2008 ASME Pressure Vessel and Piping Conference
July 27-31, 2008, Chicago, Illinois, USA

PVP2008-61648

VAPORIZATION OF LNG USING FIRED HEATERS WITH WASTE HEAT RECOVERY

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ABSTRACT

Liquefied Natural Gas (LNG) is an important component in meeting the future energy needs of the United States and other industrialized countries. The ability to locate (produce), process, liquefy, transport, and re-gasify stranded natural gas is vital to maintaining a stable long-term natural gas supply necessary for sustained economic growth [1]. Two of the key components in this supply chain are the vaporization of the LNG at the import terminal and the peak shaver trains that liquefy pipe line natural gas, store it and then vaporize the liquid to feed the gas to the pipe line when additional flow is required.

This paper outlines a novel approach incorporating a traditional fired heater with waste heat recovery to vaporize LNG at an import terminal or peak shaver train while maintaining a high thermal efficiency. A comparison is made between the new technology and more conventional methods, with emphasis on emissions. Some of the advantages and disadvantages associated with the design and implementation of these systems are explored in this presentation.

As a fundamental cannon of ethics, engineers are obligated to address the most efficient and responsible use of resources. The environmental impact of supplying the necessary natural gas energy to industry and consumers is significant. This paper addresses these aspects as considered during the development of the alternative LNG vaporization technology.

INTRODUCTION

In the recent rush to develop domestic LNG import terminal capacity, the majority of developers originally turned to Open Rack Vaporizers (ORVs) which use seawater as the vaporization heat source [3]. Increasingly, the use of ORVs has encountered significant opposition from environmental activists and other organized campaigns. Within the domestic waters of the United States, these concerns have proven to be successful in preventing the use of “environmentally unsafe” vaporization technology. As a result of the public scrutiny and increased environmental regulations, LNG import terminals were forced to evaluate more traditional combustion based vaporization technologies.

Domestic terminals and peak shaver trains have primarily focused on use of submerged combustion vaporization (SCVs) as the preferred vaporization technology. Domestically, the SCV technology is an industry standard due to high thermal fuel efficiency (greater than 98%), ease of operation, and quick efficient, start-up(s). In recent years however, this technology has come under increased governmental regulations due to public awareness regarding environmental emissions, perception about “global warming,” and general sitting requirements for these facilities. In some cases, emissions from SCVs will exceed state and local guidelines for the Prevention of Significant Deterioration (“PSD”) for air quality emission and thereby jeopardize the terminal permit application. As a result, developers of LNG import terminals are encouraged to design a facility that has the least environmental impact. In many projects, the requirement for reduced emissions will supersede overall fuel efficiency and capital installation costs for the vaporization technology.

This paper outlines a new approach to LNG vaporization utilizing fired heater vaporization technology (FHVT) with waste heat recovery and compares to more traditional methods, namely submerged combustion vaporizers (SCVs) and SCVs with Selective Catalytic Reduction (SCR). The comparison includes an evaluation of emissions. Some of the advantages and disadvantages associated with the design and implementation of these systems are explored.

NOMENCLATURE

FERC	Federal Energy Regulatory Commission
FHVT	Fired Heater Vaporization Technology
LNG	Liquefied Natural Gas
ORV	Open Rack Vaporizer
PSD	Prevention of Significant Deterioration
SCR	Selective Catalytic Reduction
SCV	Submerged Combustion Vaporization

SUBMERGED COMBUSTION VAPORIZATION

The four LNG import terminals as well as a majority of the peak shaver liquefiers operating in the United Stated use SCVs as the preferred vaporization technology [2]. Submerged Combustion Vaporizers (SCV) utilizes a stainless steel tube bundle submerged in a water bath to vaporize the cryogenic LNG. The temperature of the water is maintained by the combustion of natural gas. Combustion products are bubbled through a distribution tube into a water bath, creating a two-phase frothing action. The two-phase froth flows up through the tube bundle and the high velocity motion of the gas / water mixture efficiently scrubs the tube surface, minimizing ice build up. Heat is transferred from the water bath to the LNG fluid flowing inside the tube bundle. The tube bundle is a multi-tube, serpentine bundle mounted horizontally within the weir. The burner combustion products, after disengaging from the gas/water, are normally discharged to atmosphere via a short stack. The stack temperature of an SCV is typically about 80ºF. The water bath acts as the heat transfer media that vaporizes the LNG in the immersed tube coil. A schematic of a SCV is shown in Figure 1.

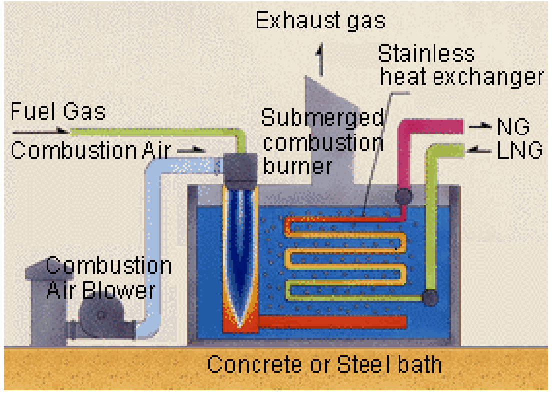

Figure 1: Submerged Combustion Vaporizer Schematic (from Sumitomo Precision Products Website)

SCVs offer extremely high thermal efficiencies, approaching 100%, due to the condensation of the combustion products water vapor in the water bath. Since the combustion products are bubbled directly into the water bath, almost all of the available heat is transferred to the water. The overall efficiency of the submerged combustion is a function of the water bath temperature, the ambient temperature, the carbon: hydrogen ratio of the fuel, and the stoichiometry of the combustion. Since the tube bundle is always immersed in a high thermal capacity water bath, SCVs provide rapid response times for start-ups, shutdowns, and rapid load fluctuations.

The condensation of the water vapor in the combustion products results in a net water production from the vaporizer water bath. Approximately 22 gpm of water is produced (per 200 MMSCFD of LNG vaporization capacity) and must be treated prior to disposal. The submerged combustion process creates acids (nitrous, carbonic, nitric, etc) in the water bath. Monitor and control of the pH of the water bath chemistry is required to minimize the effects of these acids. Sufficient dosing agent is required to maintain the pH above 6. Low chloride water is required for the initial fill of the bath to avoid chloride stress cracking in the stainless steel tube bundle.

The environmental impacts of SCV emissions are numerous as carbon dioxide (CO_2), carbon monoxide (CO), particulate matter (PM_{10}), and NOx are produced in significant quantities due to the combustion process. Typical air permitting regulatory compliance has a threshold level of 250 ton per year per pollutant for the prevention of significant deterioration (PSD). Certain State and local environmental agencies may require even lower emission requirements (state of Maine has 100 tons per year threshold). Highly concentrated industrial areas (non-attainment zones) like the Houston ship channel are extremely severe (maximum 40 tons per year per pollutant). If a PSD is triggered (triggered by exceeding target emissions) the permit application can be delayed at least one year and significantly increase the developmental costs of the project (extensive air quality modeling and operational delays). Developers wishing to avoid such risk are evaluating other vaporization technology. SCVs with Selective Catalytic Reduction (SCRs) have the potential to reduce emissions from import terminals; however this is a significant additional capital investment cost.

Selective Catalytic Reduction (SCR) technology utilizes catalyst beds on the SCV exhaust gas to reduce the environmental emissions. Commercially, this application has been installed at one operating SCV unit. A diagram of an SCV with a SCR is shown in Figure 2.

The exhaust gas from the SCV must be re-heated (typically with a duct burner or combustion chamber by-pass gas) to the catalyst operating temperature of approximately 600ºF (315ºC). While an economizer can recover most of the waste heat, the exhaust gas from an SCV is compromised (from typically 80ºF (275ºC) to approximately 180ºF (82ºC) and results in a lower overall thermal efficiency.

The neutralization of water by caustic control in the SCV water bath results in the formation of sodium and potassium salts, which are a poison to the SCR catalyst. These contaminates reduce the original catalyst activity thereby reducing the effectiveness of the SCR in achieving the environmental regulations. Typically, the catalyst supplier will account for 5-15 percent anticipated deactivation and simply add to the nominal catalyst volume to comply with the long-term catalyst performance guarantees. While these items offer some relief, the sheer size of the exhaust gas from the SCV results in significant capital and operating costs being added to the facility in order to achieve acceptable air quality emissions.

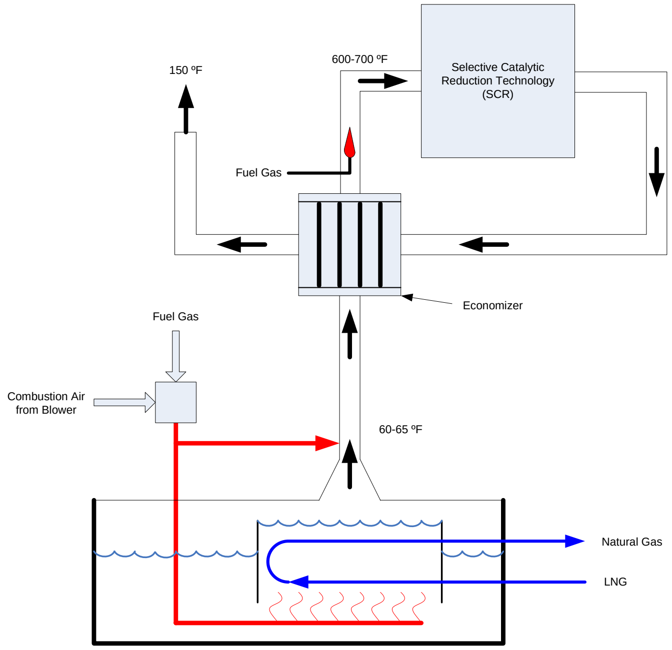

Figure 2: NOx solution – SCVs with SCR technology

To remove carbon monoxide (CO), an oxidation catalyst is required which has the potential to create a safety risk in the event of an SCV tube bundle leak. At the operating temperatures of the CO reduction catalyst, the presence of a large quantity of natural gas could result in a potential fire or detonation. As a result, CO catalyst reduction has not been installed in an operating SCV unit. Additional horsepower is required for the SCV combustion air compressor due to the additional pressure drop of the economizer exchanger and the catalyst bed.

The technology to incorporate NOx emission controls on an SCV, specifically selective catalytic reduction (SCR), is challenging and carries significant technology risks. An alternative method is the Fired Heater Vaporization Technology (FHVT).

FIRED HEATER VAPORIZATION (FHV)

Process heat for the vaporization of the LNG is supplied via a warm, closed loop circulating fluid, typically water. All components of the FHVT are conventional technology proven in general industry usage. In the closed loop, heat is absorbed in a fired heater with a Condensing Waste Heat Recovery Unit. The system incorporates a blower for the combustion air. The warm circulating water transfers heat to the LNG in a direct heat exchanger, typically a shell and tube exchanger [4]. A schematic of the vaporization process is shown in Figure 3.

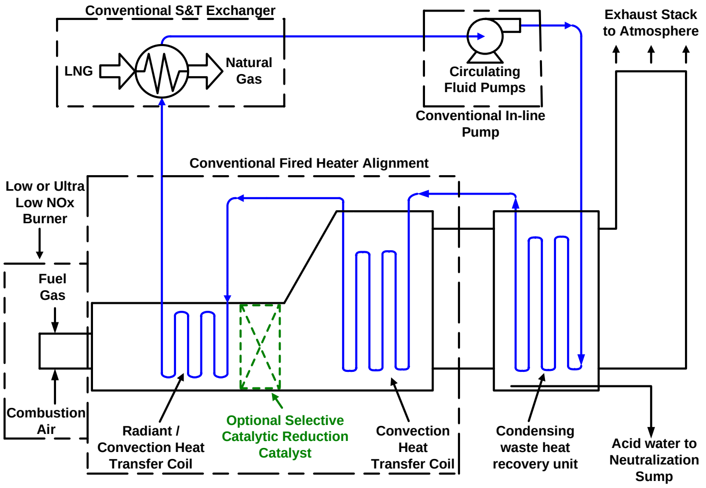

Figure 3. Fired Heater Vaporization Technology

Horizontal cabin-type fired heaters are used to warm the closed loop water from 100^{o}F (38^{o}C) to 200^{o}F (93.3^{o}C). For 2,000 MMSCFD of sendout, 40,000 gpm of 200^{o}F (93^{o}C) water is required. The exhaust gas in the fired heaters will be cooled in a condensing waste heat recovery unit to approximately 120^{o}F (48.89^{o}C). For emission reduction, the fired heater will use a proven ultra low NOx burner technology and fuel gas recirculation (FGR).

The lower than typical exhaust temperature from the fired heater exhaust (120^{o}F/48.89^{o}C) will result in the condensing of water from the exhaust gas due to normal humidity in the air and water being a by-product of complete combustion. Due to the contact with CO_2, NO_x and other trace components, the condensed water will form a weak acid solution (primarily carbonic and nitric acids). The maximum anticipated rate of condensed acidic water is 12 USGPM per operating fired heater. The water will be gravity drained to a collection sump, neutralized with caustic and released, pumped to a utility water tank, firewater pond or other outfall.

The advantage of the FHVT is the components are conventional, industry proven components with multiple vendors available. High thermal efficiency (>97%) is still available yet standard conventional designs allow the developer to meet most PSD thresholds. If required, conventional selective catalytic reduction technology can be employed between the radiant and convective sections if ultra low emissions are required. The advantage being re-heating of the exhaust gas is not required and the catalyst is not exposed to the water bath and/or salt formation.

DESIGN CODE CONSIDERTIONS

The SCV's manufactures typically design the stainless steel tube bundle and interconnecting piping to the ASME Code for Pressure Piping B31.3 Process Piping [5]. The tube bundle is designed to comply B31.3 requirements such as material application considerations, pressure design consideration and pressure relieving requirements. The balance of the system is not considered pressurized and not designed to ASME codes.

The pressurized equipment utilized by the FHV's would typically be designed to the consensus codes of ASME Boiler and Pressure Vessel Code Section VIII Div 1[6] for the heat exchangers, the ASME Code for Pressure Piping B31.3 Process Piping [5] for the interconnecting piping and the heat transfer coils. The respective code requirements such as material application considerations, pressure design consideration and pressure relieving requirements would be utilized. The specialized design requirements for the heating and vaporization of the cryogenic LNG in the shell and tube exchanger are similar to those addressed in the Porter et el paper [4] and this type exchanger is in general use for vaporization of LNG. The heat source considered the use of conventional burners and gas turbine exhaust heat recovery. The application of both of these heat sources is well proven in industry. The high thermal efficiency achieved by use of the condensing waste heat recovery unit indicated in Figure 3 is somewhat unique and requires consideration for condensing the flue gas similar to a high efficiency home furnace application.

The environmental design considerations are outlined in other sections of this paper. The FHV's design requirements to achieve the PSD requirements is well proven by many general industry applications for both fuel fired commercial burners and gas turbines.

COMPARISON OF EMISSIONS AND COSTS

In order to provide a consistent basis for comparison, engineering simulations were created to model three (3) different LNG combustion related vaporization technologies, namely Submerged Combustion Vaporizers (SCV), Submerged Combustion Vaporizers with Selective Catalytic Reduction (SCR), and Fired Heater Vaporization Technology (FHVT).

The evaluation was performed for an LNG terminal application with a sendout flow rate of 2,000 MMSCFD and a natural gas temperature of 40ºF. Pipeline delivery pressure was assumed to be 1350 psia. The composition of the LNG is assumed to be a typical light LNG feedstock and is shown in Table 1.0. The assumed location of the LNG terminal is on-shore, east coast of the United States.

The numbers utilized as a basis of comparison is based on previous information obtained from manufacturers. Some vendors will do better, some will do worse. The technologies were then compared using environmental emissions criteria as established by PSD considerations. Comparisons between the calculated emissions numbers for the three vaporization options are summarized below.

Table 1.0 Composition of LNG Feedstock

Component	Mole Fraction
Nitrogen	0.0010
Methane	0.9931
Ethane	0.0028
Propane	0.0020
i-Butane	0.0004
n-Butane	0.0005
i-Pentane	0.0002
Total	1.0000

EMISSIONS / EFFLUENTS

Current available SCV design limits NOx and CO emissions to a guaranteed value of approximately 25 ppm each. Given that constraint, Table 2.0 summaries the typical emissions from ten (10) operating SCVs:

Table 2.0. Typical SCV Operating Emissions for Terminal

2000 MMSCFD Sendout	NO_x Tons/Yr	CO Tons/Yr	PM_{10} Tons/Yr
SCVs (10 Operating)	207	374	5
CT – GE Frame 6B (2 Operating with SCRs Installed)	55	45	20
Total	261	419	25

For the SCV operations, the NOx and CO levels will exceed all PSD threshold limits (both federal, state, and local) and require significant attention to receive the required FERC permits (i.e. notice to proceed).

Incorporation of the SCR technology on the SCV has a dramatic effect on the emissions as shows in Table 3.0.

Table 3.0. Typical SCV with SCR Operating Emissions for Terminal

2000 MMSCFD Sendout	NO_x Tons/Yr	CO Tons/Yr	PM_{10} Tons/Yr
SCVs (10 Operating)	21	374	5
CT – GE Frame 6B (2 Operating with SCRs Installed)	55	45	20
Total	76	419	25

The SCR catalyst was installed to cut the NOx production by 90%. It should be noted, however, the SCR technology does not reduce the CO rate. PSD would still be triggered due to the high CO emission rates.

Incorporating the FHVT technology has an even more dramatic effect on the emissions as shown in Table 4.0.

Table 4.0. Typical FHVT Operating Emissions for Terminal

2000 MMSCFD Sendout	NO_x Tons/Yr	CO Tons/Yr	PM_{10} Tons/Yr
FHVT (10 Operating)	34	28	72
CT – GE Frame 6B (2 Operating with SCRs Installed)	55	45	20
Total	89	73	92

While the reduction is emissions allows the developer of the LNG Import Terminal to meet environmental emissions without triggering a PSD, the real advantage is the high thermal efficiency is maintained as summarized in Table 5.0. Even though the overall efficiency is high, the operating expenses are nearly identical.

Table 5.0. Technology Comparison of Operating Parameters

2.0 BCF Sendout	Operating Expenses $/yr	Vaporization Thermal Efficiency	Overall Thermal Efficiency
Submerged Combustion Vaporization	$78,892,861	98.41%	94.83%
Submerged Combustion Vaporization with SCR Catalyst	$81,370,253	95.63%	92.25%
FHVT with SCR Catalyst	$80,827,094	93.25%	92.41%

CONCLUSION

Three (3) different combustion processes for LNG vaporization were compared for a large LNG import terminal application (2.0 BCF of sendout gas). Similar results would be achieved for peak shaver trains. The SCVs have the highest thermal efficiency yet also has the highest emissions. From an environmental technology standpoint, SCVs would be considered Best Available Control Technology (BACT). SCV with SCR technology has lower overall emissions than SCVs but do not prevent the triggering of the PSD in all cases. Additionally, operating issues make the SCRs application somewhat problematic on the SCV exhaust stacks and should be avoided in most cases. The Fired Heater Vaporization Technology (FHVT) offers the lowest emissions without sacrificing significant thermal efficiency. The incorporation of the technology allows the developer to meet environmental regulations yet maintain a comparable thermal efficiency and the high reliability necessary for this basic utility.

ACKNOWLEDGMENTS

The authors wish to thank Dan McCartney and Brian Price for their comments and help in preparing this paper.

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