A REVOLUTION PROPELLED BY PUMPS

Christopher Campos, Elliott Group, USA, describes how multi-fluid cryogenic cargo pumps have revolutionised the transportation of liquefied gases.

Like the California gold rush in the mid-19th Century, the discovery of abundant shale gas reserves has sparked a 'gas rush', forever changing the energy landscape in the process. Harnessed by the hydraulic power of fracking, shale gas drilling has boosted the availability of natural gas, providing a large surplus in the US.

The abundance of shale gas has generated rising demand from global markets for ethane, a natural gas liquid (NGL), and until recently, a largely unwanted by-product of oil and gas drilling. Today, ethane has become the plentiful and inexpensive feedstock of choice for petrochemical producers around the world who convert it to ethylene, a basic building block in plastics production.

Table 1. Estimated world shale gas reserves[1]

Country	Shale reserves	Production status
South Africa	485 trillion ft^3	Exploration
Argentina	802 trillion ft^3	Exploration/political
Canada	>573 trillion ft^3	Exploration, production, exportation*
Mexico	681 trillion ft^3	Exploration/political
US	>308 trillion ft^3	Exploration, production, exportation*
China	1275 trillion ft^3 (potentially)	Exploration/initial production
India	>2000 trillion ft^3	Exploration
Indonesia	574 trillion ft^3	Exploration
Pakistan	205 trillion ft^3	Exploration
Poland	5.3 trillion ft^3	Exploration/political
Romania	51 trillion ft^3	Exploration
Ukraine	42 trillion ft^3	Exploration/initial production

*Construction in place

Figure 1. Very large ethane carrier (VLEC) – *Ethane Pearl.*

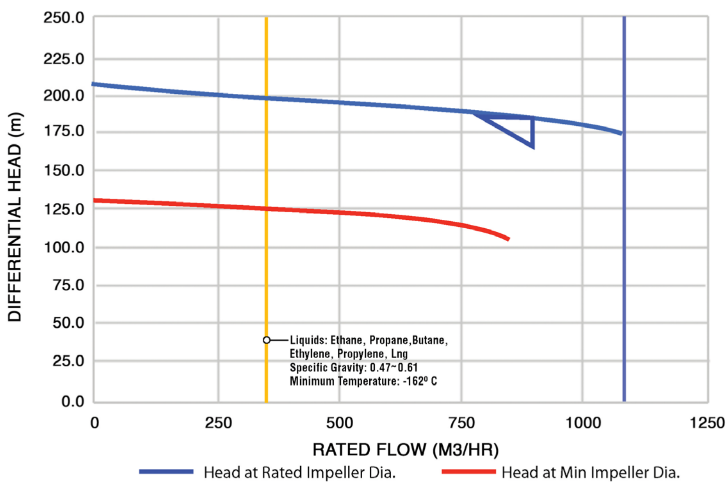

Figure 2. Gen2 multi-fluid cargo pump.

Hydraulic fracturing in the US has produced a surplus of natural gas which can be liquefied (LNG), or refined to extract by-product gases such as ethane, propane and butane.

The economics are clear. If it is possible to extract, liquefy and transport gas at a cost below the cost of other regional suppliers, then it can be exported. This is the underlying reason for the conversion of many LNG receiving terminals in the US to export terminals. Economic transport of these abundant liquefied gases is key to supplying global markets. To reach the markets, they must be transported via tankers across vast oceans. The need to transport the product is the catalyst for a new segment of the shipping industry, transport of liquefied ethane.

Ethane market – present and future

To date, shale gas production and exportation has been largely limited to the US. However, other countries possess vast shale gas reserves, and exploration projects are ongoing. The question is, how much is actually recoverable, and will these countries move forward to extraction, production and, ultimately, exportation? Available natural gas production infrastructure will have a significant impact on whether or when production will become economically feasible. Table 1 provides a brief summary (not comprehensive) of technically recoverable shale gas reserves and their current production status.

Very large ethane carriers (VLECs)

Once ethane gas is separated from natural gas for commercial sale, it undergoes a liquefaction process. The liquefaction process involves compression and cooling via a heat exchanger. Like LNG, liquefied ethane gas (LEG) is commercially transportable. Most small ethane/ethylene tankers utilise proven, cost-competitive Type C tanks, but transporting large volumes of LEG across oceans requires larger tanks to offset the cost of international transport. For larger tank hulls, membrane technology is preferred, along with a boil-off gas (BOG) system that reliquefies the vapour back into the tank. The BOG can also feed dual-fuelled engines. Membrane tanks can be custom manufactured for any size hull, and they allow for tank sizes in excess of 20 000 m^3. Tank heights can be 30 m or more.

VLECs have hulls greater than 80 000 m^3 (see Figure 1). In order to be marketable, VLECs must have the capability to accommodate alternative cargoes in case the ethane feedstock market becomes volatile. Alternative liquid hydrocarbons include LNG, liquid propane, liquid ethylene, liquid butane, liquid propylene, and liquid methane. LNG requires cryogenic construction and operating conditions to handle liquid temperatures of -163°C. At these low temperatures, most metals shrink significantly and become brittle. Aluminium or an aluminium composite construction provides ductility and resistance to shrinkage at low temperatures. Adding LNG to the mix of available cargoes for VLECs provides a huge marketing solution for potential investors, provided that the cargo containment system has been designed to handle the variety of hydrocarbon liquids.

First generation (Gen1) multi-fluid cargo pumps[2]

Accommodating the temperature ranges of various hydrocarbon liquids required the development of a new

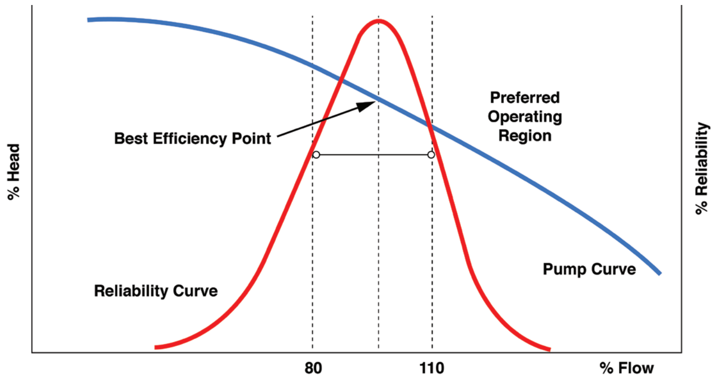

Figure 3. Multi-fluid cargo pump operating envelope and reliability curve.


Figure 4. Cargo pumps.

Table 2. Liquid temperatures and densities for Gen2 pump applications

Liquid	Temperature (°C)	Density (kg/m³)
LNG	-163	470
Ethylene	-104	566
Ethane	-90	570
LPG*	-40	493/600
Propylene	-48	511
ISO-Butane**	-11	594
N-Butane**	0	602

* Assumes mixture of propane/butane product. For pure butane, modifications are required.

** Range of butane products can vary. Elliott limits pump temperature to 0°C for butane products.

pump technology. The pump had to be capable of being installed in a membrane tank 30 m or higher. Operating temperature had to span from -104°C (ethylene) to 20°C (butane). This is a very large range to account for, exceeding 124°C.

Submerged motor cargo pumps for very large tanks have existed for 30 years. However, these pumps have been installed in LNG and LPG carriers exclusively. Prior to 2016, submerged motor cargo pumps designed for such large temperature ranges were unavailable. To meet this need, design engineers at Elliott's Cryodynamic Products operation developed a new pump to accommodate multiple liquid applications with varying liquid densities and a very wide temperature range (Table 2).

Because of the wide temperature range, the design team researched the liquid hydrocarbon composition of the intended cargo to determine how the varying liquids would react to the submerged motor and cargo pump hydraulics, and to ensure that the liquids were safe to operate with the motor, which is submerged completely in the pumping liquid. The pumping liquid also provides the cooling medium for the motor and bearings, and the lubrication medium for the bearings and wear rings. Each liquid has different properties and viscosity characteristics that had to be taken into account.

Design engineers also evaluated the different shrinkage and expansion rates of the pump materials in relation to the different temperatures of the pumping liquids. The pump clearances and shrinkage rates for an LNG pump that operates at a temperature of -160°C only have to accommodate operation at one temperature. For multiple fluids, the pump clearances and shrinkage rates, as well as its expansion rates, must accommodate each fluid temperature.

The Gen1 multi-fluid cargo pumps were developed specifically for Reliance VLECs to transport liquid ethane from the US to India. The operating temperature range was over 100°C. Because butane products have varying levels of vapour and liquid composition, the maximum operating temperature was limited to 0°C to prevent vapour and excess BOG from cavitating in the pump. Since liquid ethane was not available at the factory or the shipyard, the factory acceptance test (FAT) was conducted with liquid propane. A separate gas trial with liquid ethane was conducted at the ethane loading port in Houston, Texas, US.

Second generation (Gen2) multi-fluid cargo pumps

The Gen1 multi-fluid cargo pump met design specifications for the Reliance VLECs. However, the Gen1 pump was limited to a temperature range of 100°C. To accommodate additional liquid cargoes such as ethylene and LNG, design engineers modified the pump to allow for greater material expansions related to liquid temperature and operation in different densities, specifically the lighter specific gravity of LNG. They changed the materials for the bearing housings to a stainless steel that matched the shrinkage and expansion rates of the stainless steel bearings. They also changed internal clearances to accommodate greater material expansion rates at different temperatures.

The Gen2 multi-fluid cargo pump is the result of several years of market research and coordination with shipyards and shipowners looking for solutions for a new shipping segment for ethane transport. The Cryodynamics® Gen2 multi-fluid cargo pumps allow the tanker to offload cargoes from the coldest LNG to warm liquid butane products, and any liquid hydrocarbon between those temperatures. With this capability, a VLEC with a properly designed cargo containment system can operate as an LNG or LPG carrier as well.

The Gen1 pump was designed for duty that fit the size of the tanks on the ship. A specific rated duty point that was common to the industry, and which has a proven hydraulic and pump design, was readily available, with previously discussed modifications to allow for the different temperatures and densities.

To accommodate VLECs with liquid cargoes of 100 000 m^3 and higher, the Gen2 multi-fluid cargo pump design requires a higher discharge rate (800 – 1100 m^3/hr) to handle the increased capacity. With such a high discharge rate requirement, and a low-voltage power supply, the power requirement approaches 500 A of current. To increase the flow rate of the pump to higher capacities, medium voltage, or approximately 6600 VAC, is needed to reduce operating current and allow for safer operating and starting conditions. Additional consideration for motor design and size, and its impact on the overall footprint of the pump is required to meet higher discharge requirements. The Gen2 pump is the first submerged motor cargo pump capable of 900 m^3/hr and higher that can handle the complete range of hydrocarbon liquids (Figure 2).

Long-term reliability and maintenance

The original Gen1 multi-fluid cargo pumps are in their second year of operation and should be nearing their first dry-docking (if that has not already happened by the time this article is published). The pumps, primarily offloading ethane cargo, have been operating without issue. Data captured by the vessels indicate that all operations are running within design parameters of the pump. Although the vessel has not been used for other cargoes, the pumps are ready for that day if it happens.

Multi-fluid cargo pumps were designed with the same long-term reliability as LNG cargo pumps, with a motor life of approximately 25 years. Given how often they operate in a year, most cargo pumps are on their 30th plus year of operation. In terms of maintenance, cargo pumps are designed to follow the dry-docking requirements as put in place by their respective class society. At a 2.5 year dry-dock rotation, the pumps are intended to operate for five years between maintenance overhauls. In fact, the overhaul is only an insurance, as the maintenance is truly an inspection examination to gather an idea on how the pump is running. The bearings and other wearing components may be replaced as a preventive measure (Figure 3).

Conclusion

Global demand for ethane feed stocks has created a new market opportunity for international ethane shipping. Started in the US, other potential sources of liquid ethane can be sourced by future developing countries and transported long distances around the world. Advancements in tanker designs now allow the transport of liquid ethane at cold temperatures for long periods. The technology to safely transport and reduce liquid boil-off led to the creation of a new VLEC. The submerged motor pump technology has also advanced, allowing for greater capacities, liquid ranges, densities, temperatures and even safety. The new Gen2 multi-fluid cargo pump will allow VLECs to approach or exceed the large scale sizes of LNG carriers, should demand continue to drive the current market (Figure 4). **LNG**

References

1. US Energy Information Administration, World Shale Gas Resources, https://www.eia.gov/analysis/studies/worldshalegas/
2. CAMPOS, C., 'Multitasking', Hydrocarbon Engineering, August 2014, pp. 61 – 64