Selecting of vaporizer in LNG regasification plant

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Abstract
During last years, LNG industry has been expanding across the world. Due to the high demand for energy and natural gas, LNG plants and regasification units have been implemented or are constructing in the world. This paper presents an overview of the LNG process, gas liquefaction, loading, transportation and regasification.
Liquefied natural gas is stored in tanks. In the regassification process, the liquefied natural gas must be condensed in order to prevent flaring and venting of the boil-off gas. Then, the condensed gas is sent to the vaporizer to be re-gasified after heating. The main types of evaporators used in the LNG industry include: Open Rack Vaporizers (ORV), Submerged Combustion Vaporizers (SCV), Intermediate Fluid Vaporizers (IFV), Ambient Air Vaporizers (AAV), Shell and tube type (STV), Hot water bath type.

Keywords: LNG, LNG supply chain , Vaporizers

Introduction
The need for natural gas as a clean fuel and for use as feed in petrochemical plants is increasing worldwide more and more. The transmission of natural gas over long distances pipelines has many technical and economic limitations. One way to solve this problem is by liquefying natural gas and producing LNG.
LNG is natural gas, primarily composed of methane, which has been converted to liquid form. Natural gas is cooled to a temperature of -161 ^{o}C where it turns to liquid. LNG must be turned back into gasaus form for commercial use and this is done at regasification plants.
Liquefaction reduces the volume of the natural gas (NG) by 600 times smaller which makes it more practical to be shipped and transported through specially designed vessels. The shipped LNG is received via either onshore or offshore receiving terminals[1-4].

The LNG Process Chain
For production, transportation and consumption of LNG, It needs to be invested in various steps. These steps (excluding the communication pipelines), called LNG chain and include exploration and production, natural gas condensate and export terminal, marine transport, receiving terminals and re-gasification [5-6].
Since 1964, LNG production, export, imports and distribution has followed a process sequence similar as illustrated in Figure 1.

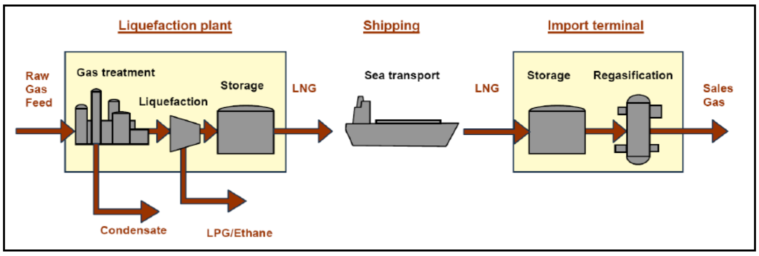

Figure 1: the LNG process chain (from extraction, processing and transport, to consumption) (Source: BV 2009)

Cretria for Selecting of Vaporizer

Re-gasification facility for LNG is generally called as LNG vaporizer. Various types of LNG vaporizers are used depending on site conditions of the receiving terminal and gas demand patterns. According to the heating source for LNG, LNG vaporizers are categorized into several types. The heating sources for LNG are sea or river water, combustion heat such as LNG, heat of operation process, waste heat , etc.

Reliability and durability, stable and safe operation, flexibility to accommodate load fluctuation and low CAPEX, OPEX and life cycle cost conditions are commonly required for vaporizers installed at an LNG receiving terminal. Use of materials with excellent low-temperature characteristics, preventing freezing on heat transfer surfaces, preventing LNG mist formation conditions are also required due to physical properties of LNG.

LNG Vaporizer types are normally classified by their heating method or heating source, which are presented as followings [6-12].

Open Rack Vaporizer (ORV)

Open Rack Vaporizer [13-17] derives the required heat to vaporize LNG from seawater. Schematic of this vaporizer is shown in Figure 2. The water is firstly filtered to avoid the presence of small solid particles in the ORV. It then falls onto panels of tubes containing LNG and then gathers in a trough underneath before being discharged back into the sea. The LNG passing through the tubes is heated and vaporized. The tubes are specifically designed to optimize heat exchange.

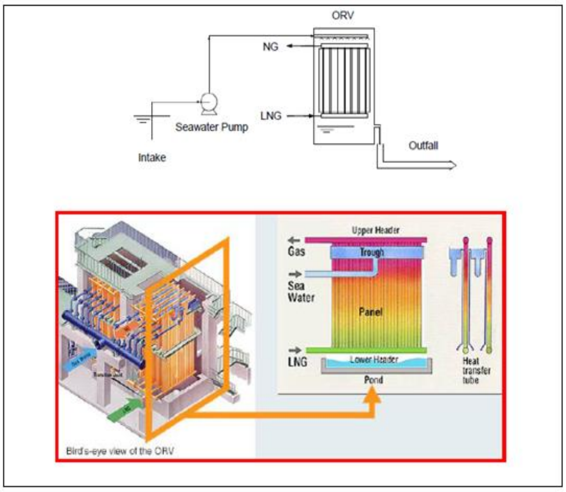

Figure 2: Open Rack Vaporizers (source: Tokyo gas)

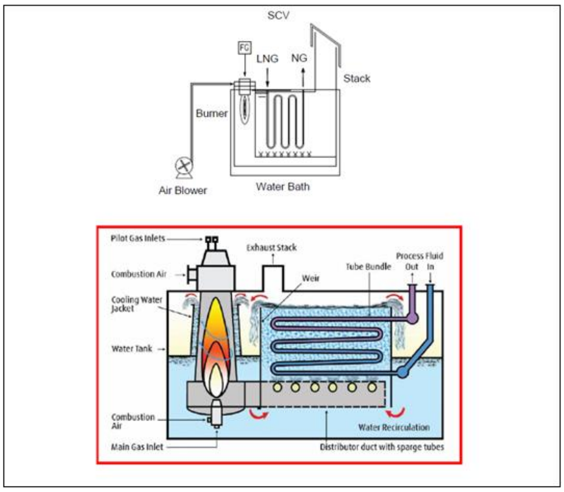

Figure 3: Submerged Combustion Vaporizer (Source: Seals fluid Processing Corporation brochure)

The low cost of operation, simplicity of structure, easy maintenance, reliability and high safety are the advantages of open rack vaporizers. On the other hand, if seawater contains large amounts of suspended solids, another type of vaporizer should be used, as the open rack vaporative components are highly susceptible to abrasive solids.

Submerged Combustion Vaporizer (SCV)

Submerged Combustion Vaporizer [15] is shown in figure 3. In this vaporizer, natural gas is burned to provide the heat needed for a water bath. The hot gas produced in the water bath, in contact with the LNG stream, is placed in a tubular heat exchanger. Gas combustion due to increase heat transfer efficiency between water and LNG and prevents freezing on the vaporaizer bundle tube.

The main characteristic of Submerged Combustion vaporizer is low investment cost and high operating cost due to combustion of natural gas. For this reason, SCV is used as an spare vaporizer.

Intermediate Fluid Vaporizers (IFV)

An illustration of the Intermediate Fluid Vaporizer is shown in Fig. 4. Intermediate Fluid Vaporizer is a shell and tube evaporator that can use sea water as a heat source. This type of vaporizer is even applicable to seawater containing high concentrations of suspended solids, in order that seawater passes through the tubes and the tube material in these vaporizers is corrosion-resistant titanium alloy.

Intermediate Fluid Vaporizer, including three heat exchangers: (1) Intermediate fluid vaporizer, (2) LNG vaporizer (intermediate fluid condenser), (3) Natural gas heater.

This vaporizer is dependent on two levels of heat transfer:

- First, between LNG and a middle fluid like propane

-Secondly, between the middle fluid and a heat source, which is usually seawater.

In the Intermediate Fluid Vaporizer, the propane is evaporated by sea water and the propane vapor in the LNG vaporizer comes into contact with the LNG. LNG steam in NG heating is heated by seawater to produce NG.

The vaporizer surface is designed based on optimizing heat transfer. These vaporizers prevent freezing and reduce the risk of sediment formation.

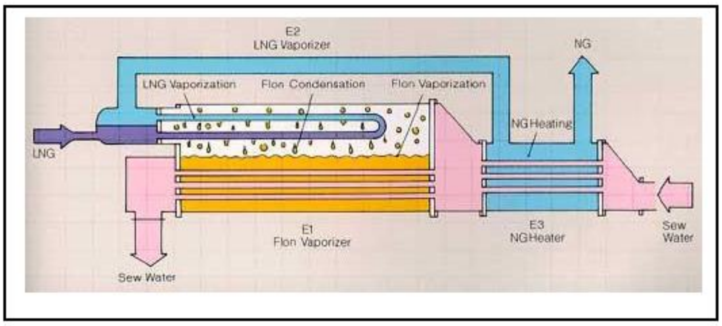

Figure 4: Intermediate Fluid Vaporizer (Source: Kogas)

Shell and Tube type Vaporizer (STV)

Shell and Tube Vaporizers [18] can use several heat sources. Wastewater effluent water (high temperature), and ambient air (in high-temperature areas) can be used as heat sources. An illustration of the shell and tube vaporizer is shown in Fig. 5.

In this vaporizer, ambient air is used as a heat source. The shell and tube vaporizer has an intermediate fluid system for heat-exchange with LNG. The intermediate fluid that is cooled in the heat exchanger after contact with the LNG is recovered by the air -fin heater. Shell and tube vaporizers are generally vertical shell and tube heat exchanger. The air heater is equipped with a fan to improve the heat-exchange between the air and the middle fluid. The disadvantage of these types of vaporizers is that they require a high level of installation due to the presence of an air heater. The temperature of the exhaust gas from the shell and tube vaporizer is strongly dependent on the ambient air temperature. The temperature shall be always kept approximately 20 degrees Celsius below ambient temperature.

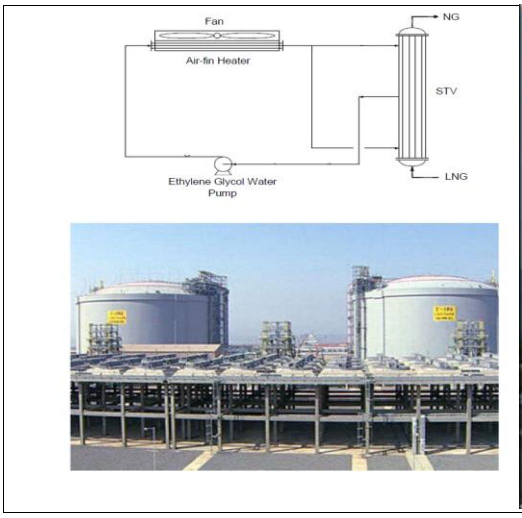

Figure 5: Shell and Tube type Vaporizer (STV)(source: the hindu business line)

Figure 6: Ambient Air Vaporizer (Source: BV 2009)

Ambient Air Vaporizer

An overview of the Ambient Air vaporizer [15 - 16] is shown in Figure 6. This vaporizer uses air as a heating source. This technology has been approved and is generally used for small units

Case Study

As an example, is considered an LNG Regassification plant with a capacity of 7.5 MMTPA. According to the LNG terminal capacity, the required evaporative capacity is about 100 to 200 tons per hour. Due to the high capacity of the plant, the possibility of using STV, ORV, IFV vaporizers were investigated. Due to the solid particles in seawater (since seawater flows on the surface of open rack vaporizers), this type of vaporizer is not suitable. Intermediate Fluid vaporizer can use seawater under any circumstances, but shell and tube vaporizer can use only air as the heating source for evaporating. The heat exchange performance of this vaporizer is affected by the ambient temperature.

The ambient temperature in the selected site, Kutubdia and Payra,Bngladesh, reaches 8-10 °C in winter. As far as above mentioned procedure, the NG temperature of the vaporizer from the shell and tube vaporizer should never be above ambient temperature, when the ambient temperature reaches about 10 ° C, the NG outlet temperature cannot exceed the design value (15 °C). Therefore, in order to keep the outlet gas temperature above the design value, it requires a high NG heater capacity (approximately 20,000 kW). This increases operating costs.

Table 1 compares the two IFV and STV vaporizers. According to this table, since the total cost for the IFV is lower than the STV, the use of this type of vaporizer is recommended for the 7.5 MMTPA plant.

Conclusion

This paper investigates various types of vaporizers used in the LNG industry. The main criteria for choosing the type of vaporizer is the terminal capacity and location of the site. Large-scale LNG receiving terminals Open Rack Vaporizers (ORV), Intermediate Fluid Vaporizers (IFV), Shell and tube type (STV), Submerged Combustion Vaporizers (SCV) are normally used. Ambient Air Vaporizers (AAV) and Hot water bath are used for LNG receiving terminal with capacity less than 1 MMTPA.
Basically, when sea water temperature is high enough during a year and there is no limit to the quality and quantity of seawater in LNG vaporizers, ORV is the most appropriate type (according to the low amount of OPEX).

Table.1 Comparison of LNG Vaporizer

case		**Case 1**		**Case 2**	
Vaporizer type		IFV		STV	
Capacity		190t/h × 6		190t/h × 6	
Installation area		Installation area can be compact		Large installation area is required because many air heaters are required for heat exchanging.	
CAPEX		Main equipment	19 MUSD	Main equipment	3 MUSD
		Auxiliaries	47 MUSD	Auxiliaries	19 MUSD
			-	NG heater	1 MUSD
		Total	66 MUSD	Total	23 MUSD
OPEX	Power Consumption	Seawater Pump	5.53 kW/t	Air Fan	5.37 kW/t
			-	Intermediate Fluid Pump	1.18 kW/t
			-	NG heater	20 kW/t (Max)
	Power price	0.1 kUSD/MWh		0.1 kUSD/MWh	
	Annual cost	4.5 MUSD/y		11.2 MUSD/y	
	Maintenance	(25years)	12 MUSD	(25years)	12 MUSD
		・The major equipment is heat exchangers and seawater facilities.		・The major equipment is heat exchangers and air heaters. ・The maintenance cost of STV is assumed to be almost the same as IFV.	
LCC[1](25years)		191 MUSD		315 MUSD	
Conclusion		**Recommended**		**Not recommended**	

[1] Life Cycle Cost

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