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The Safety Design Research of a LNG Carrier Vehicle

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Abstract

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Abstract

LNG is the abbreviation for liquefied natural gas, which is recognized as one of the world's clean energies. LNG is one product at natural gas that through purification and ultra-low temperature is liquefied. The liquefied natural gas is very suitable for LNG transportation by a truck. China is a big country rich in natural resources. The use of natural gas is in favor of Chinese energy structure adjustment. It has important strategic significance to improve the ecological environment and the quality of people's lives.

A LNG carrier vehicle is a cryogenic liquid tanker truck used to transport liquefied natural gas in an ultra-low temperature environment. Because LNG is flammable, explosive, and cryogenic and so on, it is very important the safety design of LNG carrier vehicle demanded in the road transport safety.

LNG carrier vehicles usually consist of LNG cryogenic liquid storage tanks, trailer running gears, piping systems, a control box and other components. Among them prone to accidents are mainly LNG cryogenic liquid storage tanks and safety accessories. This paper dealt with the safety design research to these two systems. The main tasks included the following:

1. The statuses of the development of LNG carrier vehicle were studied to understand the development of LNG carrier vehicle safety performance, indicating the need for LNG carrier vehicle safety design.
2. The structure and composition of LNG carrier vehicle was studied, and the accident type of LNG transport, in order to indicate the direction for the safety design of LNG carrier vehicle.
3. The main components of LNG carrier vehicle, LNG tanks and vehicle safety accessories were designed and the safety design requirements were kept in mind.
4. A LNG carrier vehicle which general size is 37m^3 in China was case studied, and the method of AHP was used to analyze the LNG carrier vehicle to see whether it can achieve safety requirements during the transportation. The analysis results show that the LNG carrier vehicle with safety design is able to meet the safety requirements.

Keywords: LNG carrier vehicle, LNG tank, safety accessories, AHP

CONTENTS

SYMBOLS AND ABBREVIATIONS

LNG	Liquefied natural gas
CO_2	carbon dioxide
H_2O	Water
NPT	Thread gauge of taper pipe in American standard
AHP	Analytic hierarchy process
THT9360	One model of split type semi-trailer chassis
GRP	Glass reinforced plastic
GB1589-2004	Specific standard of safety design
GB18442-2001	Specific standard of adiabatic pressure vessel
MLI	Multi-layer insulation
BOG	The compressor model
SS	Standard specification

1 INTRODUCTION

Recently, natural gas has been one of the three big pillars among the world's energy, and it has been widely promoted and applied in the world. It is a kind of clean energy which sufficient combustion products are mainly CO_2 and water. LNG gets the favor of governments all over the world, because of the oil crisis and global oil price rise. In China, natural gas is one of the important strategic energy to improve the ecological environment, and it can help to change the single energy structure in our country where coal is given priority as well. At present, natural gas has entered the ordinary people's home by the vast number of consumers' popularity, and it also has shown a good development in industry and automobile industry at the same time.

In recent years, natural gas has grown rapidly both at supply and demand in China. In order to solve the huge gap between supply and demand, it is needed to import 35 billion cubic meters of liquefied natural gas in China by the year of 2020. Natural gas is carried mainly through the network transmission, while LNG can be used for peak loading, complementary and alternative. In China, LNG plans are mostly concentrated in the central region at present, but the market is mainly concentrated in the eastern region, so LNG needs to be transported to the eastern region and the surrounding market by highway transportation.

This topic combines with the conclusion of the research domestic and abroad, which is basic on the risk analysis of a LNG carrier vehicle and the accident consequence analysis of LNG. Then, the safety of a LNG carrier vehicle design and solutions and suggestions are put forward.

The goals of this research are as following:

1. In-depth understanding the characteristics and risk of liquefied natural gas (LNG), realizing the structure features of a LNG carrier vehicle and the working principle and the function of safety accessories.
2. Analysis of all kinds of risk factors in the process of LNG carrier vehicle accidents during the transportation, and then determining the key points of the design.
3. The safety design of various parts of LNG carrier vehicle components, on the basis of risk analysis.
4. Using the fuzzy mathematical evaluation method to evaluate the safety design of LNG carrier vehicle transportation which based on analytic hierarchy process (AHP) through the comparisons of the results.

2 THE ROUTE OF TECHNICAL RESEARCH

The LNG carrier vehicle is a special purpose vehicle that transports cryogenic liquid of liquefied natural gas. Because the risk of LNG is high, the requirements for safety design of a LNG carrier vehicle are also very high. In order to secure as far as possible there is no accident in the process of transportation for LNG carrier vehicle, the leak is reduces as far as possible after the accident, the safety of the surrounding people is ensured and the economic losses of the enterprise are reduced. Under the researches of LNG carrier vehicles domestic and abroad, this paper covers the design of overall structure, the structure of tank, piping system and safety accessories for LNG carrier vehicle, which got through safety tests on each parts by the method of analytic hierarchy process.

This paper is divided into few chapters. The main contents include as following:

- The first chapter mainly introduces the development status and analysis of each security component of LNG carrier vehicle, also discusses the purpose, necessity and significance of safety design for LNG carrier vehicle.
- The second chapter mainly introduces the car body structure composition of LNG carrier vehicle, technological process of LNG carrier vehicle's loading and unloading, and also the accident case analysis of LNG carrier vehicle is included.
- The third chapter mainly introduces the structure of LNG carrier vehicle tank, adiabatic mode and material selection and so on, and then proposes the scheme and summary of safety design for tanks.
- The fourth chapter introduces each safety accessories of LNG carrier vehicle, such as the working principle and design process of safety relief device, emergency cut-off device, safety instruments and conducting electrostatic device, as well as carries on the design which takes these safety systems as a whole at last.
- The fifth chapter introduces the method of analytic hierarchy process to the risk of inspection and evaluation of LNG carrier vehicle tanks and safety accessories. After that analysis of the safety design whether is reasonable and available or not.
- Chapter 6 to summarizes all of the above work, and evaluates the future of LNG carrier vehicles and LNG industry. It proposes some suggestions and targets as well.

The workflow of this paper is shown in Figure 1.

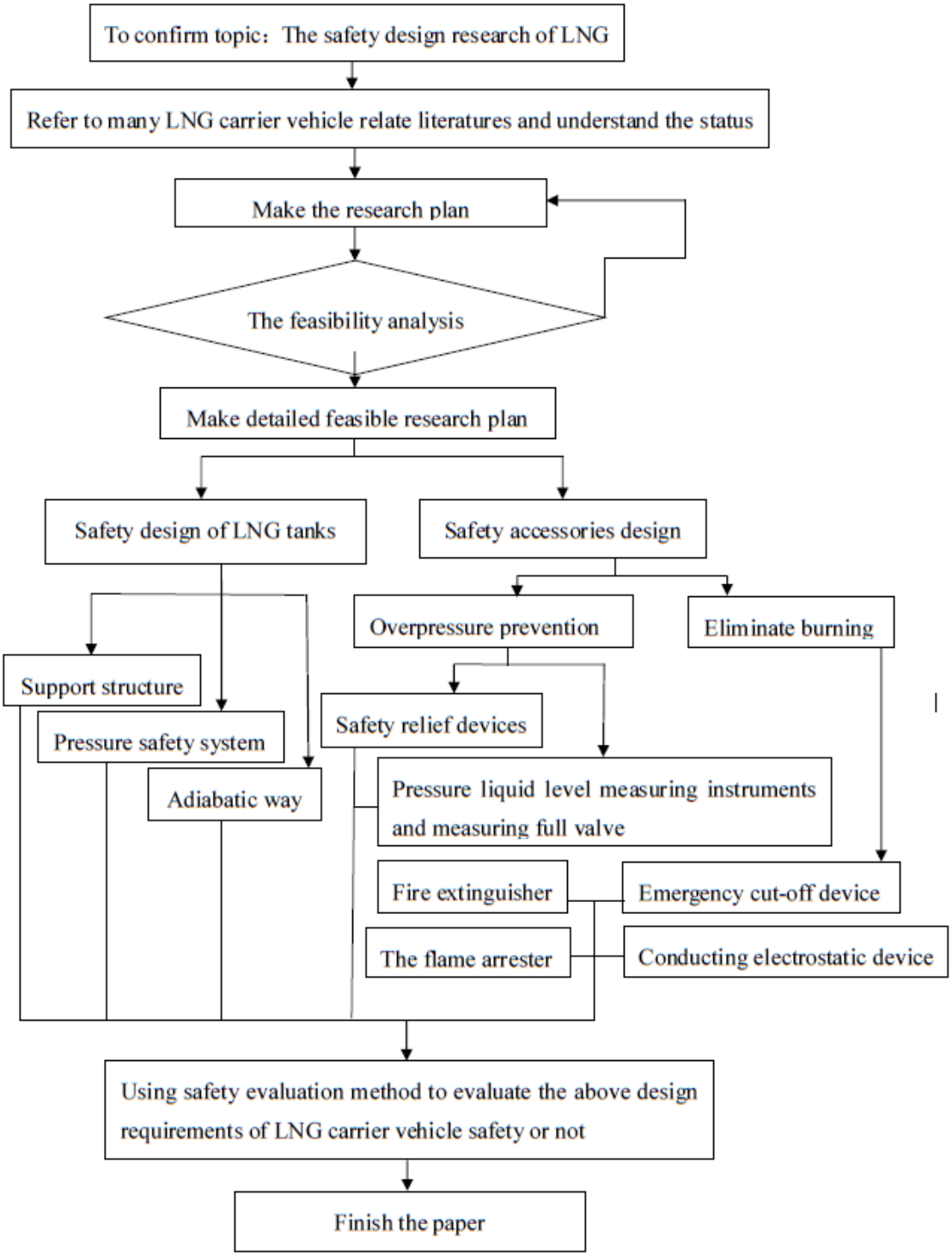


Figure 1. The technology roadmap of paper (Yi Liang.)

2.1 The necessity of LNG carrier vehicle safety design

The main composition of natural gas is methane, which has the characteristics being of flammable and explosive, and the explosion limit between 5%-15%. In addition, the method of converting natural gas to liquid is cryogenic operation, thus LNG has the

characteristics of cryogenic liquid. It will cause the harm and damage either on the human body or the body of tank. It may frostbite the human body skin when the cryogenic LNG gets in touch with human body, and is even life-threatening when the contact is serious. The low temperature can cause the damage on LNG carrier vehicle parts as well, such as relief valve leakage liquid is frozen, result in the relief valve is to get stuck and unable to action. The surrounding people and the vehicle are under threat when the safety accidents such as leak happened, and that will cause the great economic losses and casualties, if the safety accessories of LNG carrier vehicle do not work properly.

According to statistics, there was only one LNG carrier vehicle safety accidents in China during the year of 2004. However, the safety accidents have risen to seventeenth by 2011, and it shows an obviously rising trend. So after analyzing the risk of LNG carrier vehicle, the safety design of LNG carrier vehicle must be completed, and the reliability of equipment and facilities improved, in order to make LNG transportation safe and reliable.

So the theme of research content is LNG carrier vehicle safety design in this study, it takes LNG vehicle tanks and safety accessories as the research object, and then ensures the safety of LNG vehicle transport by these two aspects of research, finally obtaining good economic benefit and social benefit.

2.2 The Development Status of LNG Carrier Vehicle Domestically and Abroad

In recent years, Domestic LNG transportation highlights its importance, along with the rising number of LNG carrier vehicle accidents happened, which cause heavy casualties and huge property losses. Earlier the research of LNG carrier vehicle was mostly based on the development of cryogenic liquid transportation truck. Now more and more researches about LNG storage and transportation have been done from the different component parts of LNG carrier vehicle, and the researchers made the following researches in China:

1) The selection of LNG carrier vehicle chassis

According to the transport characteristics, Jiuxiang Gao and others have been proposed that LNG carrier vehicle should choose the modified tractor and trailer by the national public announcement in 2004, and they need to meet the dynamic properties of semi-trailer. This kind of LNG cryogenic liquid vehicle is made up of LNG cryogenic

transportation tank, semi-walking mechanism, pipeline system, operating box and other parts. (Jiuxiang Gao 2004.)

2) The tanks

In 2007, Hao Liu and others have studied for LNG carrier vehicle cryogenic tanks, and not only the factors were pointed out that had influenced the pressure rise of LNG cryogenic tanks, but also the quantitative analysis from the overpressure and negative pressure of tanks was made. Their study showed that the fixed structure between the inner and outer cylinder can be designed into eight points of group support structure with glass fiber reinforced plastic, because of the long time transport activities by moving of LNG carrier vehicle. It can protect the container between inside and outside without displacement and rigidity failure happening. Also it can ensure that the container will not face the fracture of support by chilling shrink at low temperature. At 2009, Xinhui Yuan and others analyzed the intensity change of LNG carrier vehicle tank's structure by using finite element analysis method, which got the tank's law of stress distribution, the stress changes of tank when vehicle body suddenly fall and the front bearing stress distribution. (Hao Liu, Yongchun Zhou 2007.)

3) Emergency cut-off device

The role of emergency cut-off device is pipeline truncation in the situations of accidents and emergency. The emergency cut-off device of liquefied natural gas (LNG) vehicle consists of hand pump, emergency cut-off valve, and emergency relief valve, fusible plug and other parts. Jiandong Wu did the research on the application of emergency cut-off valve in 2013, which introduced the different ways of working principle and function of emergency cut-off valve in detail. In 2011, Yaohui Yue who comes from Jiangnan University did the research on the inspection of emergency cut-off valve, and it indicated that the flow condition of internal flow field in the emergency cut-off valve was mainly associated with the inlet velocity of fluid and opening of valve. The greater the inlet velocity, the smaller the valve opening and the greater the fluctuation pressure difference of main valve core, the easier for valve closed. The flow of export is almost unchanged in the whole process valves are closed. (Yaohui Yue 2011.)

4) The safety relief devices

The role of the safety relief devices aims to ensure the safety of inner and outer cylinder in the case of vacuum damage that is caused by internal and external leakage. In 2007, Yuhong Liu and others did the research which was about the structure of safety relief devices for long tube trailer and made the improvements as well. Their study found that there are always the water appearing or ice blocking phenomenon between the rainproof membrane and the rupture disk components of safety relief devices, and it may lead to that the rupture disk cannot be used normally when the water of icicles fulfill the space of them. They suggested to use sealant seal gap at the top of the drain pipe, and put to use NPT (Thread gauge of taper pipe in American standard) sealing thread linking nuts with the base at the same time. In 2009, Long Gong and others did the research which about the set selection and calculation of the safety relief devices, introducing in detail the classification of the safety relief devices as well as the selection process and rules. (Yuhong Liu, Zhihui Zhang 2007.)

5) Extinguishing equipment and conducting electrostatic device

The extinguishing equipment can refer to the content of fire protection rule for requirement and design in the domestic market. While electrostatic conductive occurs in vehicle transportation engineering, there is a clear introduction and regulation in the transportation industry standard which is jointly complied by the Ministry of communications research institute and Beijing Shijingshan Unicom mechanical & electrical chemical technology development department. In the early year of 1995, Liang Liu already made the introduction and interpretation for the transportation industry standard which is under the support of Ministry of communications and the highway management department.

6) Piping system

Due to the infusion mode of LNG carrier vehicle there is the self-pressurization. There are some requirements for this way of infusion. Ran Zhao has proposed that it is easy to produce the phenomenon such as vortex in the process of LNG filling. The LNG can be evaporating and cause accidents, so it must avoid this kind of phenomenon in the process of filling during piping design. At the same time, ensuring the oxygen content inside the LNG carrier vehicle tank should be less than the specified value after filling. Moreover, in order to avoid the expansion and contraction that is caused by the low-temperature characteristics of LNG, as well as the pipeline loose and

damage caused by bumping in transit, it should be considered the piping materials and how to tighten the pipe in the design of piping system. In addition, it also has a problem of frost in the import pipe of LNG cryogenic vehicle. Yu Hong proposed that the connector positon of liquid pipeline could be changed as well as spray tube from middle of spray pipe to the head of spray pipe. The pipeline design of inside interlining could be improved, and the reliability and validity of these measures in practice was proved in 2009. (Yu Hong 2009.)

7) The flame arrester

The flame arresters come together on the piping of safety relief valve and exhaust valve outlet. It has the effect to cut off the flame and prevent fire to return when the entrance of vent pipe is on fire. The design of flame arrester shall not affect the normal discharge from safety relief devices, so the guiding principle of preliminary design for flame arrester is to prevent the spill, ensure to prevent fire and the respiratory function, as well as the convenient for maintenance. There are a lot of domestic researches in the design of the flame arrester. Fengshui Cui and others carried on the flame arrester design and research of breathing valve from the oil transportation vehicles. (Fengshui Chui, Wenjie Wu, Zhaofu Gao, Chaoxian Lv 2004.)

8) Measuring pressure, the liquid level measuring instrument and the full valve measurement

The purpose of these instruments is to prevent overpressure and determine the height of liquid level in the tank. In 2012, Chunjuan Wang and others proposed that these instruments without the liquid level display or liquid level are no accurate. It needs to pay more attention on the continuous explorations and in-depth research on tank structure design, in order to get more accurate measurement results.

The LNG carrier vehicle technology is relatively advanced in the foreign countries, such as Chart Industries in the USA. On the design concept of vehicle bottle, which uses of LNG cryogenic liquid saturation concept to add high saturation of LNG inside the cylinders, the cylinder is made to achieve the demand pressure to the engine automatically. There are fourteen of interface valves of LNG cylinder, which consist of liquid outlet of cut-off valve at low temperature, back to gas port of cut-off valve at low temperature, primary safety valve, second level safety valve, economic pressure regulating valve, liquid export over-current protection valve, filling check valve, liquid adding entrance, back to gas port entrance, self-pressurized liquid entrance of cut-off

valve at low temperature, self-pressurized gas return over-current protection valve, pressure regulating valve, and self-pressurized safety valve. (Chunjuan Wang, Jing-bin Li 2012.)

In addition, the LNG transportation design researches were focusing on the study of LNG ship systems at the foreign countries. There was one quantitative research about how to prevent cavitation aspects on control valve at low temperature for LNG ship in 2008, and there had been designed a new type of control valve with prominent prevent cavitation effect at low temperature.

In a large number of LNG related literature it was found that the technology of LNG carrier vehicle is relatively mature, after decades of development abroad, while the most tanker at domestic market, foreign technology is used and there are only few independent innovation. At the same time, the application of LNG carrier vehicle seems to be not very common both in China and abroad, despite it has the characteristics of fast and light on land transportation. Because of the LNG carrier vehicles are generally single full loaded and then single empty no-load, so that the transport efficiency is low, it is promoted the design requirements of LNG carrier vehicle's light weighting, in order to reduce the economic loss of single no-load. Meanwhile, in the case of guarantee volume and efficiency of LNG carrier vehicle, the safety design is also very important. However, a large number of literatures from China and abroad are concerning the design of ship structure, and there are only few terms about the safety of vehicle accessories, and for the design of LNG carrier vehicle is still rare. But the safety of LNG ships accessories research have an important reference for the design of LNG carrier vehicle. The safety protection is almost the same in the several kinds of LNG transportation mode.

In conclusion, the safety design of LNG carrier vehicles is mostly semi-trailer design in China and abroad, and the main research is focused on the part of tank. For other safety accessories designs are mostly for oil storage and transportation vehicle, LNG station and LNG ships. There is almost no as a whole design of LNG carrier vehicle classis, tanks safety accessories and so on.

2.3 Summary of This Chapter

In this chapter, the paper introduces the basic situation of Chinese LNG development, and LNG in the application of daily life is becoming more and more popular as an important strategic energy. In reality, it results in LNG leakage when the LNG

transportation accidents happen with serious accident consequences. Due to the risk of LNG, the safety design of LNG carrier vehicle is very necessary. After studying the domestic and foreign development status of LNG carrier vehicles, and identifying the research contents and the technology roadmap in this paper, goals and work process for the thesis writing were finally set.

3 THE INTRODUCTION OF LNG AND LNG CARRIER VEHICLE

Liquefied Natural Gas is a colorless, odorless and non-toxic liquid, which main composition is methane. Before usage, carrier vehicles loading LNG needs to pass specific design in order to ensure the safety.

3.1 The Brief Introduction to Liquefied Natural Gas

It is another energy form of natural gas that produced by gas pressure under -162℃.The volume of liquefied natural gas is about 1/600 volume of gaseous natural gas and has lighter mass which is only about 1/45 of the water which makes it very suitable for storage and transportation. (Jiuxiang Gao 2004.)

The boiling point of liquefied natural gas is 161.25℃, its ignition point is 650℃, and its density is between 0.420 and 0.46 t/m^3. Besides, the range of its explosion is between 5% and 15%. LNG is one kind of very clean and friendly-environmental energy. Its main products of combustion are H_2O and CO_2. Furthermore, LNG is also a high quality fuel that its heating value of gaseous is 38MJ/m^3, while the heating value of liquid can be up to 50 MJ/kg. Because of these properties, LNG can be widely used in industry all over the world and is the key to carry on the transformation of energy consumption structure in all energy superpower.

China also attaches the great importance of this kind of new clean energy. The coastal LNG project is now on planning and implementing, which will make coasts become into LNG receiving station and transmission network at last. By 2020, China will import 35 billion cubic meters of liquefied natural gas that will reduce the huge gap between supply and demand.

3.1.1 The Risk of LNG

Natural gas is mainly composed of methane, and its properties are similar to the pure methane, it belongs to pure asphyxiation that has high concentration of suffocation caused by hypoxia. Due to the properties of natural gas being colorless and odorless, so it is hard to find the leak when leakage accident occurs. Apart from that, it can also make human beings suffer headache, and be dizzy, anemic and oblivious and hard to breathe and have disease of tachycardia, when methane account for the 25% - 30% compound of air.

LNG is one sort of natural gas. Through the cryogenic technology process, it becomes the natual of liqued in low temperature. LNG will be absorbed by the heat and gasified under the atmospheric pressure with room temperature. People are also frostbited when LNG gets in touch with skin.

It would have serious consequences if LNG leaked into the air during transportation. The LNG can be ultimately formed into gas cloud with great number of volume after being leaked and will produce the danger of explosion when touching with fire. At the same time, because LNG is cryogenic liquid, it cannot be in touch with the ordinary equipment of car body directly, that will make car body and equipment to produce brittle fracture, loss ductility, and then endanger the car body structure and equipment, created by the excessive thermal stress produced by localized cooling.

3.2 The Mode of LNG Transportation

At present, LNG transportation mainly has three kinds of model, including marine transport, pipeline transport and tanker transport. Among them, natural gas pipeline transportation and marine transportation had provided effective and reliable way to a large number of natural gas transportation, which solved problems about most of the gas supply. But in some regions, natural gas pipe network is hard to be assembled. Hence it is necessary to transport liquefied natural gas with LNG a carrier vehicle. A LNG carrier vehicle will properly finish the tasks to transport LNG to each point-of-use from liquefaction plants of natural gas. In a sense, a LNG carrier vehicle is a supplement to the marine and pipeline transportation which powerfully impelled the LNG market development.

Based on different characteristics of large amount and stability of marine and pipeline transportation, LNG carrier vehicles need to adapt the polyhedral wider market, and also make sure the safety transportation under the complex road conditions exist which more and more. Because LNG is liquid and has low temperature properties. There is no instance of LNG transport through long-distance pipe. In addition, the operation of pipeline transport costs is significantly higher than the pipeline transportation of natural gas by long-distance transportation. Therefore, in terms of the current technology, the applications of LNG pipeline are inferior to LNG road transportation. The first LNG tanker used for transportation appeared in the early 1970’s in Japan. It was a special kind of road tanker, and the purpose was to transfer LNG from the receiving port to the satellite base.

3.2.1 LNG Carrier Vehicle Structure

A LNG carrier vehicle has two models, a full vehicle and a semi-trailer. The appearance of the full vehicle is small in which the cryogenic tanks of liquefied natural gas are fasten on the automobile chassis. With small volume and hard to be demolished, its efficiency is not high and not suitable to the long distance transport. Hence these kinds of LNG carrier vehicles are rare in China.

Another model is a semi-trailer of LNG cryogenic liquid transport, in which the cryogenic tank is fixed on the running gear of a truck. This vehicle is usually composed of cryogenic liquid storage tanks, running gear of semi-trailer, pipeline system, operating box and other parts. The LNG carrier vehicle structure of a semi-trailer model is shown in Figure 2:

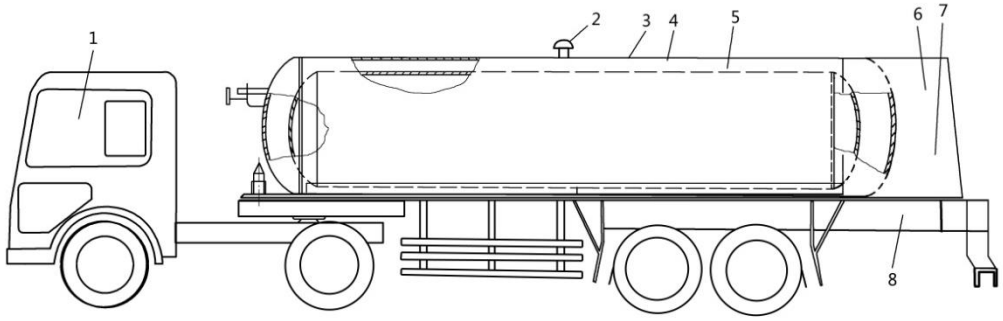


Figure 2. The structure chart of LNG carrier vehicle (Jiuxiang Gao 2004.)

In the Figure 2, there are:

1. Motor tractor
2. Explosion protection of outside cylinder
3. External cylinder
4. Vacuum fiber of thermal barrier
5. Inner container
6. Operation box
7. Instruments, valves and pipeline system
8. THT9360 split type semi-trailer chassis

A LNG cryogenic liquid storage tank is one of the core components of LNG carrier vehicles that is used for loading LNG and is providing necessary thermal insulation. The mobile tank of LNG usually has the loading capacity between 20 and 25 cubic meters in domestic and aboard and it is produced by a carbon steel vacuum cylinder

and a concentric of austenitic stainless steel internal cylinder. In order to prevent hypothermia, the space between these two cylinders has to be made into vacuum state. The support structure of a storage tank should adapt to the combination support of glass fiber reinforced plastics (GRP) that has one end fixed and the other end slip.

The running gear is one of the important components of a semi-trailer, it is not only the transport components of LNG carrier vehicle, but also the supporting gear of LNG carrier vehicle. The safety design of LNG runnig gear needs to be accorded with the national GB1589-2004 standard. The operation box at the back of LNG tanks is used to decorate operating valves and instruments. However, pipeline system includes pressurized liquid pipeline, a discharge pipeline, a liquid level meter and a side-full pipeline and so on.

3.2.2 The Infusion of LNG Carrier Vehicle

The infusion of LNG carrier vehicle is generally divided into the pressurization and pumping liquids. The pressurization is a relatively simple way of transfusion, which is used for pressurizing in the process of LNG gasification when it returns to the storage tank from a supercharger, and LNG can be extruded by means of differential pressure. The transferring time is long and the differential pressure transfer is limited in this way of transfusion. The problems also need to be considered, such as the design of the tank pressure is high, and the loading volume is relatively small that cause the low transport efficiency. However, pumping liquid is a way of transfusion to use the centrifugal pump at low temperature for pumping liquid in the truck. It has the properties of big converted production flow which need short time and can adapt to all kinds storage tanks with different pressure specifications. Besides the requirements of pressure for the storage tanks, pressure design is not high. But the transport efficiency is higher than the previous one by using the infusion of pumping liquid.

3.2.3 LNG Carrier Vehicle Accidents

Since 2001, the accidents of LNG tanker have had an increasing tendency. Combined with the LNG characteristics of being dangerous and harmful, the safety problem of LNG tanker transportation is still not neglected. The vehicle structure is one of the important factors that will cause accidents when poor design of it occurs. Due to the cylindrical design of the tank with high center of gravity, the critical value of rolling over is from 0.4 to 0.6, which is lower than car data which is from 1.1 to 1.5. There are three main factors that lead to rollover: driving the vehicle with low critical value

structure, the cornering speed, centrifugal force change and liquid sloshing can be easy to change the vehicle center of gravity when the driver hits a brake on a dangerous road.

According to the accident cases of LNG carrier vehicles throughout the world, it is found that the rollover and leakage are two main kinds of accidents which often appear in the process of LNG road transportation. LNG tankers are high vacuums of multi-layer insulated storage tanks and their adiabatic performance can directly determine the tank pressure. Undoubtedly the pressure in the tank is unstable if the thermal insulation performance is bad and that will seriously affect the safety of transportations. In addition, it can lead to LNG leakage and explosion when the safety accessories of LNG carrier vehicles fail to complete the established function and further endanger the safety of surrounding people.

Rollover accident is a kind of accident for tanks and vehicle rollover in the process of road transportation that takes place due to the poor road conditions or the design defect of LNG carrier vehicle. It will be accompanied by the leakage of LNG tankers loading with liquefied natural gas. Due to the high compressive strength structure and materials of LNG vehicle tanks, it is widespread break and fracture do not easily take place, while the most of traffic accidents caused by leakage accidents happen because the problems about the connection between gas pipe of tank, or the joint rupture and leak of safety devices.

Leakage accident is a kind of accident in which LNG spreads into the atmosphere because of tanks and its accessories breakdown. Although the main components of natural gas is methane which is the cleaning chemical, there are small amount of components in natural gas that may have the harmful effect on the surrounding people and their health, such as the sulfide, and polluted the atmospheric environment as well. Leakage can result in combustible gas exceeding, and it can lead to fire explosion and other traumatic events when the gas come across to naked flame. LNG is -162℃ cryogenic liquid, it can frostbite firefighters and other people around when the accident is handled improperly. Moreover, leaked LNG liquid can be quickly endothermic and puffs in water, and then lead to the LNG clod explosion hazard.

Thus, for LNG carrier tanks, as the main body of LNG safety design, if emergency cut-off valve and other safety settings can work properly according to their function in the provision time, the incidence of accidents will be reduced when an exception occurs for the tanks. So the safety accessories are a key part of the LNG safety design.

3.3 Summary of This Chapter

This chapter introduced more about the physical and chemical properties of LNG, as well as its risks. Compared with the three kinds of LNG transport modes, it is concluded that the advantage and need of LNG carrier vehicle exist. It was introduced the structural features of LNG carrier vehicles, the method of loading and unloading fluid, and its infusion way. It was also pointed out that the LNG carrier tanks and safety accessories is the main body of research by the analysis of LNG carrier vehicle accidents that has indicated the aspect and laid the foundation for the future work.

4 SAFETY DESIGN OF LNG CARRIER VEHICLE TANKS

If the LNG carrier vehicle tanks are damaged, it may result in serious secondary disaster such as fire, explosion, environmental pollution and other social instability. Therefore, the tank safety issues become a major research question.

4.1 Introduction to LNG Carrier Vehicle Tanks

By reason of the low boiling point of natural gas, it is difficult to liquefy under the room temperature and atmospheric pressure. Therefore, natural gas shall be liquefied by using the method of atmospheric pressure at low temperature. So the LNG container has special requirements for carrying. It needs to use the portable pressure vessel in low temperature during the transportation of LNG. (Hao Liu, Yongchun Zhou 2007.)

4.1.1 Portable Pressure Vessel in Low Temperature

The portable pressure vessel in low temperature is often applied to industrial gas transportation. Its design pressure is generally between 0.9 to 0.29 which is classified as the third type of pressure vessel in special equipment. In China, the standard of this pressure vessel is GB18442-2001 adiabatic pressure vessel in low temperature. According to the pressure vessel design qualification permission management rules, portable pressure vessel in low temperature can be divided into railway tankers, vehicle tankers and tank containers. It also can be divided into the bicycle type, half-hanging and full hanging according to the different structures. The LNG carrier vehicle in this article is the half-hanging tube trailer, because it has the features of large loading capacity, integrated transport efficiency, low fuel consumption and the little transport cost.

4.1.2 The Geometric Structure of LNG Carrier Vehicle Tanks

The general of LNG carrier vehicle tanks' structure is shown in Figure 3.

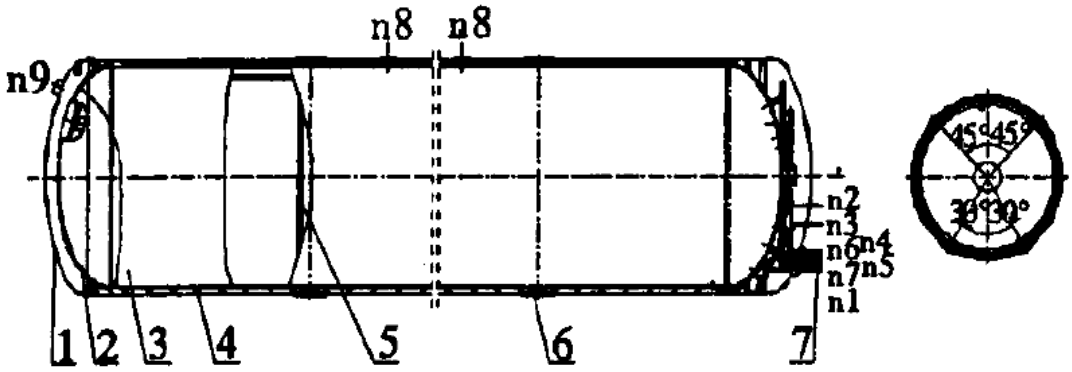


Figure 3. Structure chart of LNG carrier vehicle tanks (Hao Liu, Yongchun Zhou 2007.)

In the Figure 3, the numbers point out the following things:

1. External cylinder of tank
2. Thermal barrier
3. Internal container
4. Stiffening ring
5. Low-temperature adsorber
6. GRP structural support
7. Each pipe orifice

n1. Gas phase port of liquid level gauge
n2. Liquid phase port of liquid level gauge
n3. Port of blow-down pipe
n4. Port of top liquid inlet pipe
n5. Port of overflow pipe
n6. Port of bottom liquid inlet pipe
n7. Port of ascending pipe

n8. Port of adsorbent filling at low temperature
n9. Port of explosion-proof
n10. Port of vacuum-pumping
n11. Port of measuring vacuum

LNG carrier vehicle tanks consist of an inner container, an external cylinder, a thermal barrier, and a glass fiber reinforced plastic stent and other components. Because of the external pressure operation for outside cylinder, it needs to be combined with stiffening ring to protect. While the inner container contains many process pipelines which are connected with each pipe orifice that is used for loading and unloading of LNG. In order to prevent the cryogenic liquid from shaking and evaporating during the process of transportation, it also needs to be set up the anti-tank board. The support structure of storage tank should adapt to the combination support of glass reinforced plastics (GRP) with one end fixed and the other end slip. Its purpose is to ensure the tanker safety in the process of transportation. This structure will not lead to the displacement and structural distortion between the internal container and the external cylinder in the process of transportation. It can avoid the influence of low temperature

LNG to support as well. Nowadays, these kinds of LNG carrier vehicle tanks are widely used because of their simple structure and rare manufacturing difficulties.

4.1.3 The Material of LNG Carrier Vehicle Tanks

It is well known that LNG is cryogenic liquid, and the materials of the inner container should be corresponded to the liquefied natural gas that has good low temperature toughness of materials. The most of the domestic LNG tank containers are made by materials such as 0Cr18Ni9 austenitic stainless steel material meanwhile carbon steel and low alloy steel are used for the outside cylinder.

Austenitic stainless steel is a type of steel with good mechanical properties, and will not have brittle transition under the condition of low-temperature, which is widely used in cryogenic engineering. The weakness of austenitic stainless steel is that the yield point is quite low, so in the design there is the need to use thicker steel plate to make a container. Furthermore, the strain strengthening technology of austenitic stainless steel containers can significantly reduce the vehicle body weight, and thus realize as the product lightweight.

4.2 The Risk Analysis of LNG Carrier Vehicle Tanks

LNG is liquefied form from natural gas in -162℃, and only has 1/650 of the natural gas volume with the same mass under the room temperature and atmospheric pressure, so LNG is usually stored in the environment of atmospheric pressure at low temperature. The risks of LNG carrier vehicle tanks are:

1. The LNG leakage
2. LNG fire and explosions
3. Low temperature damage to operators

4.3 The Structure Design of LNG Carrier Vehicle Tanks

LNG tanks must meet the state regulation, and conform to the requirements of road vehicle boundaries and the stability calculation of a tanker. There shall enwind multi-layer of aluminum foil paper with high adiabatic performance between the internal and external container. It also pads glass fiber paper among the aluminum foil papers. In order to achieve the super adiabatic performance, the interlayer between the

internal and external container need to be evacuated as high vacuum. It also needs to set the absorber at low temperature in the interlayer which can maintain a vacuum.

The eight points of glass fiber reinforced plastic composite structures have been adopted between the internal container and external cylinder, with one end fixed that is close to the valve and instruments, while the other end slip for the material compensation of heat-expansion and cold-contraction. Eight FRP structures are divided into two groups, and four supporting points of each group, in this kind of structural support will not lead to the displacement and structural distortion between the internal container and external cylinder in the process of transportation. It can also prevent the filling pipeline be pulled at the same time.

In addition, the tank vehicle's center of mass is generally in the high side, and the volume of a LNG carrier vehicle tank is big as well and the total height of the vehicle shall reach four meters basically. So it is needed to increase the angle of the tank when tanks are designed. Furthermore the sink-style operating box is used to reduce the weight of the tank in order to increase the maximum stable roll angle of vehicle and lower the center of mass which can make less rollover accidents happen.

4.4 The Choice of Adiabatic Way for LNG Carrier Vehicle Tanks

There are three kinds of adiabatic way to make cryogenic liquid storage tanks, which include vacuum powder insulation, glass fiber winding insulation and high vacuum multilayer insulation. (Jiuxiang Gao 2004.)

The vacuum powder insulation is filled into a certain density and particle size of powder materials in the interlayer of thermal insulation which can achieve better adiabatic effect under low vacuum of 1.33 Pa. The gas conduction also has been weakened, because of the function of shielding and radiation by vacuum powder. It is commonly used liquid nitrogen and liquid oxygen in the storage tank. (Jiuxiang Gao 2004.)

The glass fiber winding insulation is a way of insulation that enwind around the glass fiber material between the internal container and external cylinder. It is an ancient way of insulation. The thermal conductivity of glass fiber is small, and it presents linear relationship that is the reduction of capacity with the loss of temperature. Its adiabatic effect depends on the thickness of the adiabatic layers. (Jiuxiang Gao 2004.)
The high vacuum multilayer insulation has the highest adiabatic efficiency that is evacuated the adiabatic space to less than 10 Pa's negative pressure, and installed

high reflectivity of metal film in the interlayer of thermal insulation. (Jiuxiang Gao 2004.)

In terms of thermal insulation performance, the adiabatic efficiency is not high for glass fiber winding insulation. The differences of structure between vacuum powder insulation and high vacuum multilayer insulation are shown in the following Table 1, which has the main technical parameters that are under conditions of same boundary temperature (80K, 300K).

Table 1. The comparison of main technical parameters (Yuhong Liu, Zhihui Zhang 2007.)

Adiabatic form	Thermal insulation material	Effective thermal conductivity/ （$mW/m^2 \cdot k$）	Vacuum degree of interlayer/ Pa
Vacuum powder insulation	Perlite powder 128kg/m^3（190K）	1.5	10^{-1}
High vacuum multilayer insulation	MLI，Aluminizing films， 50 layers	0.06	5×10^{-3}

It can be seen from above that the thermal insulation performance of high vacuum multilayer insulation is significantly superior to vacuum powder insulation. Moreover, by using high vacuum multilayer insulation can greatly reduce the equipment weight of a tanker, and achieve the purpose of a tank being lightweight.

4.5 The Pressure Safety System Design of LNG Carrier Vehicle Tanks

There are two reasons for pressure rising of the LNG cryogenic tank that are the volumetric displacement effect when LNG is transported into the tank, and the atmospheric pressure drop along with heat inhaled from the environment. However, the influences of LNG cryogenic tank pressure dropping are the volume replacement from a pump to the external transport, the empty suction by a BOG compressor and the outside atmospheric pressure rise.

A BOG compressor is one kind of machine used to compress the cryogenic liquid. Its working principle is the same as working principle of the common reciprocating compressor where it makes use of the connecting rod to push the piston and do repeated

movements. At last, it makes the pressurization of gas for transmission. It requires an opening the relief valve or vacuum valve of the tank for solving the problems, when the BOG compressor is at failure or the drastic changes of the pressure of LNG storage tanks occurs.

To sum up, the pressure control of tanks is to offset the change of atmospheric pressure by adjusting the BOG compressor, and the pressure change from material inlet and outlet. Under the extreme conditions, such as in the fire, it needs to protect the tanks safety in accidents through the safety system. So the pressure safety system can be divided into the pressure control system and the safety protection system.

4.6 Summary of This Chapter

The LNG carrier vehicle tanks have been regarded as the research object in this chapter, and the structure and material selection of tanks have been introduced, to ensure that the safety design of tanks lies to the way of adiabatic, structural support, material selection of internal cylinder and the pressure system of tanks. Ultimately the goal is to ensure that the tank itself has the status of relatively safe and rare to have accidents in the process of LNG transportation through the several ways of the safety design.

5 THE REQUIREMENT OF SAFETY ACCESSORIES DESIGN

Safety accessories are a kind of safety devices installed on the machine in order to make operation of a pressure vessel safe. According to usability and purpose, they can be divided into four categories:

1. Pressure relief device: it can automatically discharge pressure when a pressure vessel overpressures. There are the safety valve, rupture disk and fusible plug, etc.
2. Metering device: it refers to automatically display processing parameters which are related to the safety in the operation of container. Such as pressure gauges, temperature gauge, liquid level meter and so on.
3. Alarming device: it is one kind of instrument that can automatically send audio or other obvious alarm signals when the container is in danger caused by the unsafe factors appearing in the operation. Such as the pressure alarm and temperature detector
4. Interlocking device: it is the control mechanical device to prevent errors in operation. There are an interlock switch, an interlock valve and so on.

A LNG carrier vehicle is a mobile pressurized storage tank which must meet the requirements of tanks' safety design, It also needs to be equipped with safety accessories which includes double safety relief valves, an emergency cut-off valve, a flame arrester, a pressure gauge, a liquid level meter, a conducting electrostatic device, a fire extinguisher, etc. (Jiuxiang Gao 2004.)

5.1 Safety Relief Devices

The protective effect of relief valve is to make the system pressure not exceed the allowable values and to further ensure that there is no any accident with help of the high pressure of protection system. The relief valve may be open and discharge a part of gas and liquid into the air or outside the pipe, when the system pressure is more than the specified value.

a) The Classification of Relief Valve

1. Based on the overall structure and the loading mechanism, it can be divided into a heavy hammer lever-type relief valve, a spring-load relief valve and a pulsed relief valve.

2. According to different ways to emit dielectric, there are totally enclosed a relief valve, a semi-enclosed relief valve and an open relief valve respectively.
3. On the basis of opening ways of a valve clack, it can be divided into a spring raise enclosed high-pressure relief valve, a full lift relief valve and a safety valve.
4. In accordance with the action principle, it can be divided into a direct-operated relief valve and an indirect-operated valve.
5. According to the pressure regulation, it is generally divided into a fixed non-adjustable valve and an adjustable relief valve.
6. Depending on the operating temperature, it can be divided into the room temperature and high temperature valves.

b) Double Safety Valve and Relief Valve Design

Double safety valve design is aimed to use the other relief valve to ensure the normal work of distributing system, when one relief valve needs to be replaced or repaired. The analysis of the accident report has pointed out that the high accident rate would happen with only one single valve in the process of LNG transportation. These two sets of relief valves can be connected through a three-way ball valve.

Because of the cryogenic properties of LNG and cryogenic liquid tankers, the components of the relief valve can be frozen and unable to open in the cryogenic system. This phenomenon is caused by the leakage of a valve and the low temperature dielectric continuously getting through the valve body. In addition, the tanker can also install a depressurization regulating valve, and the relief pressure of this valve is much less than the highest operating pressure of the tank and the takeoff pressure of the relief valve. It can reduce the pressure of tank shell caused by static pressure, when the pressure drop is occurred during the transportation. However when the pressure is increasing in the process of transport, the valve may slowly open and reduce the pressure, which can prevent the large amount of LNG loss due to the low takeoff of the relief valve and it also can improve safety and LNG loss.

The double safety valve and relief valve are shown in Figure 5.

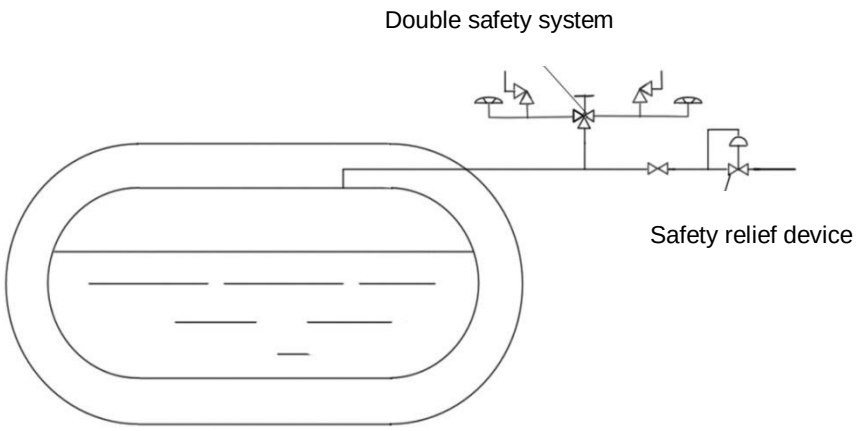


Figure 5. Diagram of safety relief device of road transport (Yuhong Liu, Zhihui Zhang 2007.)

5.1.1 The Selection Steps of Safety Relief Devices

The selection steps of safety relief devices are as following:

1. To determine the nominal pressure
2. To determine the opening pressure of relief valve
3. To determine the nominal diameter

The parameters of a relief valve must be matched with the different design parameters of LNG carrier vehicles' tanks. In general, the nominal pressure of a relief valve should be greater than the pressure of a relief valve when it is fully opened. Besides, the opening pressure of a relief valve is greater than the operation pressure of the equipment, which will be from 1.05 to 1.1 times more, and less than the design pressure of the equipment. Then the discharge pressure of a relief valve is less than or equal to 1.1 times of the design pressure. The nominal diameter of a relief valve is identified by the capacity of a relief valve. In addition, the selection principle is that the specified capacity of a relief valve must be greater than or as close as possible to the capacity of a relief valve.

According to the general principle of a relief valve type, the tank-truck of LNG should use the built-in relief valve. The valve clack and nozzle of a relief valve are made of the Cr-Ni steel with abrasion resistance and the body of valve is suitable to use the austenitic steel at same time the stem of valve is make of SS316 or the stainless steel.

5.1.2 The Safety Requirements of Safety Relief Devices

The rupture disk and relief valve must be connected in the way of series combination, and in the condition of emissions, the rupture disk is in contact with the medium. However, the discharge capacity of the combination unit must be greater than the safety capacity of the tanks. The rupture discs may not be made of brittle materials. The busted rupture discs are not allowed to have fragments, fall off and spark as well. The burst pressure shall be higher than 10% of the relief valve opening pressure. Apart from that, the area should be greater than the throat diameter cross-sectional area of a relief valve.

In the cavity between the relief valve and rupture disk it should be set the exhaust valve and pressure gauge, or other suitable indicators in order to detect whether the rupture disk leaks and bursts or not, and to discharge the stored cavity pressure in time which can avoid the impact of rupture disk's action pressure due to the back pressure. When the tanker is in a fully fire environment, the ability of emissions of the safety device combination should be sufficient to limit the in-tank pressure to no more than 120% of the design pressure. The export of the pressure relief device should be concentrated and discharged by a flame arrester.

5.2 Emergency Cut-Off Device

An emergency cut-off device is indispensable to the safety protecting components of a LNG tanker. It is a closed system that is composed of an emergency cut-off valve, an emergency relief valve, an oil hand pump, several fusible plugs, an oil-pressure pipeline, LNG loading and unloading pipelines, a spherical valve, a cut-off valve, a pressure gage, a quick-change connector and so on. One of the most important parts is the emergency cut-off valve which is also called a safety cut-off valve. Its role is to prevent the leakage of LNG by quickly closing the valve with the help of a mechanical structure at the scene and from the certain distance. A drive mode can be divided into electromagnetic, mechanical, hydraulic, pneumatic, etc. Due to the cryogenic properties of LNG, LNG carrier vehicles should not use hydraulic emergency cut-off valves, and to prevent the low temperature to make the hydraulic device be out of order.

5.2.1 The Operating Principle of Emergency Cut-Off Device

The emergency cut-off device of LNG carrier vehicles can use oil-pressure type of emergency cut-off valve. The valve is opened by an oil hand pump pressure, and

discharge the system pressure by an oil hand pump when it needs to be shut down. The several fusible plugs installed in oil-pressure pipeline will achieve melting point and is melting automatically when a LNG carrier vehicle is in a fire accident. Hence it makes the emergency cut-off valve shut down immediately. During the operation of loading and unloading, the differential pressure of the valve will be increased if there are the problems such as pipeline rupture has occurred and the liquid flow is suddenly increased. Then the valve is pushed to the closed state to prevent a large number of medium outflows, and form the over-current protection.

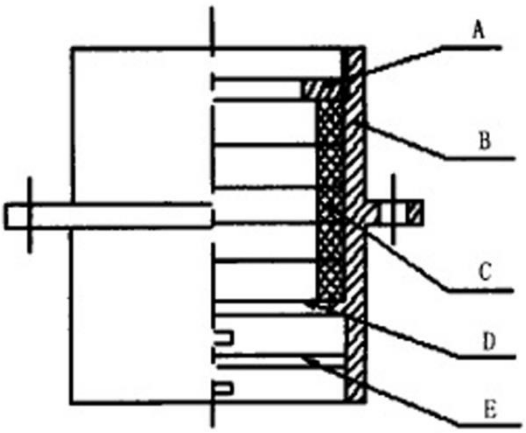
The electromagnetic emergency cut-off valve can also be used in LNG carrier vehicles. This type of cut-off valves utilizes electromagnetic signal to reach the purpose of emergency cut-off. When accepted the external pulse signal, the electromagnetic mechanism within the valve responses and makes a spring close valve fast. After that the supply of LNG is cut-off and the gas explosion is prevented. Under the conditions of no electromagnetic force, the electromagnetic emergency cut-off valve can keep the state of normally open and normally off in the gas pipelines. In addition, this type of electromagnetic emergency cut-off valve needs to ensure the safety requirements of anti-explosion, in order to avoid detonated source.

5.3 The Flame Arrester

The role of the flame arrester is to prevent external flame where flammable gas flees into the equipment, pipe or to prevent fire in the equipment, and the spread between the pipes. The flame arrester is composed of fire components. The characteristics of these components are that they have very tiny channels and aperture. The flame will be divided into tiny flames when it gets through these channels finally to achieve the goal of fire prevention according to the heat transfer effect and the wall effect.

5.3.1 Basic Principle and Structure

Heat loss theory suggests that in the process of the spread of flame, as the pipeline directly decreases, it will be accompanied with the larger heat loss. The flame propagation speed and temperature will reduce at the same time, while the flame will gradually be extinguished when the diameter of pipe reaches the limit, and the limit value is generally from 0.1 to 0.2 mm. The common structure of flame arrester as shown in Figure 6.



A	Pressure plate
B	Shell
C	Spacer
D	Wire netting
E	Spill septum

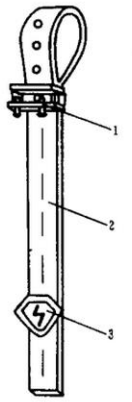
Figure 6. The structure diagram of flame arrester (Fengshui Chui, Wenjie Wu, Zhaofu Gao, Chaoxian Lv 2004.)

5.3.2 The Safety Design Requirements of Flame Arrester

1. The installation position of the flame arrester shall be installed on the pipeline to the relief valve and the exhaust valve export, so its boundary dimension should be designed based on these two valves size which can be got by measuring.
2. The layers of fire resistance and pore density are calculated by the pore fire resistance theory, which it usually adopts 196 mesh/cm^2 aluminum metal mesh, and set up four layers of metal mesh. The thickness of metal mesh is 4 cm.
3. The design of the flame arrester shall not affect the regular operation of the safety valve and exhaust valve.

5.4 Conducting Electrostatic Device

A conducting electrostatic rubber drag strip consists of a conductive rubber belt, the regulators, a fixed block and a counterweight. Its structure is shown in Figure 7.



1	Fixed block & regulate device
2	Conductive rubber belt
3	Counterweight

Figure 7. The diagram of a conducting electrostatic rubber drag strip (Liang Liu 2009.)

The conducting electrostatic device is one kind of components installed on the outside of the car body, which are not in contact with LNG liquid substances. So there is no need to take into account the requirements of the characteristics in device selection. The settings and selection of conducting electrostatic device must meet stated examination requirement, which is in order to avoid the drag strip flutter in the process of high speed. In addition for LNG carrier vehicles, tanks are easy to produce electrostatic in the process of road transport. To avoid the LNG electrostatic effect during the process of loading and unloading, it needs to be ensured that the resistance value of tanks is less than 5 Ω between any two points.

5.5 Fire Extinguisher

According to the special nature of LNG, it is easier for it to explode when LNG encounters water. So the fire extinguisher needs to be used when it is burning. For LNG it is mostly used carbon dioxide fire extinguishers and dry powder fire extinguishers at present.

Carbon dioxide fire extinguishers are based on the smothering action and carbon dioxide gasification endothermic effect to the firefighting. It has the properties of good liquidity and high injection rete, as well as a non-perishable and corrosion-resistant container.

Dry powder fire extinguishers are made up of a hydrophobic element, an inert filler, active extinguishing components, etc. Fire extinguishing principle is to use of ammonium carbonate dry powder extinguishing agent to put out the fire. Dry powder extinguishing agent comprises some inorganic salt which, with fire extinguishing performance, has fine solid powder that has small amount of additive by the mixture of dry-

ing and crushing. With volatile decomposition from the inorganic salt in dry powder, it will take place the chemical inhibition and negative catalytic effect with free radicals or active group that are produced by fuel in the process of burning, and then make the interruption from the chain reaction of burning till extinguishment.

5.6 Safety Instrument Systems

The setting purpose of safety instrument systems is that there can be real-time monitoring of LNG carriers tank pressure and liquid level in the container. The safety instrument includes a pressure gauge, a differential pressure level meter and a measuring full valve. The pressure gauges need to be installed in the front of vehicle and the operating box, while the pressure gauges are assembled in front of the vehicle just for convenience to observe the vehicle tank pressure in the cab and take timely measures. The measuring full valve is one kind of instrument to measure the filling liquid position when liquid loading, the filing liquid outflowing from the measuring full valve when it has reached the highest level.

5.7 Summary of This Chapter

In this chapter, it has been clearly shown the working principle and characteristics of safety accessory through the introduction of a relief valve, an emergency cut-off valve, a flame arrester and the others. According to the characteristics of the LNG carrier vehicle, the specific safety accessories have been chosen in order to ensure the safety of LNG road transportation.

6 THE ANALYTIC HIERARCHY PROCESS ANALYSIS

The analytic hierarchy process is shortened for AHP. It is proposed by an American professor, A.L.Saaty, from the University of Pittsburgh in the 1970s. AHP is a kind of method to qualitative and quantitative analysis by simulating human thinking process in which it takes a complicated multi-objective decision-making problem as a system first, and then decomposes the system into several hierarchy of multiple targets and standards, makes the factors combination of hierarchy that is based on the relationship between each components, next form a hierarchical model, and analyze the importance of each hierarchy in the model. At last it is calculated the associated weight and general rank of hierarchy by the method of fuzzy quantitative and qualitative index and they are taken as the basis of target multiple scheme optimization decision.

The basic works of AHP are the hierarchical structure model and establishing the judgment matrix. The basic steps of analytic hierarchy process are as following:

1. Hierarchical structure model is established which includes the target hierarchy, criterion hierarchy and scheme hierarchy.
2. The pairwise comparison matrix is established so that it starts from the second hierarchy.
3. The single sorting weight vector is calculated and the consistency check is done. It needs to re-establish the pairwise comparison matrix if the test is not passed.
4. The general sequencing weight vector is calculated and the consistency check is done, and decisions are made according to the results of general sequencing weight vector, otherwise, the model needs to be rethought.

6.1 Analysis of LNG Transportation Evaluation by AHP

The hierarchized result of LNG carrier vehicles on road transportation is as presented the following table:

Table 2. The risk indicators of LNG road transportation (The safety research of LNG carrier vehicle)

The safety of LNG carrier vehicle on road transportation （S）	Vehicle factors R_1	Load capacity of trailer R_{11}
		Used age R_{12}
		The brake system R_{13}
		Maintenance record R_{14}
	Safety system R_2	Relief valve R_{21}
		Emergency cut-off device R_{22}
		Flame arrester R_{23}
		Other safety accessories R_{24}
	Human factors R_3	Route familiarity R_{31}
		Driving habits R_{32}
		Response speed R_{33}
		Special training R_{34}
	Road conditions R_4	Road speed limits R_{41}
		Road surface situation R_{42}
		Road type R_{43}
		Hazardous of road side R_{44}
	Environmental factors R_5	Size of wind power R_{51}
		Lightning stroke R_{52}
		Heat R_{53}
		Natural hazard R_{54}
	Tank factors R_6	Adiabatic mode R_{61}
		Structural strength R_{62}
		Support mode R_{63}
		Explosion-proof equipment R_{64}

6.2 Building the Weight Sets

1. Establishing the weight sets of target hierarchy and criterion hierarchy.

a) First the judgment matrix is established, in order to scientifically determine the weight of each index in the index system. The judgment matrix which is built by the safety of LNG carrier vehicle on road transportation and each criterion hierarchy as following has used every two factors' values to determine the relative importance between factors.

Table 3. The judgment matrix of target hierarchy and criterion hierarchy (The safety research of LNG carrier vehicle.)

S	R_1	R_2	R_3	R_4	R_5	R_6
R_1	1	1	1/3	4	2	1
R_2	1	1	1/5	1/2	1/3	1
R_3	3	5	1	4	3	6
R_4	1/5	2	1/4	1	1/2	2
R_5	1/2	3	1/3	2	1	3
R_6	1	1	1/6	1/2	1/3	1

b) Consistency check is done, which is to ensure that the constructed judgment matrix conforms to logic. According to the above judgment matrix, the eventual consistency inspection result can be calculated by software that is CR=0.0986, and CR<0.1, while the weight value is W= (0.1646, 0.0764, 0.4314, 0.0918, 0.1617, 0.0741), which is through the consistency check by the characteristic vector normalization processing.

2. Establishing the weight sets of vehicle factors (R_1) and its index hierarchy

a) The judgment matrix is established as following:

Table 4. The judgment matrix of vehicle factors and its index hierarchy (The safety research of LNG carrier vehicle.)

R_1	R_{11}	R_{12}	R_{13}	R_{14}
R_{11}	1	3	1/3	1/2
R_{12}	1/3	1	1/7	1/5
R_{13}	3	7	1	2
R_{14}	2	5	1/2	1

b) Consistency check, the eventual consistency inspection result through the calculation of the software is CR = 0.0072, and CR< 0.1, while the weight value is A_1= (0.1619, 0.0601, 0.4901, 0.2879), which is through the consistency check by the characteristic vector normalization processing.

3. Establishing the weight sets of safety system (R_2) and its index hierarchy

a) The established judgment matrix is as following:

Table 5. The judgment matrix of safety system and its index hierarchy (The safety research of LNG carrier vehicle.)

R_2	R_{21}	R_{22}	R_{23}	R_{24}
R_{21}	1	1/5	1/3	1
R_{22}	5	1	5	3
R_{23}	3	1/5	1	3
R_{24}	1	1/3	1/3	1

b) Consistency check, the eventual consistency inspection result through the calculation of the software is CR = 0.0975, and CR< 0.1, while the weight value is A_2= (0.0980, 0.5674, 0.2233, 0.1113), which through the consistency check by the characteristic vector normalization processing.

4. Establishing the weight sets of human factors (R_3) and its index hierarchy

a) The established judgment matrix is as following:

Table 6. The judgment matrix of human factors and its index hierarchy (The safety research of LNG carrier vehicle.)

R_3	R_{31}	R_{32}	R_{33}	R_{34}
R_{31}	1	1	2	2
R_{32}	1	1	2	2
R_{33}	1/2	1/2	1	1
R_{34}	1/2	1/2	1	1

b) Consistency check, through the calculation of the software, the eventual consistency inspection result is CR = 0.0000, and CR< 0.1, while the weight value is A_3= (0.3333, 0.3333, 0.1667, 0.1667), which through the consistency check by the characteristic vector normalization processing.

5. Establishing the weight sets of road conditions (R_4) and its index hierarchy

a) The established judgment matrix is as following:

Table 7. The judgment matrix of road conditions and its index hierarchy (The safety research of LNG carrier vehicle.)

R_4	R_{41}	R_{42}	R_{43}	R_{44}
R_{41}	1	1/6	1/3	3
R_{42}	6	1	2	9
R_{43}	3	1/2	1	7
R_{44}	1/3	1/9	1/7	1

b) Consistency check, through the calculation of the software, the eventual consistency inspection result is CR = 0.0174, and CR< 0.1, while the weight value is A_4= (0.1077, 0.5434, 0.3034, 0.0455), which through the consistency check by the characteristic vector normalization processing.

6. Establishing the weight sets of environmental factors (R_5) and its index hierarchy

a) The established judgment matrix is as following:

Table 8. The judgment matrix of environmental factors and its index hierarchy (The safety research of LNG carrier vehicle.)

R_5	R_{51}	R_{52}	R_{53}	R_{54}
R_{51}	1	5	7	1/2
R_{52}	1/5	1	2	1/7
R_{53}	7	1/2	1	1/9
R_{54}	2	7	9	1

b) Consistency check, through the calculation of the software, the eventual consistency inspection result is CR = 0.0151, and CR< 0.1, while the weight value is A_5= (0.3308, 0.0791, 0.0483, 0.5419), which through the consistency check by the characteristic vector normalization processing.

7. Establishing the weight sets of tank factors (R_6) and its index hierarchy

a) The established judgment matrix is as following:

Table 9. The judgment matrix of tank factors and its index hierarchy (The safety research of LNG carrier vehicle.)

R_6	R_{61}	R_{62}	R_{63}	R_{64}
R_{61}	1	1/3	1/2	1/2
R_{62}	3	1	1	5
R_{63}	2	1	1	3
R_{64}	2	1/5	1/3	1

b) Consistency check, through the calculation of the software, the eventual consistency inspection result is CR = 0.0735, and CR< 0.1, while the weight value is A_6= (0.1149, 0.4210, 0.3348, 0.1293), which is got from the consistency check by the characteristic vector normalization processing.

6.3 Establish Factors Evaluation Matrix

The weight sets of parts were established in the previous chapters that showed the importance of each index. In order to present the differences between safety performances after the combination of all factors, this chapter adopted the way of collecting data and questionnaire to establish a single factor evaluation matrix, which indicates each index factor affiliated to the safety evaluation of membership degree. Finally two figures were formed:

Table 10. LNG carrier vehicle safety factors' risk assessment questionnaire of counselling (The risk evaluation of liquefied natural gas in the road transportation.)

Comment / Risk factors	Very high safety	High safety	Very Low safety
Load capacity of trailer R_{11}	0.7	0.3	0
Used age R_{12}	0.85	0.15	0
The brake system R_{13}	0.8	0.2	0
Maintenance record R_{14}	0.75	0.25	0
Relief valve R_{21}	0.8	0.2	0
Emergency cut-off device R_{22}	0.8	0.2	0
Flame arrester R_{23}	0.7	0.3	0
Other safety accessories R_{24}	0.6	0.4	0
Route familiarity R_{31}	0.8	0.2	0
Driving habits R_{32}	0.75	0.25	0
Response speed R_{33}	0.7	0.3	0
Special training R_{34}	0.75	0.25	0
Road speed limits R_{41}	0.9	0.1	0
Road surface situation R_{42}	0.8	0.2	0
Road type R_{43}	0.8	0.2	0
Hazardous of road side R_{44}	0.65	0.35	0
Size of wind power R_{51}	0.9	0.1	0
Lightning stroke R_{52}	0.75	0.25	0
Heat R_{53}	0.7	0.3	0
Natural hazard R_{54}	0.8	0.2	0
Adiabatic mode R_{61}	0.9	0.1	0
Structural strength R_{62}	0.7	0.3	0
Support mode R_{63}	0.8	0.2	0
Explosion-proof equipment R_{64}	0.7	0.3	0

The factors of fuzzy membership degree were as following:

$$R_1 = \begin{bmatrix} 0.7 & 0.3 & 0 \\ 0.85 & 0.15 & 0 \\ 0.8 & 0.2 & 0 \\ 0.75 & 0.25 & 0 \end{bmatrix}$$

$$R_2 = \begin{bmatrix} 0.8 & 0.2 & 0 \\ 0.75 & 0.25 & 0 \\ 0.7 & 0.3 & 0 \\ 0.75 & 0.25 & 0 \end{bmatrix}$$

$$R_3 = \begin{bmatrix} 0.8 & 0.2 & 0 \\ 0.75 & 0.25 & 0 \\ 0.7 & 0.3 & 0 \\ 0.75 & 0.25 & 0 \end{bmatrix}$$

$$R_4 = \begin{bmatrix} 0.9 & 0.1 & 0 \\ 0.8 & 0.2 & 0 \\ 0.8 & 0.2 & 0 \\ 0.65 & 0.35 & 0 \end{bmatrix}$$

$$R_5 = \begin{bmatrix} 0.9 & 0.1 & 0 \\ 0.75 & 0.2 & 0 \\ 0.7 & 0.2 & 0 \\ 0.8 & 0.35 & 0 \end{bmatrix}$$

$$R_6 = \begin{bmatrix} 0.9 & 0.1 & 0 \\ 0.7 & 0.3 & 0 \\ 0.8 & 0.2 & 0 \\ 0.7 & 0.3 & 0 \end{bmatrix}$$

Then, every single factor was evaluated through the formula $B = A_i \cdot R_i$ （i=1, 2…4）

$B_1 = A_1 \cdot R_1 =$ （0.7724 0.2276 0 ）

$B_2 = A_2 \cdot R_2 =$ (0.7554 0.2446 0)

$B_3 = A_3 \cdot R_3 =$ (0.7583 0.2417 0)

$B_4 = A_4 \cdot R_4 =$ （0.8039 0.1961 0）

$B_5 = A_5 \cdot R_5 =$ （0.8244 0.1757 0）

$B_6 = A_6 \cdot R_6 =$ （0.7565 0.2435 0）

Thus it is concluded that comment membership for criterion hierarchy is as:

$$B=\begin{bmatrix} 0.7724 & 0.2276 & 0 \\ 0.7554 & 0.2446 & 0 \\ 0.7583 & 0.2417 & 0 \\ 0.8039 & 0.1961 & 0 \\ 0.8244 & 0.1757 & 0 \\ 0.7565 & 0.2435 & 0 \end{bmatrix}$$

Through the above obtained weight of each factor in the process of LNG transportation and the fuzzy membership degree matrix, the criterion hierarchy fuzzy evaluation results can be calculated with the formula $I = W.B$, and it is $I =$ (0.7751 0.2249 0). So according to the maximum membership degree principle and the conclusion from the table is that equipped with conform to the safety design of LNG carrier vehicle in the state of risk in the process of transportation is “ the safety is very high, and there is no potential safety hazard”.

If we do not consider the safety design in the LNG carrier vehicle design phase, the safety consulting questionnaire results can be obtained as presented in the following table.

Table 11. LNG carrier vehicle safety factors' risk assessment questionnaire of counselling (The risk evaluation of liquefied natural gas in the road transportation.)

Comment / Risk factors	Very high safety	High safety	Very Low safety
Load capacity of trailer R_{11}	0.7	0.3	0
Used age R_{12}	0.85	0.15	0
The brake system R_{13}	0.8	0.2	0
Maintenance record R_{14}	0.75	0.25	0
Relief valve R_{21}	0	0.2	0.8
Emergency cut-off device R_{22}	0	0.2	0.8
Flame arrester R_{23}	0	0.3	0.7
Other safety accessories R_{24}	0	0.4	0.6
Route familiarity R_{31}	0.8	0.2	0
Driving habits R_{32}	0.75	0.25	0
Response speed R_{33}	0.7	0.3	0
Special training R_{34}	0.75	0.25	0
Road speed limits R_{41}	0.9	0.1	0
Road surface situation R_{42}	0.8	0.2	0
Road type R_{43}	0.8	0.2	0
Hazardous of road side R_{44}	0.65	0.35	0
Size of wind power R_{51}	0.9	0.1	0
Lightning stroke R_{52}	0.75	0.25	0
Heat R_{53}	0.7	0.3	0
Natural hazard R_{54}	0.8	0.2	0
Adiabatic mode R_{61}	0	0.1	0.9
Structural strength R_{62}	0	0.3	0.7
Support mode R_{63}	0	0.2	0.8
Explosion-proof equipment R_{64}	0	0.3	0.7

The factors of fuzzy membership degree were as following:

$$R_1 = \begin{bmatrix} 0.7 & 0.3 & 0 \\ 0.85 & 0.15 & 0 \\ 0.8 & 0.2 & 0 \\ 0.75 & 0.25 & 0 \end{bmatrix}$$

$$R_2 = \begin{bmatrix} 0 & 0.2 & 0.8 \\ 0 & 0.25 & 0.8 \\ 0 & 0.3 & 0.7 \\ 0 & 0.25 & 0.6 \end{bmatrix}$$

$$R_3 = \begin{bmatrix} 0.8 & 0.2 & 0 \\ 0.75 & 0.25 & 0 \\ 0.7 & 0.3 & 0 \\ 0.75 & 0.25 & 0 \end{bmatrix}$$

$$R_4 = \begin{bmatrix} 0.9 & 0.1 & 0 \\ 0.8 & 0.2 & 0 \\ 0.8 & 0.2 & 0 \\ 0.65 & 0.35 & 0 \end{bmatrix}$$

$$R_5 = \begin{bmatrix} 0.9 & 0.1 & 0 \\ 0.75 & 0.2 & 0 \\ 0.7 & 0.2 & 0 \\ 0.8 & 0.35 & 0 \end{bmatrix}$$

$$R_6 = \begin{bmatrix} 0 & 0.1 & 0.9 \\ 0 & 0.3 & 0.7 \\ 0 & 0.2 & 0.8 \\ 0 & 0.3 & 0.7 \end{bmatrix}$$

Then, every single factor was evaluated through the formula $B = A_i \cdot R_i$ （i=1, 2…4）

$B_1 = A_1 \cdot R_1 =$ （0.7724 0.2276 0 ）

$B_2 = A_2 \cdot R_2 =$ （0 0.2446 0.7554 ）

$B_3 = A_3 \cdot R_3 =$ （0.7583 0.2417 0）

$B_4 = A_4 \cdot R_4 =$ （0.8039 0.1961 0）

$B_5 = A_5 \cdot R_5 =$ （0.8244 0.1757 0）

$B_6 = A_6 \cdot R_6 =$ （0 0.2435 0.7565）

Thus it is concluded that comment membership for criterion hierarchy was as:

$$B=\begin{bmatrix} 0.7724 & 0.2276 & 0 \\ 0 & 0.2446 & 0.7554 \\ 0.7583 & 0.2417 & 0 \\ 0.8039 & 0.1961 & 0 \\ 0.8244 & 0.1757 & 0 \\ 0 & 0.2435 & 0.7565 \end{bmatrix}$$

Through the above obtained weight of each factor in the process of LNG transportation and the fuzzy membership degree matrix, the criterion hierarchy fuzzy evaluation results can be calculated with the formula $I = W.B$, and it is $I =$ (0.6614 0.2249 0.1137). According to the maximum membership degree principle and the conclusion from the table is that equipped with conform to the safety design of LNG carrier vehicle in the state of risk in the process of transportation is “the safety is very high, and there is no potential safety hazard”, but there is unsafe state.

6.4 Obtain Results

According to the maximum membership degree principle and the conclusion from the table is that equipped with conform to the safety design of LNG carrier vehicle in the state of risk in the process of transportation is as shown in table 12:

Table 12. The safety status membership degree comparison of an ordinary LNG carrier vehicle and the safety design of a LNG carrier vehicle (The risk evaluation of liquefied natural gas in the road transportation)

Comment / Items	Very high safety	High safety	Very Low safety
Ordinary road transportation of LNG carrier vehicle	0.6614	0.2249	0.1137
Road transportation through the safety design of LNG carrier vehicle	0.7751	0.2249	0

According to the above table, it can be observed that the safety performance created by the safety design of LNG road transportation is higher than ordinary LNG carrier vehicle in the process of road transportation. Thus it has proved the necessity and importance of LNG carrier vehicle's safety design. It can be a very good help to reduce the road accidents through the safety design of LNG carrier tanks and its safety accessories which can make it up to standards.

6.5 Summary of This Chapter

In this chapter, the risk evaluation of LNG carrier vehicle was analyzed, by using the fuzzy comprehensive evaluation which is based on the analytic hierarchy process (AHP). The LNG carrier road transportation was divided into six indicators, and to construct the judgment matrix, it was calculated the weights and fuzzy membership degree for comparison. Finally it is concluded that the safety is relatively high for a LNG carrier vehicle which is through the safety design in the process of road transportation, and the accidents do not happen easily.

7 CONCLUSIONS

An LNG carrier vehicle is one of the important transportation equipment that takes the ultra-low temperature of liquefied natural gas (LNG) from producers to the practical points across the country. With the extensive use of natural gas, the need for LNG carrier vehicle is increasing. They need to be adapted to some polyhedral wider market with the complex transport environment and traffic conditions. Not only because of the LNG cryogenic characteristics, but also the nature of flammables and explosives, the accident consequences will be very serious in the process of transportation. Therefore, it is very important to complete the safety design of LNG carrier vehicles.

At the end of this paper, the evaluation of LNG carrier vehicles was analyzed, and it has been used the fuzzy comprehensive evaluation which is based on the analytic hierarchy process (AHP). First of all, the LNG road transportation was hierarchized, and then the weight set and judgment matrix were built, followed by the consistency check by using the method of fuzzy mathematics and the principle of maximum membership degree. Finally it was concluded the risk state of safety. The necessity of LNG carrier vehicle's safety design was concluded by the comparison of safety design and without safety design for LNG carrier vehicles. Although the safety performance of LNG carrier vehicle is higher after design, its potential safety hazard cannot be ignored. The safety inspection and maintenance needs to be done frequently.

8 OUTLOOK

A preliminary research was made for the safety design of LNG carrier vehicles in this paper, and some safety advices to the development of LNG carrier vehicle in the future were provided. At the same time, there are also a lot of shortages in this paper. In order to help our country to speed up the energy transformation and new energy construction, the further studies of domestic scholars and experts are needed to contribute to the development of LNG carrier vehicles, and to promote the sustainable development of national economy.

According to the provisions of state, the transport speed of cryogenic liquid and dangerous goods should be less than 60 km/h. This goes against to the improvement of transport efficiency and the hope that high speed of LNG transportation needs to be improved.

Due to the technical limitations of LNG carrier vehicles, the capacity has reached the limit elementary. The greater of the capacity, the heavier of its weight, and the transport efficiency will be lower under the full-loaded. So the lightweight of LNG carrier vehicle is an imperative technology in the future. It also must be ensured that the safety performance of LNG carrier vehicle tank and other mechanisms are taken into consideration at the same time of light weight features.

REFERENCES

Chunjuan Wang, Jingbin Li 2012 <Two questions of decussion on the instrument accessories to LNG carrier vehicle> Special purpose motor vehicle press.

Fengshui Chui, Wenjie Wu, Zhaofu Gao, Chaoxian Lv 2004 <The flame arresters design and application of LNG carrier vehicle> Chinese journal of safety, health and environment.

Hao Liu, Yongchun Zhou 2007 <The pressure relief system design of LNG cryogenic storage tank> Chemical engineering designs press.

Jiuxiang Gao 2004 <Safety design requirements of LNG carrier vehicle> Special vehicle press.

Jiandong Wu 2013 <The research of emergency cut-off valve application> Technology and Business press.

Long Gong, Wenjun Zhou 2009 <The setting, selection and calculation of safety relief devices> Zhejing chemical industries press.

Liang Liu 2009 <Industry standard profile of vehicle conducting electrostatic rubber drag strip> Standardization works.

Ran Zhao 2012 <Standard technical requirements of trailer by illustrations> Special purpose motor vehicle press.

Yu Hong 2009 <The frosting problem of liquid inlet pipeline to carrier vehicle in low temperature> Accident and defect analysis.

Yaohui Yue 2011 <The emergency cut-off valve of carrier vehicle and its calibration technology research> Technology design and theory of Jiangnan University.

Yuhong Liu, Zhihui Zhang 2007 <The safety relief devices' structure improvement of long tube trailer> Special purpose motor vehicles press.

Xinhui Yuan, Yi Feng 2009 <The finite element analysis of structural strength to the cryogenic LNG carrier vehicle tanks> Cryogenic engineering press.

Internet Sources:

Introduction to liquefied natural gas (LNG) carrier vehicle elements [reference made 22.10.2014]. Available from:
http://www.cqvip.com/read/read.aspx?id=26480189

The structure design of liquefied natural gas (LNG) cryogenic liquid carrier vehicle tank [reference made 28.10.2014]. Available from:
http://cnbyxf.cngspw.com/Doc/WebNote/200908/Y2009M08D19H10m12s28/u5929u7136u6C14u4F4Eu6E29u6DB2u4F53u8FD0u8F93u8F66u8D2Eu7F50u7ED3u6784u8BBEu8BA1.pdf

The Development Status of LNG Carrier Vehicle at Domestic and Abroad [reference made 30.10.2014]. Available from:
http://www.zhihu.com/question/23566391

The safety research of LNG carrier vehicle [reference made 24.11.2014]. Available from:
http://www.doe.zju.edu.cn/xnzl/showindex/299/108

The risk evaluation of liquefied natural gas in the road transportation [reference made 12.12.2014]. Available from:
http://d.wanfangdata.com.cn/periodical_hggl201418028.aspx