gas vehicle industry, the most important criteria is safety. Therefore, CPVs for the natural gas vehicle industry are manufactured using primarily carbon fibre with an overlay of glass fibre. This design provides high strength and a high level of impact resistance.

For a CNG transportation system where the CPVs would be protected inside the hull of a ship, it is likely that the allowable factors of safety may be less than those required under NGV-2 specifications. Although this may be the case, all work performed thus far has used the NGV-2 code.

The main criteria for a ship-based CNG transportation system are safety and weight. Within the safety criteria, corrosion is a significant concern. Since the proposed CPVs are corrosion resistant, that concern is alleviated. Regarding potential pressure vessel failure; CPVs do not violently rupture, eliminating the risk of a domino catastrophic failure. Therefore, using CPVs in a CNG transportation system alleviates the safety criteria.

A fully loaded CNG carrier can weigh as much as its deadweight capacity. An analysis using the cargo hold capacity of a container ship has determined that the required CPVs could be made entirely of glass fibre. An all-glass CPV would also be marginally less expensive. Thus, the weight criteria has also been alleviated.

This leaves only cost to be contended with. Once the allowable factor of safety for glass and carbon fibre has been stipulated for CNG transportation, a cost optimization analysis will determine the optimal use of glass and carbon fibre. This analysis may include fuel savings of the CNG carrier from overall weight reduction.

THE CNG CONTAINMENT SYSTEM

To use the proposed CPVs in the Trans Ocean Gas CNG transportation method, two rows of 10 pressure vessels would be assembled vertically in a steel frame. An upper manifold would connect the top of all pressure vessels; whereas, a lower manifold would connect the bottom of all pressure vessels respectively. Hence the entire frame with upper and lower manifolds would become one storage unit. Each frame or “cassette” would have the same dimensions as four forty foot modal containers stacked on top of each other (40 ft. x 40 ft. x 8.5 ft. wide).

The use of cassettes will significantly reduce the potential of ship-induced forces into the gas containment system. This is an important consideration for classification societies. Once installed, each cassette would be tied into the CNG carrier’s piping network for loading and unloading of natural gas. A module would consist of one or more cassettes.

The cassette system is designed to allow visual inspection of all CPVs while installed in the ship. The CPVs in each cassette are staggered one half diameter every second cassette. Stepping pads are installed at strategic elevations of the steel frame so that inspectors can visually inspect every CPV.

As cassettes are modal in dimension, the existing guides and supports of an existing container ship may be utilized. Using the existing guides of a container ship, a cassette may be installed or removed for maintenance without disturbing adjacent cassettes. The use of an existing container ship will significantly reduce the start up time and capital cost of a pilot project.

To protect the cassettes from the elements, a housing would be constructed above the main deck. The longitudinal stiffness of the carrier could be increased by making the housing integral with the ship. For safety and fire suppression, the insides of the housing or cargo holds would be purged with inert gas to displace any oxygen in the compartments containing gas storage pressure vessels. For safety of personal, the first isolation valves for each module would be positioned on the exterior of the housing.

As noted, the use of composites will allow for container ship hull forms to be utilized in the Trans Ocean Gas CNG Transportation Method. Container ships are referenced by the number of total equivalent units (TEU’s) that a ship can carry. A unit is the standard 20-foot modal container with an
allowable gross weight of 20 metric tons. Each cassette would therefore equate to eight (8) TEU’s in size.

Depending on the pressure rating of the containment system and the proportional use of carbon and glass fiber, a fully loaded cassette will weigh between 110 and 180 metric tons. Since the allowable weight of eight TEUs is approximately 160 metric tons, the Trans Ocean Gas method can match or come under the deadweight capacity of any container ship.

Each cassette will hold between 1.5 to 1.9 MMscf of natural gas. Therefore, the capacity of a Trans Ocean Gas CNG carrier is directly proportional to the TEU capacity of the host ship, with the cassette containment system utilizing about 85% of TEU capacity. The resulting natural gas capacity will therefore range from 150 MMscf to 1.7 Bcf:

- A small CNG carrier would have cassettes one tier high;
- A medium sized CNG carrier (Panamax in size) would have cassettes stacked two tiers high; and
- A large capacity CNG carrier would have cassettes stacked three or four tiers high.

Additional natural gas capacity can be obtained through the use of conventional refrigeration. CPVs have excellent low temperature characteristics; therefore, a low temperature environment is not a concern. During offloading, the refrigeration system would be used in reverse to combat Joule-Thomson effects, which may cause hydrates to form. If conventional refrigeration were used, the cargo hold area would be insulated.

The Trans Ocean Gas CNG Transportation Method has the ability to extract natural gas liquids (NGL’s) while on route. This is a value adding feature conducted while the CNG carrier is on route to its destination. NGL’s consist of propane, butane, pentane and hexane, which can be stored at relatively low pressures. Since each cassette has an upper and lower manifold, the contents of each module can be cycled without reducing the pressure. The extracted NGL’s would then be segregated for separate but concurrent offloading when the CNG carrier arrives at its destination.

The NGL extraction feature of the Trans Ocean Gas method has another potential benefit. Offshore producers would not need to strip solution or non-associated gas. The reduction of equipment on an offshore structure will allow for a faster rate of flow-through and therefore, an increased rate of gas production. The potential for increased oil production therefore exists if the handling of solution gas is the limiting production factor.

New-build CNG carriers may be powered by natural gas fired turbine generators (gen-sets). Multiple gen-sets would allow for maintenance to be performed without a schedule disruption. Being modular, each gen-set may be removed and replaced with a refurbished one on a rotating basis. Compression and refrigeration equipment would be of a similar modular nature for non-disruptive maintenance.

To offload its cargo of natural gas and possibly NGL’s, a CNG carrier may dock at a pier or use an offshore mooring buoy located several kilometers from shore. Using a mooring buoy to offload will reduce turn-a-round time, as a pilot would not be required to bring the carrier into a harbour. To keep a CNG carrier on station while connected to a mooring buoy, it would have dynamic positioning capabilities. The ability to offload away from populated areas provides for a high level of public safety. It also removes the potential that such a ship would be a target for a terrorist attack.

**ADVANTAGES OF THE CNG TRANS OCEAN GAS TRANSPORTATION METHOD**

**Personnel and Asset Safety** - CPVs do not violently rupture. Thus, the potential of a domino catastrophic failure is eliminated;

**National Security** - Gas can be loaded or unloaded from an offshore mooring buoy, keeping the CNG carrier away from populated areas;
Environmental Safety - In the unlikely event that gas has to be vented from a CNG carrier, environmental damage would be negligible. At atmospheric pressure, natural gas is a vapour. Thus, it would simply dissipate into the atmosphere with no environmental impact;

Economical Alternative - CNG transportation an economical alternative to LNG;

Monetization of Stranded Gas Reserves - CNG development shall allow numerous stranded gas reserves to be economically brought to market;

New Market Creation - CNG transportation shall allow new markets for natural gas to emerge. Island nations would be most benefited;

Environmental Benefits - CNG transportation of solution gas from an oil play will eliminate the requirement to flare large amounts of gas. It will also allow for a greater proportion of electrical power to be generated from natural gas rather than coal or oil, reducing greenhouse gas emissions;

Light Weight - The use of CPVs will allow for the use of a high-speed and voluminous container ship hull form. Being relatively lightweight will allow for Trans Ocean Gas CNG carriers to avail of applicable-length dry docks for hull inspection and maintenance;

Modular Gas Storage - The use of the cassette gas containment system allows for the efficient installation of modular cassettes. The cassette system also allows for relatively easy and non-disruptive removal of a cassette for maintenance or replacement purposes;

Variable Capacity - Being modular allows the Trans Ocean Gas CNG Transportation Method to adjust to supply and demand changes. Cassettes may be removed or added, or a whole carrier removed or added;

Mobility of Assets Between Projects - The main assets of the Trans Ocean Gas CNG Transportation Method are the CNG carriers themselves. Therefore, assets can be transferred between projects;

Flexibility in Delivery Destinations - A CNG project may change its delivery location by moving the location of the offshore mooring buoy or using a different pier. This is not possible with a pipeline or LNG regasification plant;

Long Life Expectancy - Composite pressure vessels have a long life expectancy due to long fatigue cycles and being non-corrosive; and

Natural Gas Liquids Extraction - The Trans Ocean Gas CNG Transportation Method will allow for the extraction of NGL's while on route. Therefore, a gas supply would not need to be stripped before being loaded onto a CNG carrier.

Conclusion

The utilization of composite pressure vessels in the Trans Ocean Gas CNG Transportation Method overcomes all of the perceived deficiencies of a steel based gas containment system. The non-rupture characteristics of CPVs provide an unparalleled level of safety for a CNG transportation system. Being corrosion resistant will allow for the transportation of highly corrosive natural gas if required.

The relative lightweight of CPVs allows the Trans Ocean Gas CNG Transportation Method to avail of high-speed voluminous container ship hull forms. This provides a significant economic advantage over all other proposed CNG methods.

The development of the cassette module provides for the use of existing container ships. This is an important cost advantage to starting a pilot project. It also provides isolation from ship-induced
forces into the gas containment system – an important consideration for classification approval. Being modular, cassettes may be installed or removed without disruption to adjacent cassettes.

Using the Trans Ocean Gas CNG Transportation Method, natural gas can be efficiently stored at or below ambient temperature.

The ability to extract natural gas liquids while on route provides the Trans Ocean Gas CNG Transportation Method with a significant value-adding feature. It will also allow offshore producers to achieve higher rates of gas production, as offshore processing is not required. If oil production is limited by the processing and handling of solution gas, oil production could also be increased.

Public safety is greatly increased through the use of an offshore mooring buoy to offload CNG. Being isolated also removes the threat that a terrorist would target such a vessel. Therefore the Trans Ocean Gas CNG Transportation Method provides for a high level