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Study on risk assessment of methanol fueled ship

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STUDY ON RISK ASSESSMENT OF METHANOL FUELED SHIP

By

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DECLARATION

I certify that all the material in this dissertation that are not my own work has been identified, and that no material is included for which a degree has previously been conferred on me.

The contents of this dissertation reflect my own personal views, and are not necessarily endorsed by the University.

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ABSTRACT

Title of Dissertation: **STUDY ON RISK ASSESSMENT SYSTEM OF METHANOL FUELED SHIP**

Degree: **MSc**

In order to meet the increasingly stringent emission standards, the use of Marine alternative fuels has been increasingly favored by the shipping industry. Although liquefied natural gas (LNG) has been the favorite alternative fuel in the past few years, and this trend is expected to continue in the future, a growing number of studies and cases show that methanol, with its advantages of clean, environmental protection and high availability, has fully demonstrated its potential as a Marine fuel in the future.

According to the latest provisions of the International Convention on the Prevention of Pollution from Ships (MAROPL) of the International Maritime Organization (IMO), since January 1, 2020, the quality requirement of Marine fuel oil with sulfur content of no more than 0.5%m/m has been increased by seven times. So, it is imperative to increase the use of other clean energy sources.

This paper briefly introduces the background of methanol as ship fuel and the basic situation of its application at home and abroad.

Secondly, it introduces several professional analysis methods, including Delphi method, risk assessment method and fuzzy comprehensive evaluation method.

Next, the composition of the methanol fuel ship system is introduced in detail, and the possible risk points are analyzed. With Delphi method as the research method, the risk assessment of the methanol fuel ship is carried out.

Finally, the future of methanol fuel is summarized and prospected.

KEYWORDS: DELPHI METHOD METHANOL

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LIST OF ABBREVIATIONS

HFO	Heavy fuel oil
MGO	Marine gas oil
DMU	Dalian maritime university
LNG	Liquid nature gas
LPG	Liquefied Petroleum Gas
SOX	Sulfur oxide
IMO	International Maritime Organization
THC	Total hydrogen carbon
TRL	technology readiness level
WMU	World maritime university

CHAPTER 1 INTRODUCTION

1.1 Background

In order to meet the increasingly stringent emission standards, the use of Marine alternative fuels has been increasingly favored by the shipping industry. Although liquefied natural gas (LNG) has been the favorite alternative fuel in the past few years, and this trend is expected to continue in the future, a growing number of studies and cases show that methanol, with its advantages of clean, environmental protection and high availability, has fully demonstrated its potential as a Marine fuel in the future. (Gan) According to Chris Chatterton, COO of the Methanol Society, methanol is probably the least discussed option, even though it is sustainable, and can meets the Low Sulphur 2020 standard and future low carbon requirements, with manageable costs and minimal operational changes. Chatterton believes methanol is "ready to become a ship fuel" and could play an even more important role after 2020. This is primarily due to the shift of the Marine fuel market from the spot market to the contract market, which has made methanol more competitive with low-Sulphur fuels or diesel. (Qi,2018) The technical challenges of using methanol as a fuel in new ships, or of retrofitting existing ship fuels, have proven to be much less than those of LNG. "The interior of the MAN two-stroke and Wartsila four-stroke methanol dual-fuel engines does not require any changes, except the addition of new injectors and a fuel common-rail system," Chatterton noted. And the fuel supply system is usually double-decked, and sometimes nitrogen is injected into the fuel storage tank to keep it safe, because methanol is liquid at room temperature and will leak out by gravity if it leaks (whereas gaseous LNG will disperse into the air)." Therefore, the methanol engine fuel supply system is more convenient to work and maintain, as the methanol removal from the pipeline requires only simple "dry cleaning", which is more convenient than conventional fuels.

Methanol is the simplest structure of saturated mono alcohol, and its chemical formula is CH3OH. Its physical and chemical properties are similar to gasoline, and it is a kind of colorless, transparent, toxic, volatile flammable liquid. The molecular structure of methanol is shown in **Figure 1**, and it is compared with several other common Marine fuels as shown in **Table 1**. The biggest advantage of methanol over LNG is that it does not require low temperature storage and insulation, so the design and construction of the fuel tank is very simple and the cost is greatly reduced. Methanol bunkers can be monolithic or independent. (Riaz,2013) There is a lot of experience in the application of monolithic cargo bunkers on methanol carriers. Methanol does not contain sulfur, so the sulfur oxide (SOX) emission of methanol fuel engine (from fuel injection) can be reduced by 99% compared with that of diesel engine (using heavy oil), which can well meet the requirements of IMO emission control zone and SOX emission control zone of three major ships in China. In terms of nitrogen oxide (NOx) emission, according to the test report of WOTSILVASA 32 engine, NOx emission is 3 ~ 5g/kWh when methanol is used, while NOx emission is about 11.8g/kWh when low sulfur oil (MgO) is used. Tests on another modified engine, the Wartsila Sulzer Z40SMD, showed NOx emissions of 4 to 5g/kWh using methanol, compared with about 11.5g/kWh using low Sulphur oil. Therefore, methanol fuel engines can easily meet the current IMO Tier II and domestic NOx emission standards for ships. In addition, because methanol is rich in oxygen atoms and burns more fully, it can effectively reduce the emission of harmful gases, and the emissions of carbon monoxide (CO), carbon dioxide (CO2) and total hydrogen carbon (THC) can be reduced to varying degrees. Talking about the applicable market for methanol fuel, Chatterton said that methanol is well suited for use in short-distance sea, coastal and inland river voyages, where vessels spend most of their time in emission control zones close to land and populated areas. (Riaz,2013)

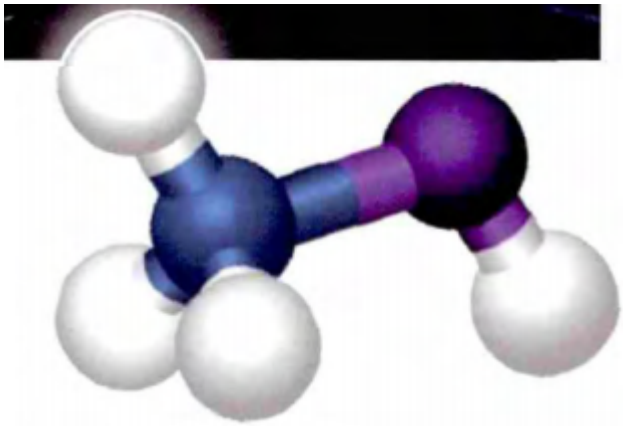


Figure1 Methanol molecular formula

Source: Gan, S.W. (2016). Methanol: Marine Fuel of the Future. *Technology*, 90-94.

Table1 Comparison of physicochemical properties between methanol and several common Marine fuels

Source: Gan, S.W. (2016). Methanol: Marine Fuel of the Future. Technology, 90-94.

Fuel	HFO	MGO	LNG	Methanol
State of matter	liquid	liquid	Cryogenic liquid	liquid
Density at 15 ℃ [kg/m3] (LNG at -160 ℃)	989	MAX900	448	796
Boiling point (℃)	30~190	180~360	-162	65
Flash point (℃)	>60	>60	-	12

Spontaneous combustion point (℃)	-	250~500	540	465
Ignition limit [% by volume]	-	0.3~10	5~15	6~36
Net calorific value (MJ/kg)	40	43	50	20

Internationally, Europe is the pioneer in the research and practice of Marine methanol fuel, and the research and application of Marine methanol fuel are in the world's leading level. As early as 2006, the European Commission funded a project called METHAP (Feasibility Study for Merchant Ship Auxiliary Power Systems Based on Renewable Methanol) to evaluate the technology and feasibility of using methanol fuel cells to power important equipment on SOLAS ships. Since then, the Swedish National Innovation Agency has carried out a series of research or pilot projects, which has realized the leap of methanol as a Marine fuel from scientific research to practical ship application. (Hendriks,2019) Although liquefied natural gas (LNG) has been the favorite alternative fuel in the past few years, and this trend is expected to continue in the future, a growing number of studies and cases show that methanol, with its many advantages such as clean, environmental protection and high availability, has fully demonstrated its potential as a future Marine fuel. Marine fuel has also become one of the emerging fields using methanol fuel. (Zincir,2019)

1.2 Literature review

Abstract

With the decrease of petroleum resources and the pressure of environmental protection, people are constantly looking for new combustion technology of engine and new and cleaner latent petroleum resources. LNG, LPG, methanol, biofuels and hydrogen are among the most powerful potential energy sources actively seeking to reduce CO2 and other emissions. Among them, methanol has a great advantage in the production of our country. It is a new potential fuel with low production cost. Therefore, this paper analyzes the characteristics of methanol fuel, discusses the problems and countermeasures of methanol fuel as a new potential engine energy, which has important practical significance for the research and development of methanol fuel ships. (Cheng,2019)

With the decrease of resources and environmental problems getting more and more attention, methanol fuel as a new type of high-quality potential energy is being paid more and more attention by more and more countries, while vigorously developing and using methanol resources as ship fuel, we should also pay attention to the potential problems of methanol fuel.

1.2.1 Domestic status quo of methanol fuel ships

On July 23, 2019, China's first methanol fuel-powered ship, independently developed by JIANGLONG ship Technology Co., Ltd, was officially launched in Zhongshan SHENWAN JIANGLONG ship Technology Park. This ship not only fills the gap in the field of methanol ship design and construction in China, but also has positive demonstration significance for the promotion and industrial application of methanol fuel in the domestic ship field. This huge vessel is about 40 meters long, 8 meters wide, 2.7 meters deep and 172 tons in weight as shown in **Figure2**.

Figure2 China's first methanol-powered ship

Source: https://www.sohu.com/a/328920463_99930566

"In today's increasingly serious problem of ship emissions pollution, environmental protection is paid more and more attention by governments around the world, governments have introduced various regulations to limit ship emissions. "Fang Hong Pei, technical director of JIANGLONG Shipbuilding Co. Ltd, said that among the mainstream new energy sources and clean fuels in the world, methanol fuel is recognized as a clean fuel in the world. Using methanol fuel as ship power conforms to the development trend of energy saving and emission reduction in ship industry. (Raman,2019) Under this background, JIANGLONG Shipbuilding Co. Ltd, together with Guangxi YUCHAI Machinery Co. Ltd, Tianjin University and Guangdong Yichang LISHI Machinery Co. Ltd, has carried out the research, development, design and manufacturing of methanol fuel-powered ship. After three years, China's first methanol fuel-powered ship with independent intellectual property rights has been successfully developed and launched. According to the research report of State Key

Laboratory of Internal Combustion Engine Combustion of Tianjin University, methanol clean energy powered boats, compared with pure diesel powered boats, have more than 10% improvement in economy, 96% reduction in CO carbon oxides, 99% reduction in THC hydrocarbons and 54% reduction in smoke in the current application scenario, and all emission values are better than the latest "Emission Limits of Marine Engine Exhaust Pollutants" and all the emission values are better than the latest Emission Limits and Measurement Methods for Ship Engine Exhaust Pollutants (Stage I and II)" limits. With good economy and environmental protection, the prospect of commercial application is worthy of expectation. (Raman,2019)

Although the supply of methanol fuel in China is still low, the promotion of the fuel and related power units can contribute to the development of related industrial systems and sales channels, and the economics of methanol fuel is an important basis for the development of the methanol ship market. Therefore, the challenge for methanol fuel is not only to increase the production and sales of methanol, but also to produce it more efficiently and effectively, and to reduce its actual production cost.

At the national policy level, the development of the national economy cannot be overly dependent on a single type of fuel resource, which can lead to interruptions in industrial economic development and massive economic losses if there are problems with its supply. China's current national situation is the world's leading energy-consuming country, so it is all the more necessary to adopt an effective strategy of energy diversification. In the current environment, it is necessary to formulate policies based on the relevant characteristics of China's energy distribution and geographical environment. (Zincir,2019)

Considering China's existing coal and oil reserves, alternative fuels such as methanol will certainly become an important part of China's energy diversification, especially in areas where coal resources are abundant and oil resources are relatively poor. Methanol fuel provides a great opportunity for China's energy industry to develop effectively, which can reduce the dependence on oil resources to a certain extent and is also beneficial to environmental protection. At the same time the relative methanol

diesel engine and other equipment will have more room to develop in the era of diversification. (Wu,2019)

1.2.2 Present situation of methanol fuel ship abroad

Internationally, Europe is the pioneer in the research and practice of Marine methanol fuel, and plays a leading role in the research and application of Marine methanol fuel. As early as 2006, the European Commission funded a project called METHAPU (Feasibility Study for Merchant Ship Auxiliary Power Systems Based on Renewable Methanol) to evaluate the technology and feasibility of using methanol fuel cells to power important equipment on SOLAS ships. Since then, the Swedish National Innovation Agency has carried out a series of research or pilot projects, which has realized the leap of methanol as a Marine fuel from scientific research to practical ship application. (Dere,2019)

In 2014, MARINVEST and WESTFAL-LARSEN ordered four 50,000-dwt series tankers to be built in accordance with DNV GL (a combined company of Det Norske Veritas and Lloyd's Register) low flash point fuel codes. It is the first ship to use methanol as a fuel, significantly reducing local pollution emissions. The oil product vessels, which can also be used for methanol transport, will be built at Hyundai MIPO Shipyard and are scheduled to be delivered in 2016.

"The ship will implement a number of important safety measures involving the placement of tanks and pipelines to avoid energy shocks such as grounding or cargo movement, as well as a complete two-layer maintenance system for the fuel system, leak detection, automatic shutdown and ignition prevention. The safety concept is similar to that of gas-based ships." "Said SKARET, director of tanker operations for DNV GL. (Sayin,2010)

DNV GL is the first classification society in the world to issue a low flash point liquid fuel specification and sees methanol as part of the future energy mix for ships. In addition to reducing sulfur oxide and nitrogen oxide emissions, fuel system retrofits

are not difficult.

Although liquefied natural gas (LNG) has been the favorite alternative fuel in the past few years, and this trend is expected to continue in the future, a growing number of studies and cases show that methanol, with its many advantages such as clean, environmental protection and high availability, has fully demonstrated its potential as a future Marine fuel. Marine fuel has also become one of the emerging fields using methanol fuel. The Nordic region, for example, plans to operate 25 methanol fuel carriers by 2018.

1.2.3 Why use methanol as ship fuel

With more and more high Marine fuel sulfur limit, the use of alternative energy as fuel is imminent. **Figure 3** shows future and present sulfur limit values for ship fuels.

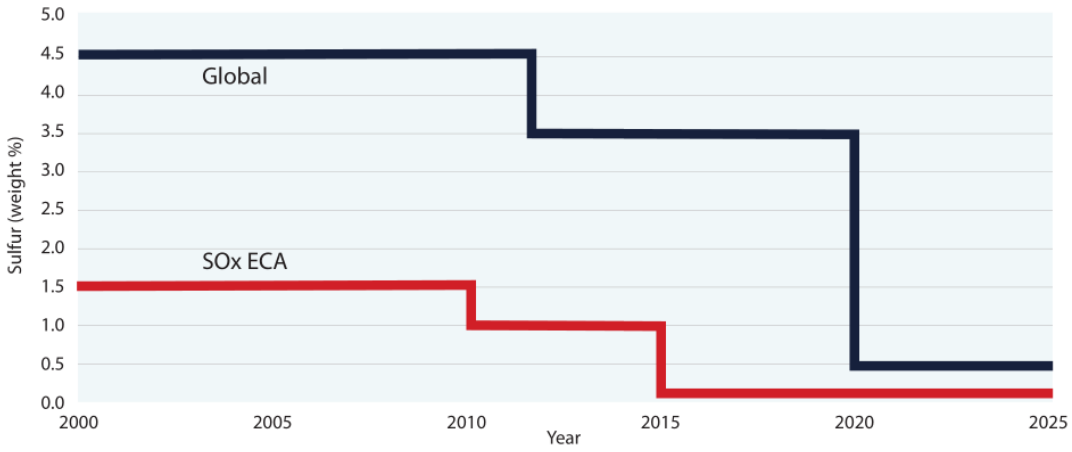


Figure3 Sulphur limits for future and present ship fuels

Source: V. Alexandria. (2017). Alternative Fuel For Today's Automobiles and Cleaner Burning Octane For Today's Oil Refinery. Methanol Gasoline Blends, 1-19.

Emission Control Areas (ECAs) are mandated by the International Maritime Organization (IMO) to regulate emissions of sulfur dioxide and nitrogen oxides. **Figure 4** is ECAS requirements for NOx emissions from newly built ships.

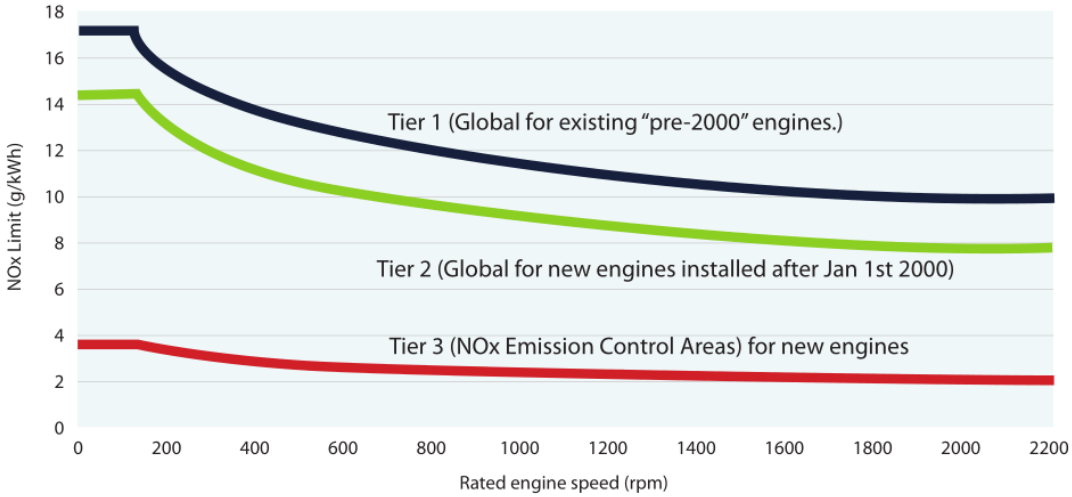


Figure4 ECAS requirements for NOx emissions from newly built ships

Source: V. Alexandria. (2017). Alternative Fuel For Today's Automobiles and Cleaner Burning Octane For Today's Oil Refinery. Methanol Gasoline Blends, 1-19.

1.2.3.1 Advantages of methanol fuel

a. Methanol fuel can reduce pollutant emission

Diesel oil has different sulfur content depending on where it is produced. Liquefied natural gas (LNG) generally requires desulfurization prior to liquefaction. (Sayin,2019) However, methanol basically contains no sulfur, and the sulfur oxide (SOX) emission of methanol fuel engine (from fuel injection) can be significantly reduced, which can well meet the requirements of the IMO emission control zone and the SOX emission control zone of China's three major ships.

In terms of CO, HC and NOx emissions, compared with diesel fuel, the addition of methanol oxygen-rich fuel can improve the oxygen-fuel ratio in the engine combustion. The viscosity of methanol is low, which facilitates the diffusion of methanol, and more favorable to the formation of mixture, and makes the combustion more sufficient. The emissions of CO, CO2 and total carbon and hydrogen (THC) are reduced to varying degrees. In addition, due to the high latent heat of vaporization, the intake temperature can be reduced, the low compression negative work can improve the charging efficiency, the maximum combustion temperature is low, the NOx

emission of the engine is low, (Datta,2018) and is conducive to improving the efficiency of the diesel engine.

b. Methanol fuel is easy to use and transform

Methanol emissions are comparable to those of liquefied natural gas (LNG) and liquefied petroleum gas (LPG). (Datta,2018) The main component of LNG is methane. Although it is not corrosive, it will continue to vaporize due to heat in the storage process and may be released into the atmosphere if it is not used in time. The LNG project of Tianjin fishing boats has the problem of port release, which aggravates the economic burden of fishermen and environmental pollution. In addition, there is the possibility of leakage in the process of transportation and application. Although the use of LNG reduces CO2 and NOx emissions, the methane emitted by LNG is four times more harmful than CO2 and 298 times more harmful than NOx. (Qi,2018) In addition, the use of LNG fuels in ships requires high modification costs.

CHAPTER 2 OVERVIEW OF RISK ASSESSMENT METHODS

2. Introduction

In the academic community, there is disagreement on the definition of Risk. The difference is whether the emphasis is on the subjective perception or the objective presence of risk. In a broad sense whenever there are two or more possibilities for the occurrence of an event of an event, then the event is considered to be at risk, i.e., the probability of an unexpected event occurring. An unexpected event may cause economic losses, outbreaks of epidemics or social problems. Therefore, the risk is analyzed and countermeasures are developed in advance to prevent the possible risks. The application of risk assessment research emerges by analyzing risks and developing countermeasures in advance to prevent possible problems.

Risk assessment has become an area of high interest in academia, and in recent years significant research has been made, and many scholars both at home and abroad have researched and summarized the major events around the world from different perspectives, which has laid a solid theoretical foundation for this. This has laid a solid theoretical foundation for further development of forecasting and risk assessment. In today's economic globalization, the popularity of network information, the contradiction between ecological carrying capacity and the contradiction of tourism fever, global climate change and other scientific, technological and socio-economic The development of science and technology and socio-economics such as global climate change make new risks emerge continuously. The dynamics and impact paths of traditional risks are also changing. These risks, if they occur, will far exceed the current capacity of society to prevent them. Through assessments, management can have first-hand knowledge of potential risks and failures at all times. The results can provide management with a basis for developing incident management plans and safety guidelines, scheduling personnel, etc. The assessment results can provide a certain basis for management to formulate accident handling plans and safety guidelines, arrange personnel scheduling, etc. Through a series of measures risks and accidents can be reduced to a minimum. (Gan,2016)

2.1 Delphi method

2.1.1 Definition

Delphi method is a very important method in the expert investigation method. It is a method to conduct comprehensive analysis and research on the research object, seek its characteristics and development law, and make prediction based on the situation obtained through investigation, relying on the knowledge and experience of experts, directly or through simple calculation.

The biggest advantage of this method is that it is simple and intuitive, and there is no need to establish tedious mathematical model. Moreover, it can also make effective prediction of the unknown or future state of the research object in the absence of sufficient statistical data and similar historical events for reference. (Gan,2016)

2.1.2 Characteristic

a. Anonymity

Forecasting experts are unaware of each other's participation and exchange ideas in complete anonymity. The Delphi method adopts the form of anonymous letter survey, which overcomes the shortcoming of the expert meeting survey method being susceptible to the influence of authority, meeting trend, atmosphere and other psychological influences. The experts were able to express their opinions independently on the questions raised in the questionnaire without any interference and had sufficient time to reflect, conduct research and consult data. Anonymity ensures the adequacy and reliability of expert advice. (Hansen,2017)

b. Feedback

The Delphi method uses the anonymous form, the mutual contact between experts, only on a survey, expert opinions tend to be scattered, It is not easy to make the conclusion. In order to make the invited experts to understand summary of each round of consultation and other experts, organizers want to sort the results of each round of consultation, analysis, synthesis, and feedback to each invited experts, in the next

round of consultation to experts according to the new questionnaire to comment further. (Yusri,2017)

c. Statistical

In the application of Delphi method to information analysis and prediction research, the evaluation or prediction of the research topic is not made by the information analysis researchers, nor by individual experts, but by a group of relevant experts, and the answers of many experts must be statistically processed. Therefore, the results obtained by the Delphi method have statistical characteristics and often appear in the form of probability, which reflects both the concentration degree and the dispersion degree of expert opinions.

2.1.3 General steps

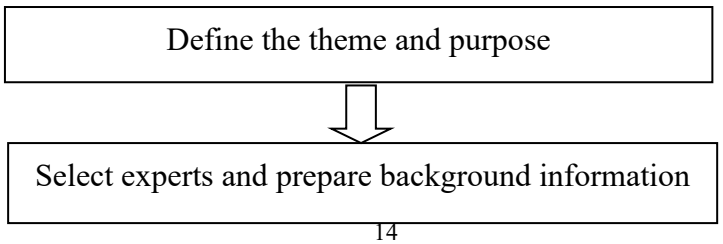
a. Determine the survey forecast target. The survey organizer defines the survey topic, designs the questionnaire or the survey outline, collects and sorts out the background materials about the survey topic, and makes a good preparation before the survey.

b. Hire experts. The number of people is generally 10-15, and can be exceeded if it is a major forecast.

c. Repeatedly seek expert advice. Generally, 3-5 rounds.

d. Statistical processing is carried out on the opinions consulted by the experts at the last time, and the results of investigation and prediction are made.

Delphi method has a unique forecasting procedure, which mainly includes three stages: preparation stage, consultation stage and data processing stage as shown in the **Figure5** below.



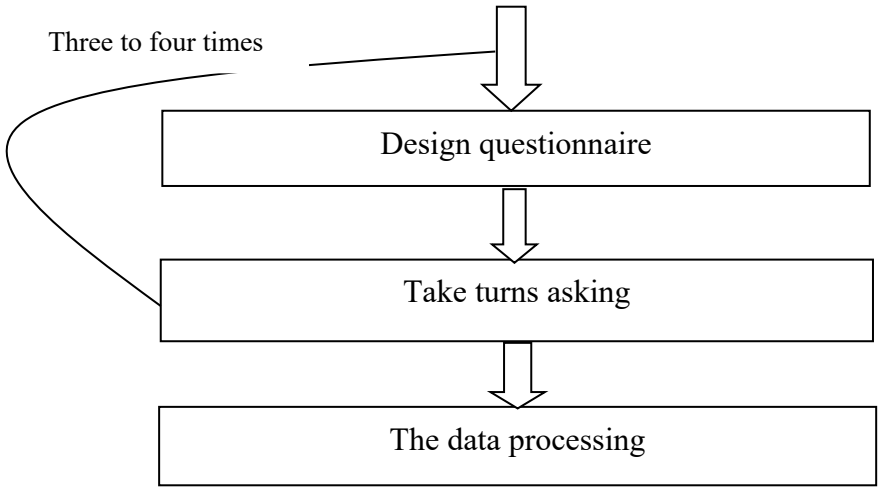


Figure5 Delphi method prediction procedure

Source: Wang, T. (2021). Application of Delphi Method in Risk Identification of Subway Line Upgrade Construction. PROJECT MANAGEMENT TECHNOLOGY, 4, 112-115.

2.1.4 Implementation process

The first round: The moderator sends an unstructured, loosely structured list of questions with no specific purpose, which simply points out the predicted topic, without any framework, to each expert chosen according to the field in which the predicted topic is to be studied.

After a certain period of time, the moderator will collect the first round of questions, summarize and sort out all the opinions put forward by the experts, and eliminate the opinions that are irrelevant or of little significance for the purpose of prediction, and synthesize the second list of questions with standard terms. (DNV,2016)

The second round: A second list of questions will be sent to each expert by the host, who shall make an evaluation of the events listed in the second list and explain the reasons.

The moderator will collect the second list of questions, then process and summarize the expert opinions again, and synthesize the third list of questions.

The third round: The moderator gave a third list of questions to each expert. Each expert should evaluate the various opinions and reasons summarized according to the third list of questions. (DNV,2016)

The experts then send revisions and new arguments to the presenters. The host again summed up the opinions of the experts and synthesized the fourth list of questions.

The fourth round: The moderator will send a fourth list of questions to each expert, including a list of events, various evaluations of the expert, and so on. Each expert must consider various arguments and comments and make new predictions.

In the fourth round, whether the experts need to present a new argument will depend on whether the moderator considers it necessary.

After the fourth round of the response results were statistically processed to form a more consistent forecast result. (DNV,2016)

2.1.5 Matters needing attention

a. The above four rounds of surveys are not simply repeated, but a kind of spiraling process. With each cycle and feedback, experts absorb new information and have a deeper and more comprehensive understanding of the predicted objects. The accuracy of the forecast results also improves round by round.

b. Not all predicted events go through four steps. There may be events that reach unity in the second step and do not have to occur in the third.

c. At the end of the fourth step, the experts' predictions of each event do not necessarily reach a consensus. You can also use the median and the upper and lower quartiles to draw conclusions when you don't agree. (Yi,2016)

d. Appropriate compensation is required: in order to mobilize and encourage the initiative of experts. Experts should be appropriately remunerated in organizing the Delphi method of forecasting. The amount of compensation depends on the predicted workload. Finally, the scale of remuneration is issued with a list of expert responses.

e. Determine the proper interval between wheels: Experience has shown that the predicted interval between wheels varies considerably. Most predictions take four to six weeks to complete one round, while others predict a total of 26 days for two rounds. Therefore, the wheel spacing is related to the expert's interest in predicting the problem as well as the difficulty of the problem. (Yuan,2017)

f. The leading group (or moderator) should not assume that all the experts participating in the response understand the Delphi method and its prediction procedure. In fact, many experts have little or no knowledge of the Delphi method and its procedures. In order to give experts a complete picture of the situation, the general questionnaire should have a preface, which describes the purpose and task of the forecast, the procedure of the Delphi method of forecasting, and the relevant issues to be noted. (GCS,2019)

2.1.6 Evaluation of the method

Advantages

a. The ability of the experts to express their views independently and fully, without interference;

b. The forecast value is based on the opinions of the experts, which can give play to the wisdom of the collective.

c. It has a wide range of applications and saves the cost.

Disadvantages

a. When synthetically predicting the value, it is only based on the subjective judgment of various experts, lacking objective standards, and seems to insist on consistency.

b. Due to some subjective and objective reasons, some experts did not carry out in-depth investigation and thinking on the filling of the form, thus affecting the accuracy of the evaluation results.

2.2 Risk matrix analysis

2.2.1 Definition

A method to evaluate the impact of risk factors on the project through qualitative analysis and quantitative analysis, which comprehensively considers the risk influence and risk probability.

The table below shows the original risk matrix.

Table2 Original risk matrix

Source: https://wenku.baidu.com/view/712779e8aeaad1f346933fff.html

The project requirements	The technology used	Risk	The risk impact	The risk probability	Risk level	Risk management

2.2.2 Determination of risk impact level (qualitative and quantitative)

This is shown in the following table3.

Table3 Risk Impact Hierarchy

Source: https://wenku.baidu.com/view/712779e8aeaad1f346933fff.html

The risk impact	Definition or description
Critical	Once a risk event occurs, the project will fail.
Serious	Once a risk event occurs, it will result in a substantial increase in funding and a prolonged project cycle, which may not meet the secondary needs of the project.
Moderate	Once a risk event occurs, it results in a general increase in funding and a general extension of the project lifecycle, while still meeting some of the important project requirements.
Minor	Once the risk event occurs, the cost is only slightly increased, the project cycle extension is not large, and the indicators of the project demand can still be guaranteed.
Negligible	Once a risk event occurs, it has no impact on the project.

2.2.3 Determination of risk probability (qualitative and quantitative)

This is shown in the following table4.

Table4 Risk probability table

Source: https://wenku.baidu.com/view/712779e8aeaad1f346933fff.html

Risk probability range (%)	Explain
0-10	Very unlikely to happen
11-40	Unlikely to happen
41-60	It can happen in the middle of a project
61-90	May happen
91-100	Likely to happen

2.2.4 Determine the risk level

This is shown in the following table5.

Table5 Risk scale

Source: https://wenku.baidu.com/view/712779e8aeaad1f346933fff.html

Risk probability range (%)	Can be ignored	Tiny	General	Serious	The key
0-10	low	low	low	medium	medium
11-40	low	low	medium	medium	high

41-60	low	medium	medium	medium	high
61-90	medium	medium	medium	medium	high
91-100	medium	high	high	high	high

2.2.5 The BORDA sequence value method

The first choice is A, A, B, B, C, C

The second choice is B, C, A, C, A, B

The third choice is C, B, C, A, B, A

The number of votes 1, 7, 1, 6, 1, 5

A to 8 points according to first preference; B-7 score C-6 score; A selected

According to BORDA's proposed scoring system A-39 points; B - 41 points; C - 46 points; C in.

The BORDA method of voting theory is introduced into the risk matrix, namely, the BORDA order value method. Its basic principle is as follows:

Let N be the total number of risks (the same as the number of rows in the risk matrix), let I be a particular risk, and k represent only two criteria in the original risk matrix for a certain criterion. K =1 represents the risk impact I, and K =2 represents the risk probability Po. If RIK represents the risk level of risk I under criterion k, then the BORDA number of risks I can be given by the following formula:

$$b_i = \Sigma (N\text{-}r_{ik})$$

The BORDA order value of a factor is the number of risk factors that are greater than the BORDA number of that risk factor. (Imran,2018)

2.2.6 Advantages of risk matrix method

Risk matrix, as a simple and easy-to-use structural risk management method, has the

following advantages in project management practice:

- Identifying which risks are the most critical to the project;
- Strengthen analysis of the interrelationships among project requirements, technologies and risks;
- Allow industry to be involved at the early stage of project risk management;
- The risk matrix approach is a direct method for assessing and managing risks throughout the project lifecycle;
- Provide a detailed historical record of project risk and risk management for further study.
- Excel 510/ Visual Basic, the software of risk matrix, has good compatibility when running on Macintosh and PC;
- Provide an intuitive spreadsheet interface;
- The BORDA method adopted is a voting algorithm for ranking risk levels based on multiple evaluation criteria;
- The risk matrix approach is a method for assessing and monitoring risk mitigation activities;
- A method for assessing the sensitivity of risk sequences based on specific evaluation criteria;
- With the function of automatic classification and list. (Imran,2018)

2.2.7 Application fields of risk matrix method

Risk Matrix has been widely used in the U.S. Air Force Electronic Systems Center, and its application analysis software has been used in the Joint Surveillance and Target Attack Radar System (JSTARS) and the National Air and Space System Upgrade Program. Moreover, the risk matrix method has been attached great importance to in the American defense procurement, and has been developing in the

application practice. At present, risk analysis is mainly used in mining, equipment maintenance and renewal, automation instrument reliability analysis and other fields in China.

2.3 Fuzzy comprehensive evaluation method

2.3.1 The basic principle

Firstly, the factor (index) set evaluation (grade) set of the evaluated object is determined. Then the weight of each factor and its membership vector are determined respectively to obtain the fuzzy evaluation matrix. Finally, fuzzy evaluation results are obtained by fuzzy operation and normalization of fuzzy evaluation matrix and weight vector of factors. (Yusri,2017)

Its characteristic is that the evaluation is carried out object by object, and it has unique evaluation value to the evaluated object and is not affected by the object set of the evaluated object. The purpose of comprehensive evaluation is to select the superior objects from the object set, so the comprehensive evaluation results of all objects need to be sorted.

2.3.2 Models and steps

a. Determine the factor field of the evaluation object

$$U= \{u_1, u_2 \dots u_m\}$$

That is to say, there are M evaluation indicators, indicating the aspects from which we evaluate and describe the evaluated objects.

b. Determine the field of evaluation hierarchy

Comment set is a set of various possible total evaluation results made by the evaluator on the evaluated object, represented by V:

$$V= \{v_1, v_2 \dots v_n\}$$

In fact, it is a division of the change interval of the evaluated object.

Where, V_i represents the ith evaluation result, and n represents the total number of evaluation results.

Specific levels can be described in appropriate language according to the evaluation content. For example, to evaluate the competitiveness of products, we can use V={strong, medium, weak}; to evaluate the social and economic development level of the region, we can use V={high, high, ordinary, low, low}; and to evaluate the economic benefits, we can use V={good, good, ordinary, poor, poor}

c. The fuzzy relation matrix R was established by single factor evaluation

The evaluation based on a single factor to determine the membership degree of the evaluation object to the evaluation set V is called single-factor fuzzy evaluation. After constructing the hierarchical fuzzy subset, the evaluated object should be evaluated from each factor u_i (i =1,2..., m), that is, the membership degree of the evaluated object to the fuzzy subset of each level is determined from the single factor, and then the fuzzy relational matrix is obtained: As shown in the **figure6**

$$R = \begin{pmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{22} & \cdots & r_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ r_{m1} & r_{m2} & \cdots & r_{mn} \end{pmatrix}$$

Figure6 Fuzzy relational matrix

Source: Source: https://wenku.baidu.com/view/712779e8aeaad1f346933fff.html

r_{ij}= (i = 1, 2 ,... m; j=1,2, …n) represents the membership degree of an evaluated object to the fuzzy subset of V_j level from the perspective of factor u_i. An evaluated object's representation of a factor u is expressed by the fuzzy vector $r_i=(r_{i1}, r_{i2};2,...rim)$ to describe The other evaluation method is characterized by an index practical value to more, so from this perspective, the fuzzy comprehensive evaluation for more

information), r_i is called a single factor evaluation matrix. Evaluation set is U and V can be regarded as a factor set, a fuzzy relationship between the influencing factors and the reasonable relationship between the evaluation objects. (Jin,2015)

When determining the membership relationship, experts or professionals related to the evaluation issue usually score the evaluation objects according to the evaluation level, and then statistic the scoring results. Then r_{ij} can be obtained according to the absolute value subtraction method, that is:

$$r_{ij} = \begin{cases} 1, (i = j) \\ 1 - c\sum_{k=1} \left| x_{ik} - x_{jk} \right|, (i \neq j) \end{cases}$$

Figure 7 Fuzzy relational matrix

Source: Source: https://wenku.baidu.com/view/712779e8aeaad1f346933fff.html

Wherein, c can be selected appropriately, such that $0 \leqslant r \leqslant 1$.

d. Determine the fuzzy weight vector of the evaluation factors

In order to reflect the importance of each factor, each factor U should be assigned a corresponding weight a_i (i =1,2...,m), usually requires ai to satisfy $a_i, \geqslant 0$; $\Sigma a_i = 1$ then represents the weight of the ith factor, and then a fuzzy set composed of all weights A is the weight set.

In fuzzy comprehensive evaluation, weight will have a great influence on the final evaluation result, and different weights may sometimes get completely different conclusions. (Jin,2015)

2.3.3 Advantages of fuzzy comprehensive evaluation method

Fuzzy evaluation deals with fuzzy evaluation objects by precise digital means, which can make a relatively scientific, reasonable and practical quantitative evaluation of the data containing fuzzy information.

The evaluation result is a vector rather than a point value, which contains rich information. It can not only describe the evaluated object more accurately, but also further process to obtain reference information. (Yi,2016)

2.3.4 Disadvantages of fuzzy comprehensive evaluation method

The calculation is complicated and the determination of index weight vector is subjective.

When the indicator set U is bigger, every index set number is larger, the weight vector and 1, under the conditions of relative membership degree of weights is often small, the weight vector and fuzzy matrix R do not match. The results will be fuzzy phenomenon, and resolution is very poor. It is impossible even for the judge to distinguish whose membership degree is higher, so the hierarchical fuzzy evaluation method should be available and improved. (Plante,2013)

CHAPTER3 METHANOL AS MARINE FUEL

3.1 Production of methanol

In nature, methanol is produced by many bacteria through anaerobic metabolism. It is also a by-product of the ethanol fermentation process. Methanol also occurs naturally in many plants, especially fruits. MEOH is synthesized mainly from natural gas, but also from coal, mainly in China and South Africa. Biomass can be converted to methanol by thermochemical and biotechnological routes, as shown below.

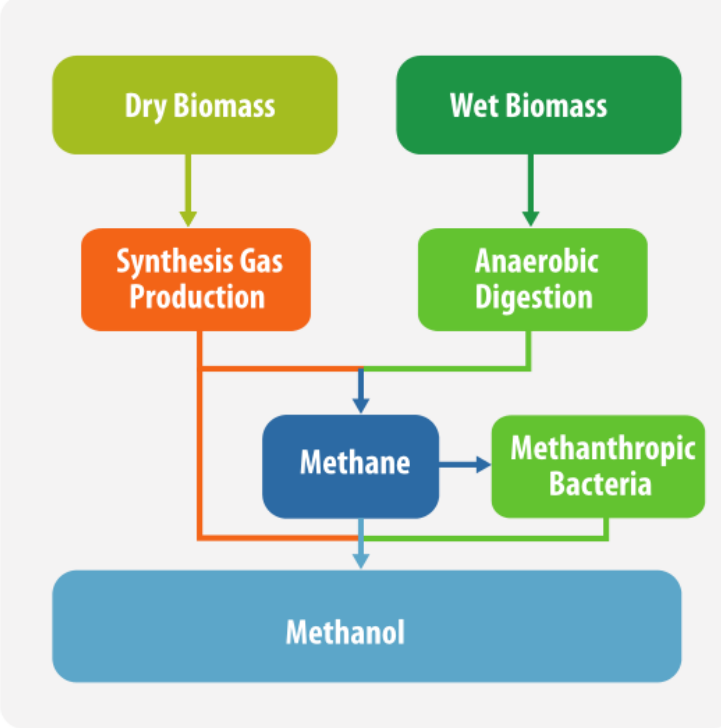


Figure8 Methanol conversion pathway

Source: Jin, K. Liu, J.J. (2015). Marine methanol tank design. *China Water Transport*, 8, 15-18.

(Methanol-fact-sheet)

At present, methanol is mainly produced from natural gas, but other feedstocks such as coal, biomass and waste can also be used. In a future scenario, methanol could also be produced in a carbon-neutral form using renewable electricity, carbon dioxide and water. Methanol can be a bridge to sustainable transportation systems in the future.

Today, producing methanol from natural gas is associated with significant energy losses in the synthesis gas process. The best methanol plants are close to 70% efficient, which means that more than 30% of the energy in the natural gas is lost during the conversion of natural gas to methanol. In this respect, LNG has a significant advantage over methanol, as large LNG plants use less than 10% of the energy to cool natural gas into LNG. A life cycle assessment comparing methanol from natural gas and methanol from biomass with some other Marine fuels has shown that methanol will have a reduced environmental impact compared to heavy fuel oil in most areas. The assessment also shows that the environmental impact of methanol produced using natural gas is comparable to that of using liquefied natural gas. (Jamrozik,2017)

Small-Scale Production

MEOH-TO-GO (small-scale methanol production) as shown in the figure9

Traditional focus

- Economy of scale
- Focus on energy consumption

Small scale focus

- Reliable, proven, ease-to-operate
- 215MTPD Methanol, Grade AA and IMPCA specs
- Competitive CAPEX
- Fast on-site construction
- Ease of transportation

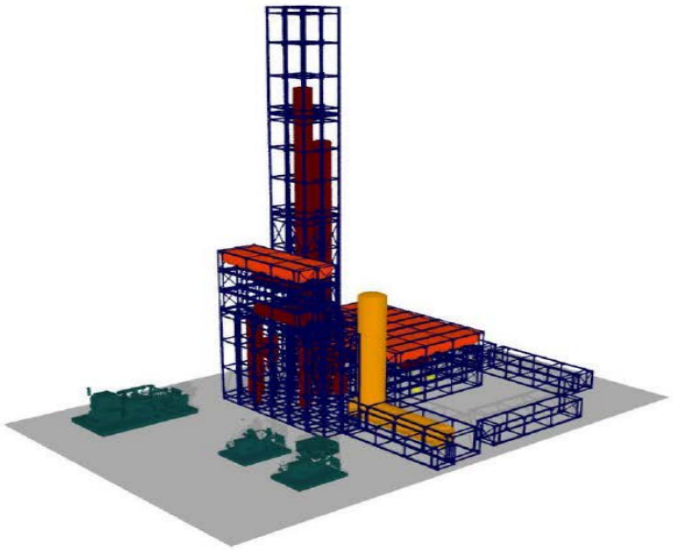


Figure9 HALDOR TOPSOE

Source:(http://www.effship.com/PublicPresentations/Final_Seminar_2013-03-21/09_EffShip-Handout.pdf)

Primus Green Energy as shown in the figure10

- The systems are simple and economical at scales as low as 500 MMBtu/day.
- Feedstocks: flare gas; stranded ethane; pipeline natural gas; excess syngas from underutilized reformers.
- Primus has developed a range of flexible gas-to-liquids systems that can produce methanol, DME or gasoline.

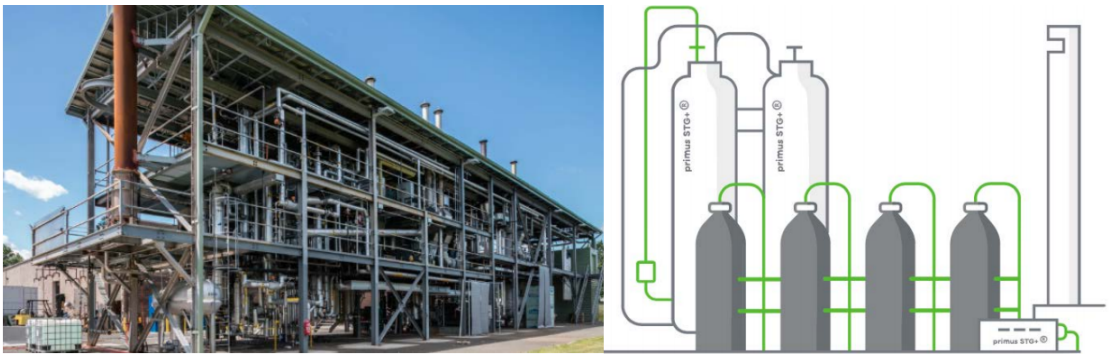


Figure10 Primus Green Energy

Source:(http://www.effship.com/PublicPresentations/Final_Seminar_2013-03-21/09_EffShip-Handout.

pdf)

Gas Techno as shown in the figure11

- The Gas Techno process is a non-catalytic gas-to□liquids technology that converts methane to methanol in one step.
- The “Methanol in a Box” system is housed in a 40-foot shipping container.
- Designed to monetize flare gas from 50,000 cubic feet per day to 30 million cubic feet per day.

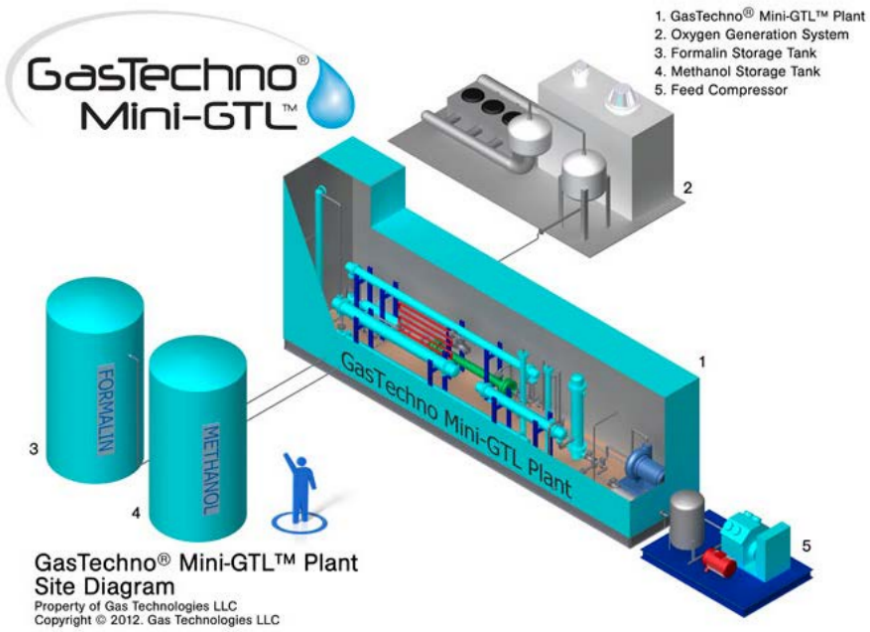


Figure11 Gas Techno

Source:(http://www.effship.com/PublicPresentations/Final_Seminar_2013-03-21/09_EffShip-Handout.pdf)

3.2 Methanol fueled ship system composition

Diesel engines used on ships are available as two-stroke or four-stroke engines. Two-stroke and four-stroke engines can now be adapted to use methanol in dual fuel mode. In these adaptations, the fuel injection of the engine is modified to achieve higher injection pressure, which is necessary to ignite the methanol. (Andersson,2015)

Because methanol has a very low viscosity compared to conventional HFO and diesel fuel, special efforts are required to prevent seal leaks. (Wu,2021) The fuel delivery system must also be safe for the technician performing maintenance or repairs, which in practice means avoiding direct contact with methanol. For this reason, methanol engines are equipped with a double-layer fuel distribution system. In addition, the engine system is designed with a nitrogen purge to ensure that the operator can work safely on the engine. In contrast to HFOs, there is no need to heat the fuel; instead, sometimes the fuel must be cooled before injection. (Xuan,2020)

There are three plans for current engine refits. “EFFSHIP” “SPIERTH” “Pilot Methanol”

Most of the engine conversion experience came from the three programs mentioned above. One of the goals of the SPIRETH project was to modify a marine diesel engine to create a dual-fuel engine using methanol as the primary fuel (Ellis et al, 2014). The main focus was on the development of an improved methanol solution for a medium-speed four-stroke engine. This concept was further developed in a retrofit project involving the existing engines of the German passenger ship Steiner. This engine type is well suited for retrofitting. There are several other engine models that can be retrofitted, but this does not apply to all older marine diesel engines (HARALDSSON, 2015b).

A two-stroke dual-fuel methanol propulsion engine has been developed to meet an order for seven newly built tankers that will be used to transport methanol. As in most other cases, the engine is built on an existing concept (MAN, 2015b).

A typical methanol fuel system can be broken down into five modules based on function: methanol refueling, methanol storage, methanol handling and supply, methanol utilization, and post-machine processing. (Wang,2019)

3.2.1 Methanol refueling

Methanol refueling: The refueling system includes the refueling station, refueling piping system (including valve parts), refueling joints and inerting and purging piping,

etc. These parts are similar to LNG refueling and are not new or complicated. However, considering the low flash point and toxicity of methanol, the location, construction, ventilation, detection, fire protection and personnel protection of the refueling station need special consideration. (Wang,2021)

3.2.2 Methanol storage

Methanol storage: The main considerations for methanol fuel tanks should be their tank type, location, fuel tank protection, ventilation, environmental control, etc. The pilot retrofit vessels can adopt independent bunkers because of the low fuel demand; large methanol-fueled vessels can adopt integral bunkers. According to the existing draft IGF rules, the bunker should not be arranged below the living premises and the distance from the side should not be less than 760mm; when the bunker is located below the deck, there should be isolation compartment to separate it from other premises (except for fuel pumping compartment and bilge), and the isolation compartment should be equipped with methanol vapor and liquid leakage detection device. The requirements for air permeability and environmental control should conform to IBC rules. (Kim,2016)

3.2.3 Methanol handling and supply

Methanol handling and supply: All systems and components from the methanol fuel tank to the engine, should include the methanol supply system and fuel manifold. The requirements of this part are similar to those of the fuel supply system for LNG-powered vessels, with emphasis on supply line protection, valve arrangement, fuel pump location and protection, temperature control, etc. The large number of valve fittings and joints in the fuel supply line and the low viscosity of methanol mean that the risk of potential leakage is greatly increased, so the selection of suitable sealing materials, installation of vapor detection, negative pressure ventilation and double-walled piping are all necessary risk control measures. (Wang,2019)

3.2.4 Methanol utilization

Methanol utilization: through the engine. In the draft IGF rules, the requirements of

methanol engine are similar to those of natural gas fuel engine, both of which are functional requirements, relatively macroscopic and principled. Different manufacturers of engine research and development route is not the same, mostly inheriting their traditional advantages, such as MAN company research and development of the ME - LGI methanol - diesel dual fuel engine is high pressure injection, low speed two stroke, dual fuel engine. Caterpillar research and development is high speed, four-stroke, pure methanol engine with glow plug ignition, relevant manufacturer of methanol engine as shown in table6. (Wang,2019)

One of the problems associated with the use of methanol fuel is that the wear of engine will increase significantly due to the creation of a cleaner lubrication environment, which, similar to natural gas fueled engines, should be considered in the design phase.

Post-machine methanol treatment: it mainly refers to the purging and recovery system. Nitrogen device plays a core role in the whole system. For dual-fuel engines, in the case of fuel conversion, engine maintenance, etc., the fuel supply line must be scavenged and inert. According to the MAN ME-LGI engine design, the fuel line must be arranged to allow the methanol to be emptied and returned to the daily tank by purge, after which all double-wall piping systems should be fully inerted. All purging and inerting shall be carried out on each subsystem through a nitrogen unit. (Gan,2016)

Table6 Overview of methanol fuel engines

Source: C. Sayin. (2019). The influence of operating parameters on the performance and emissions of a DI diesel engine using methanol-blended-diesel fuel, 1407-1414.

Factory	Fuel	Type of engine	The prototype	Note
WARTSILA	Methanol and MGO	Medium speed, four stroke Marine	WARTSILA Sulzer	In 2015, it was installed on STENA

		engine, fuel ignition	8cylinder Z40S, modified machine	Germanica
MAN	Dual fuel - conventional fuel and methanol, ethanol, LPG, etc.	Low speed, two stroke Marine engine, fuel ignition	Newly designed model	It was installed on a methanol transport ship in 2016
CATERPILLAR	Pure methanol	High speed, four stroke heavy truck engine, 261kW, preheat plug ignition	Cater pillar 3406 DITAS	Run over 5000 hours on a heavy truck test

3.2.5 WARTSILA

At SPIRETH, various combustion concepts and design options were evaluated with the goal of obtaining low emissions, high efficiency, robust solutions and cost-effective conversions. The development builds on the experience of designing LNG/HFO dual-fuel engines with low-pressure gas systems. The concept has been tested for more than ten years. (Alexandria,2017)

Low cetane number is a common characteristic of both methanol and LNG, and engines require cetane boosters to ignite. In the dual fuel solution, a small amount of diesel is used as a pilot fuel. To retrofit the existing engine, natural gas-diesel technology was used. (Varone,2016)

Unlike gas dual-fuel engines, the gas compressor for natural gas is replaced by a high-pressure methanol pump to increase fuel pressure. In a converted vessel, the conventional fuel system can be kept operable as a backup system.

Methanol injection is done through a common rail system. All methanol piping is designed to be double mounted. Methanol in the high-pressure piping system can be purged by nitrogen so that the operator is not exposed to methanol. (Yebo,2019)

The exhaust valves have been modified to reduce exhaust gas wear by having fewer lubricating particles than when using diesel or heavy oil. The concept has been tested by converting the WARTSILA-Sulzer eight-cylinder Z40S into a laboratory-tested Z40S. The same type of engine was also adapted to power the ferry Stena Germanica. (Yebo,2019)

WARTSILA engine with additional piping for methanol is shown in the figure12

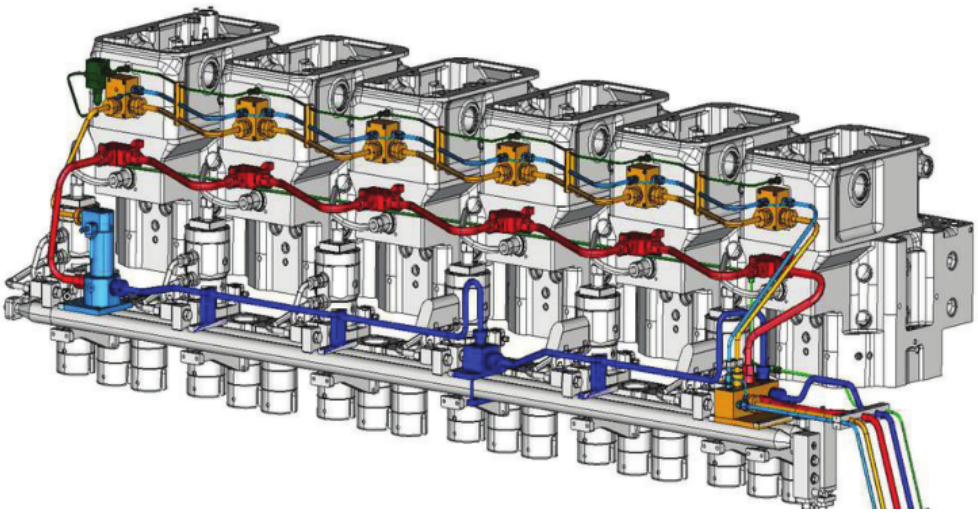


Figure12 WARTSILA engine with additional piping for methanol

Source: Jamrozik. (2017). The effect of the alcohol content in the fuel mixture on the performance and emissions of a direct injection diesel engine fueled with diesel methanol and diesel-ethanol blends. Energy Conversion and Management, 461-476.

3.2.6 MAN

MAN is retrofitting the engines, which will be used in seven newly built methanol tankers. The first engine was delivered in August 2015. (SEJER LAURSEN, 2015a).

These vessels are scheduled for delivery between April and October 2016.

The engine under discussion is the two-stroke 10 MW ME-LGI engine. This engine provides a dual fuel solution for low ignition liquid fuels. The cylinder head is equipped with an additional methanol booster injector. (MAN, 2015b), achieving a typical injection pressure of 10 bars. The engines are undergoing long-term tests in

Japan (SEJER LAURSEN, 2015a).

Pressurized methanol is transported by double-walled pipes, ventilated with dry air, and all methanol fueled equipment is double-walled (MAN, 2015a). This figure13 shows the MAN engine adapted for methanol.

Figure13 MAN engine adapted for methanol

Source: Source: Jamrozik. (2017). The effect of the alcohol content in the fuel mixture on the performance and emissions of a direct injection diesel engine fueled with diesel methanol and diesel-ethanol blends. Energy Conversion and Management, 461-476.

3.2.7 Application in a ship

When changing fuel, there are devices on board that must be added or modified. This includes fuel tanks, piping and bunkering systems. Other equipment used on HFC-fueled ships, such as boilers and fuel separators, are not required if methanol is the primary fuel, or if the other fuel for the dual-fuel engine is light diesel. In retrofitting, cooling fuel may be required (HARALDSSON, 2015b).

3.2.8 Future engine technologies

Current methanol engines are modified from dual fuel engines with HFO, diesel and natural gas. The number of engines suitable for conversion is limited (HARALDSSON, 2015b).

The modified engine performed well, but was not optimized for this purpose. The change in methanol fuel made it possible to build a more efficient and smaller engine.

Several universities are developing new engine concepts for burning methanol and other alcohols in the diesel process. They include the Massachusetts Institute of Technology, (Cohn,2015) Ghent University (Verhelst,2015) and Lund University of Technology (Tuner,2015).

Within the next two years, an engine concept will be developed that will likely use glow plugs to help with ignition. Another concept that could easily be developed would be to mix the fuel with air before the compressor fumigates the fuel. This would result in higher combustion temperatures, but would make it more difficult to control the methanol content of the exhaust gas (FAGERLUND and RAMNE, 2014).

There are many ways to build engines that meet the needs of the three stages. Exhaust gas recirculation (EGR) is one example. Today, the third tier can be achieved by using SCR catalysts. A number of future engine concepts are in development that can reduce NOx emissions and meet Tier III requirements. This figure14 shows the installations on board for methanol conversion of ferry. (Appels,2018)

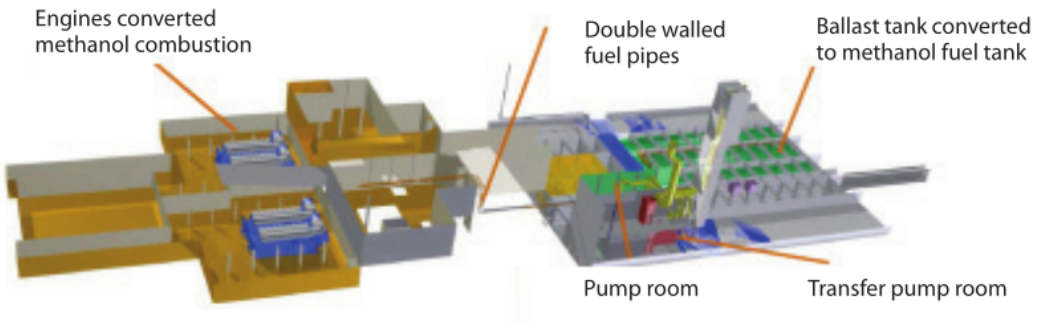


Figure14 Installations on board for methanol conversion of ferry

Source: Source: Jamrozik. (2017). The effect of the alcohol content in the fuel mixture on the performance and emissions of a direct injection diesel engine fueled with diesel methanol and diesel-ethanol blends. Energy Conversion and Management, 461-476.

And this figure15 shows the installations on board new-build methanol tanker

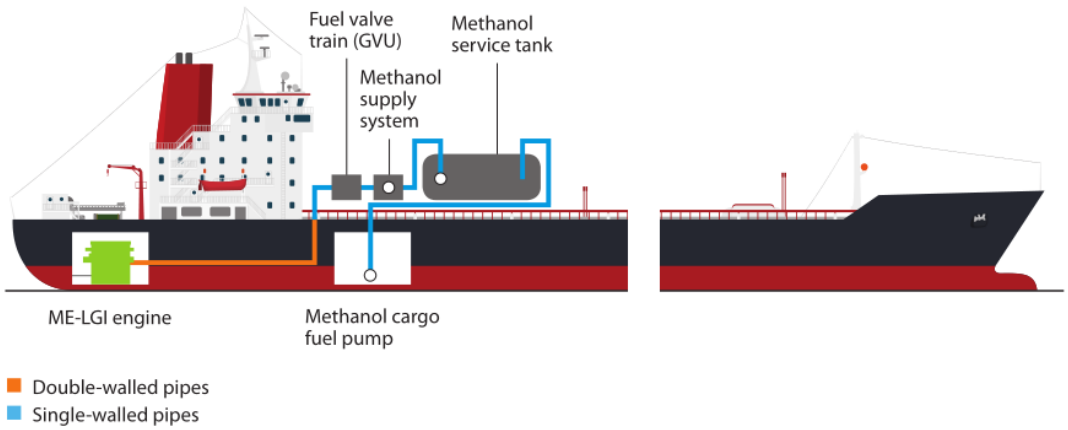


Figure15 Installations on board new-build methanol tanker

Source: Source: Jamrozik. (2017). The effect of the alcohol content in the fuel mixture on the performance and emissions of a direct injection diesel engine fueled with diesel methanol and diesel-ethanol blends. Energy Conversion and Management, 461-476.

Various technical parameters must be considered when deciding on a fuel change, and the technology readiness level (TRL) is important for both cost and operational possibilities. Table summarizes the TRLs for selected parameters of HFO, LS HFO,

MDO, methanol, and LNG.

Table7 Marine fuels' readiness

Source: M. Svanberg. J. Ellis. (2018). Renewable methanol as a fuel for the shipping industry. Renewable and Sustainable Energy Reviews, 1217-1228.

	HFO	Low-sulfur HFO	Marine diesel	Methanol	LNG
Engine technology	Existing	Existing	Existing	Some existing engines can be converted at similar cost as scrubber installations. Converted engines can be expected to perform at efficiency levels equal to or higher than scrubbers. Future engines built for methanol are expected to be more efficient. Methanol needs a pilot fuel/ignition enhancer.	Dual-fuel LNG engines on market. Retrofit of diesel engines can be performed at two to three times the cost of retrofitting to methanol. Gas-only engines are also available
Heating of fuel	Needed	Needed	May not be needed	Not needed. Cooling may be required	Not needed
Fuel separators	Needed	Needed	May not be needed	Not needed	Not needed
Piping	Standard	Standard	Standard	Double-walled. Purging possible	Vacuum-insulated, double-walled
Safety	Existing rules	Existing rules	Existing rules	Apart from low flashpoint, most properties are the same as diesel. Low-flashpoint fuel, risk-based rules, regulations coming based on LNG regulations. May be simplified in future	Low-flashpoint fuel with many demands due to low temperature and high pressure requirements. Boil-off from tanks has to be handled if not in service
Bunkering	Existing	Existing	Existing	Can use same type of barges as for HFO/MGO. Precautions for fire. System for purging the fuel supply system. Bunkering from mobile terminals on land developed	Special built barges. 20-30 times more expensive than for liquid fuels. Special precautions for bunkering including purging of system after bunkering
Terminals	Existing	Existing	Existing	Terminals can be built at low cost	LNG terminals are few and need large volumes to justify cost. About 10 times more expensive than methanol terminals
Distribution and logistics	Existing	Existing	Existing	Available globally. Transported in tank ships, barges, trucks and rail.	LNG terminals are under construction in Europe, but still relatively few are in operation.
Scrubber	Needed	Not needed	Not needed	Not needed	Not needed

Table8 Marine fuels' readiness (continued)

Source: M. Svanberg. J. Ellis. (2018). Renewable methanol as a fuel for the shipping industry. Renewable and Sustainable Energy Reviews, 1217-1228.

	HFO	Low-sulfur HFO	Marine diesel	Methanol	LNG
SCR/catalyst	Needed	Needed	Needed	Not needed	Not needed
Education of crew				Required	Required
Maintenance				May be longer intervals than for HFO due to clean fuel. No indication of increased wear in studies performed	

3.3 Risks and challenges

3.3.1 Risks

a. Diesel engines on the combustion of non-conventional emissions issues need to be studied in depth, the exhaust contains unburned alcohol, formaldehyde formic acid and other non-conventional emissions, especially formaldehyde emissions can be about 5 times the conventional engine, these substances pose a certain threat to humans and the environment, easy to bring secondary pollution. (Bailera,2017) After methanol is absorbed into the body, it can be rapidly distributed in all tissues of the body, among which, the highest content is in cerebrospinal fluid, blood, bile and urine, and the highest content is in ocular atrial fluid and vitreous fluid, and the lowest is in bone marrow and adipose tissue. Methanol is metabolized in the liver and oxidized to formaldehyde and then to formic acid by the action of alcohol dehydrogenase. The oxidation of this product in the body is slow, only 1/7 of ethanol, excretion is also slow, there is a significant accumulation effect. The unoxidized methanol was excreted through the respiratory tract and kidneys, and some of it was excreted slowly through the gastrointestinal tract. It is speculated that inhalation of methanol in the air with a degree of 39.3-65.5g/m3 for 30 ~ 60 minutes can cause poisoning. Oral administration of 5 ~ 10ml can cause serious poisoning. Blindness can be caused by oral administration of 15ml at a time or by oral administration of 124-164ml within 2 days. It has been reported that a single oral dose of 30ml can cause death. Methanol mainly acts on the nervous system and has obvious anesthetic effect, which can cause brain edema. The anesthetic concentration of methanol is close to that of LC, so it is more dangerous. It has a special selective effect on optic nerve and retina, which can easily cause optic nerve atrophy and lead to blindness in both eyes. Methanol vapor has a strong stimulating effect on respiratory mucosa. The toxicity of methanol is related to the accumulation of its metabolite's formaldehyde and formic acid. (Tao,2008)

b. The problem of corrosion has not yet been solved. The low carbon content of methanol has a strong corrosive effect on metals and a swelling effect on plastics and rubber, thus adversely affecting components such as valves and valve seats, spark plug electrodes, plastic and rubber parts, injection pump parts and high-pressure fuel lines. (Liu,2018) Compatibility problems with methanol and fuel system components increase with methanol content, and methanol fuel has been shown to cause soft components in the fuel system to shrink, harden, expand, or soften. (Paulauskiene,2019)

c. In most fires, burning materials, building materials, engine oil, upholstery, paint, etc. produce smoke and visible flames. However, unlike Marine diesel, methanol can catch fire and burn at room temperature, making it even more challenging: due to its high purity, this fire is completely transparent during the day. And in some cases the only evidence of the existence of a fire is a slight hot fog. Therefore, methanol does require special safety protocols for disposal. (Svanberg,2018)

3.3.2 Challenges

Despite all the advantages, there is still a long way to go to achieve the widespread application of methanol fuel on board ships, overcoming many challenges in terms of technical standards, fuel cost, ship layout and key equipment.

a. Technical standards

Currently, the IGF Code Part A-2 "Methanol/Ethanol as a Marine Fuel" is still under development and it is not known when it will be completed. Although a few classification societies have issued technical standards for methanol-fueled ships, there are still many differences, and most of them are functional requirements, which are not easy to operate.

b. The cost of fuel

Although the price of a single ton of methanol is lower, the price of methanol with the same calorific value needs to be doubled for consideration as the calorific value of

methanol is only about half of HFO. In this way, methanol has no advantage over HFO, and only in certain scenarios does it have an advantage over LNG. (Ammar,2019)

c. Ship arrangement

Similarly, due to the low calorific value of methanol, the volume of methanol fuel tank is nearly twice that of fuel tank, which is about 20% larger than that of LNG fuel tank. For ships of the same size, a larger fuel tank means the loss of cargo tank, thus affecting the ship's operating income. In addition, the current draft IGF rules require methanol bunkers to be protected by isolation tanks, and the distance to the side of the bunkers is higher than that of the methanol cargo tanks in the IBC rules, which is a disadvantage for ship layout. (Shi,2016)

d. Key equipment

Methanol engine is the key equipment for methanol-fueled ships, and several foreign production plants have developed related products, but they are all in the initial stage, and the prices are high because of the small orders and the lack of batch production. In China, the development of methanol-fueled engines for ships has not been seen yet. The State Key Laboratory of Internal Combustion Engine of Tianjin University has developed methanol-diesel dual-fuel combustion technology, but it has only been partially applied on land-based heavy-duty diesel engines, and is not yet available for shipboard application. In short, there are few marine methanol engines available in the market, especially the medium and high-speed four-stroke marine methanol engines. (Qi,2016)

Methanol fuel has become an alternative fuel to the shipping industry because of its clean, environmentally friendly, renewable and accessible characteristics. Scientific research projects and real ship pilots have shown that the safety and environmental protection of methanol as a marine fuel can be fully guaranteed, and the use of methanol fuel is also conducive to absorbing the excess capacity of coal. Although there are still many challenges in terms of fuel cost, usage experience and power

equipment, it is believed that with the increasingly stringent requirements of shipping emission reduction and the continuous progress of technology, methanol will have a bright future in the future marine alternative fuel market. (Gotz,2016)

3.4 Treatment of sulfur and carbon in ship exhaust gas

Exhaust gas reciriration technology (EGR) has been used in the treatment of ship tail gas. By reducing the highest burst pressure in the combustion chamber of diesel engine, the NOX emission rate in ship tail gas has been effectively reduced, which meets the standards of the International Maritime Organization.

But must pass through post-processing of CO2 and SO2 can meet the requirements of the international maritime organization, tail gas treatment in the present stage of research often only for single gas processing, but the single processing technology in practice will inevitably lead to repeated post-processing equipment installed, this not only need larger space, brings to the engine room layout is difficult, also will increase the back pressure of diesel exhaust, It is often difficult in practical application.

Several combined treatment technologies for CO2 and SO2 in ship tail gas are introduced as follows. In combination with EGR technology, the emissions of the three harmful gases can simultaneously meet the standards of the International Maritime Organization, which has a very broad prospect in ship tail gas treatment in the future.

3.4.1 Combined desulfurization and decarbonization technology of ammonia solution

a. The reaction mechanism

Ammonia can react with carbon dioxide to produce ammonium carbonate, and with sulfur dioxide to produce ammonium sulfite. The basic principle of the reaction is shown in Formula (1) - (3):

$NH_3+H_2O+CO_2=NH_4HCO_3$ (1)

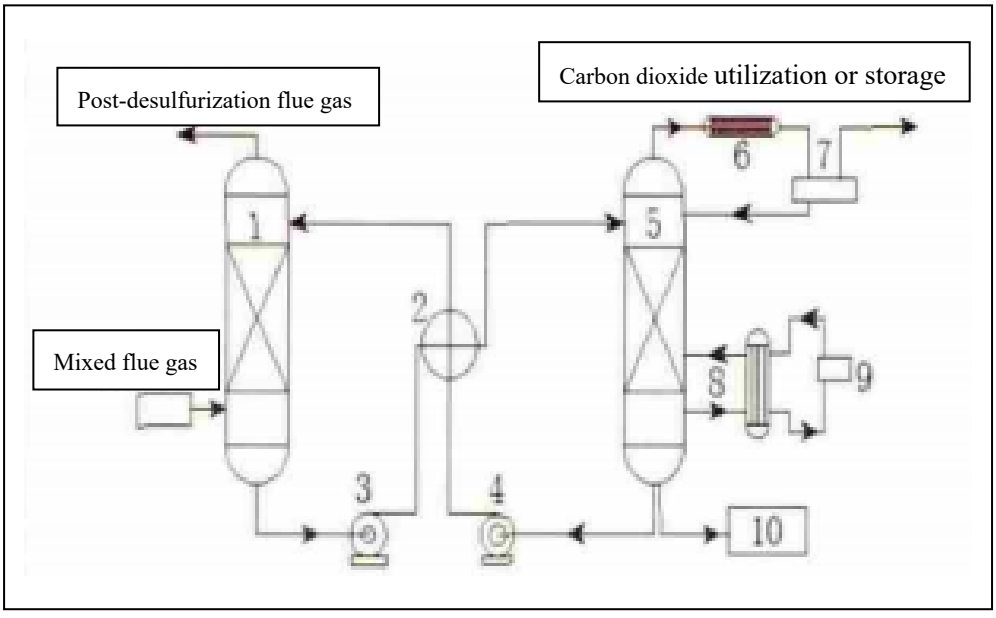
$NH_3+H_2O+SO_2=(NH_4)_2SO_3$ (2)

$(NH_4)_2SO_3+H_2O+SO_2=2NH_4HSO_3$ (3)

According to the reaction mechanism, ammonia solution can absorb two kinds of pollution gases in ship tail gas at the same time, and the efficiency of carbon desulfurization is very high. After the reaction, there is no waste residue and no secondary pollution.

b. The process flow

The process of combined desulfurization and decarbonization with ammonia solution is shown in the figure. CO2 and SO2 in the tail gas of ships are absorbed by ammonia solution in the absorption tower, and the ammonia solution absorbing CO2 and SO2 gas in the analytical tower is heated and will release high-purity CO2 gas again, while SO2 gas reacts with ammonia solution to generate stable salts. The different solubility of these salts can be used for recycling purposes.



1. Absorption tower 2. Heat exchanger 3. Fluid pump 4. lean (solution)pump 5. Analytic tower 6. The condenser 7. Carbon dioxide storage tank 8. Fluid pump heat exchanger 9. Reboiler 10. The crystallization device

Figure16 Process flow of ammonia solution combined desulfurization and decarbonization

According to the above reaction process, it can be seen that ammonia solution combined desulfurization and decarbonization technology can not only meet the requirements of the International Maritime Organization, but also obtain high-purity CO2 gas, and the product potassium sulfate can also be used as fertilizer.

3.4.2 Sodium-alkali solution combined desulfurization and decarbonization technology

a. The reaction mechanism

As a strong alkali, sodium hydroxide solution has a very strong absorption effect on acid gas, but the price of sodium hydroxide solution is relatively expensive, and its first step reaction products (that is, the products of reaction 4 and 6) also have a certain alkaline, can be used as absorbent for the reaction again.

The double reaction of sodium hydroxide absorbing carbon dioxide is shown in reactions (4) and (5):

$2NAOH+CO_2=NaCO_2+H_2O$ (4)

$Na_2CO_3+CO_2+H_2O=2NaHCO_3$ (5)

The double reaction of so2 absorption by sodium hydroxide is shown in reactions (6) and (7):

$2NAOH+SO_2=Na_2SO_2+H_2O$ (6)

$Na_2SO_3+SO_2+H_2O=2NaHSO_3$ (7)

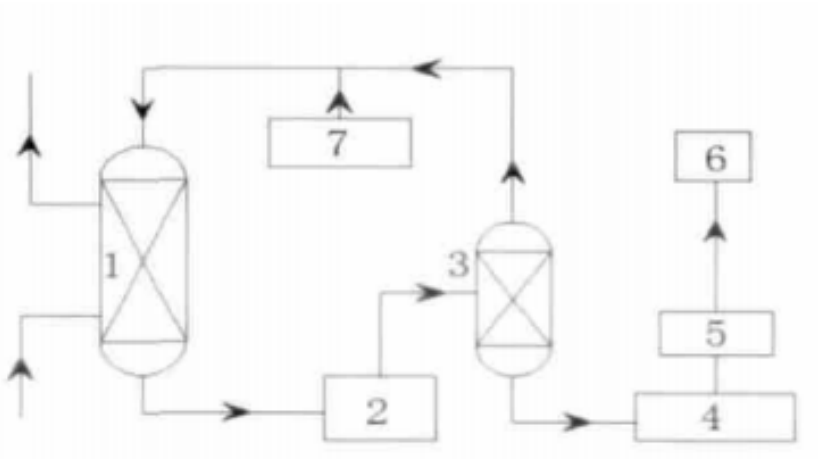
Sodium alkali solution is a mixed solution composed of sodium hydroxide and sodium carbonate and sodium sulfite. Sodium hydroxide and sodium sulfite are weaker than sodium hydroxide in alkalinity and less corrosive to equipment, but they still have very good absorption effect on acid gas. Compared with simple sodium hydroxide, they have very big advantages.

b. The process flow

Sodium alkali solution combined desulfurization decarburization process, as shown in the figure of ship exhaust gas from the bottom of the reaction with sodium alkali solution after entering the reaction tower, reaction after solution for rich liquid containing sodium bicarbonate and sodium bisulfite, then put the rich have low liquid state membrane electrolysis process, the reaction product is back into barren solution of sodium carbonate and sodium sulfite,

The newly formed lean solution is mixed with the sodium hydroxide solution and then re-absorbed into the next step of the reaction, thus forming a cycle and ensuring the efficient use of resources.

The ultrasonic analytical technology and membrane electrolysis technology work together to produce high purity SO2 gas when the rich liquid is transformed into the poor liquid, and obtain certain economic benefits.



1. Absorption tower 2. Fluid pump storage 3. Membrane electrolysis 4. Ultrasonic resolution 5. Sulfur dioxide gas 6. Concentrated sulfuric acid 7. NAOH solution

Figure17 Sodium-alkali solution combined desulfurization and decarbonization process

3.4.3 Combined desulfurization, decarbonization and denitrification technology after urea hydrolysis and pyrolysis

As can be seen from the above, the combined desulfurization and decarbonization effect of ammonia solution is good without secondary pollution. However, ammonia is volatile and not easy to store. Besides, ammonia is a toxic gas, which will cause harm to the body of the crew if it is leaked out. Urea solution is non-toxic, has no irritating smell, is easy to store, and is cheap. Reaction will occur after hydrolysis of urea (8):

NH_2-CO-NH_2(solution)---NH_2-CO-NH_2(Solid state) +H_2O (8)

At this point, the urea in the solution will be rapidly transformed into solid urea and water vapor, and then the solid urea is heated to produce urea pyrolysis reaction. The reaction equation is shown in Formula (9):

NH_2-CO-NH_2(Solid state) ---NH_3(The gas phase) +HNCO (The gas phase) (9)

After pyrolysis reaction, urea will be converted into a mixture of ammonia and isohydric acid. Isohydric acid in normal state is relatively stable, but if catalyst is added for catalysis, isohydric acid will react with water vapor to form ammonia.

After the reaction, the success will be easier to deal with urea solution into excellent effect on absorption of ammonia, ammonia gas can not only fulfill the task of desulphurization decarburization, it also has the very strong reducibility, using EGR technology of diesel engine, there will be a few nitrogen, ammonia reduction can make harm serious carbon oxide into non-toxic nitrogen.

However, the pyrolysis reaction of ammonia requires a lot of heat, so it is necessary to ensure that urea can get enough heat from the exhaust gas after entering the reactor. If the beat temperature of the diesel exhaust gas is low, the pyrolysis reaction will not be perfect. Therefore, how to control the reactor temperature and ensure a higher pyrolysis rate of urea has become the key of urea hydrolysis and pyrolysis technology.

CHAPTER4 RISK ASSESSMENT OF METHANOL FUELED SHIP BASED ON DELPHI METHOD BETWEEN PORT RECEPTION FACILITY

4.1 Principle of risk identification

4.1.1 Comprehensive risks

When performing risk identification, the methanol-fueled ship conversion design project team should systematically develop an identification methodology by considering equipment design, manufacturing, personnel operations, and management controls. (Methanex,2019)

4.1.2 Timeliness principle

In the process of project implementation, we should take the initiative to control the risk as the main means to avoid the passive acceptance of risk as far as possible. At the same time, risk response strategies should be adjusted at any time according to different characteristics of external environment, personnel and operations.

4.1.3 Systemic principles

Ship equipment has a strong systemic nature, with some common links between different equipment, and the failure of a single equipment may lead to a series of problems. Therefore, comprehensive identification should be made and a perfect all-round identification method should be established. (Ammar,2018)

4.1.4 Operational principles

Methanol fuel drive technology for marine equipment involves complex specialties. If the risk identification method is too complicated, it is difficult to identify the risk quickly. Therefore, the risk identification method should have strong operability.

4.2 Pre-preparation for risk identification

4.2.1 Establish a risk management coordination group

The coordination group plays a key role in the implementation of Delphi method. The research and coordination team of this project is composed of personnel with rich management experience and high technical level. (Yilmaz,2012)

4.2.2 Establishment of an expert group

The risk identification expert group for this project consists of 10 experts in the fields of shipbuilding engineering, equipment safety, equipment management, and cargo services. The statistics of risk identification expert group members for methanol-fueled ships are shown in Table 9

Table9 Methanol fuel ship risk identification expert group members' statistical table

Source: C. Dere. (2019). Load optimization of central cooling system pumps of a container ship for the slow steaming conditions to enhance the energy efficiency. Clean, 206-217.

Number	position	Years of work
1	Chairman of Shipbuilding Engineering Society	25
2	Member of Shipbuilding Engineering Institute	22
3	Shipbuilding Professorial Senior Engineer	20
4	Vice President of Safety, Ship Operation Company	21
5	Freight Minister	17
6	Safety and Quality Minister	18

7	Minister, Global Methanol Industry Association	16
8	Equipment Director	19
9	Equipment manufacturers in charge	12
10	Equipment manufacturers in charge	7

4.2.3 Expert interviews

The risk management coordination team initially established the relevant risk factors by interviewing the internal management of the shipping company as well as the project manager of the equipment manufacturing unit and the person in charge of the equipment manufacturer, and compiled a questionnaire around the identified risk factors for weighting and scoring.

4.3 Risk identification process

4.3.1 Delphi Method Process

Based on the principles of Delphi method, three rounds of research were conducted in this study. The first round was an open-ended questionnaire collection; the second round was to judge the importance of risk factors; and the third round was to classify risk factor categories. The Delphi method process is shown in Figure 16

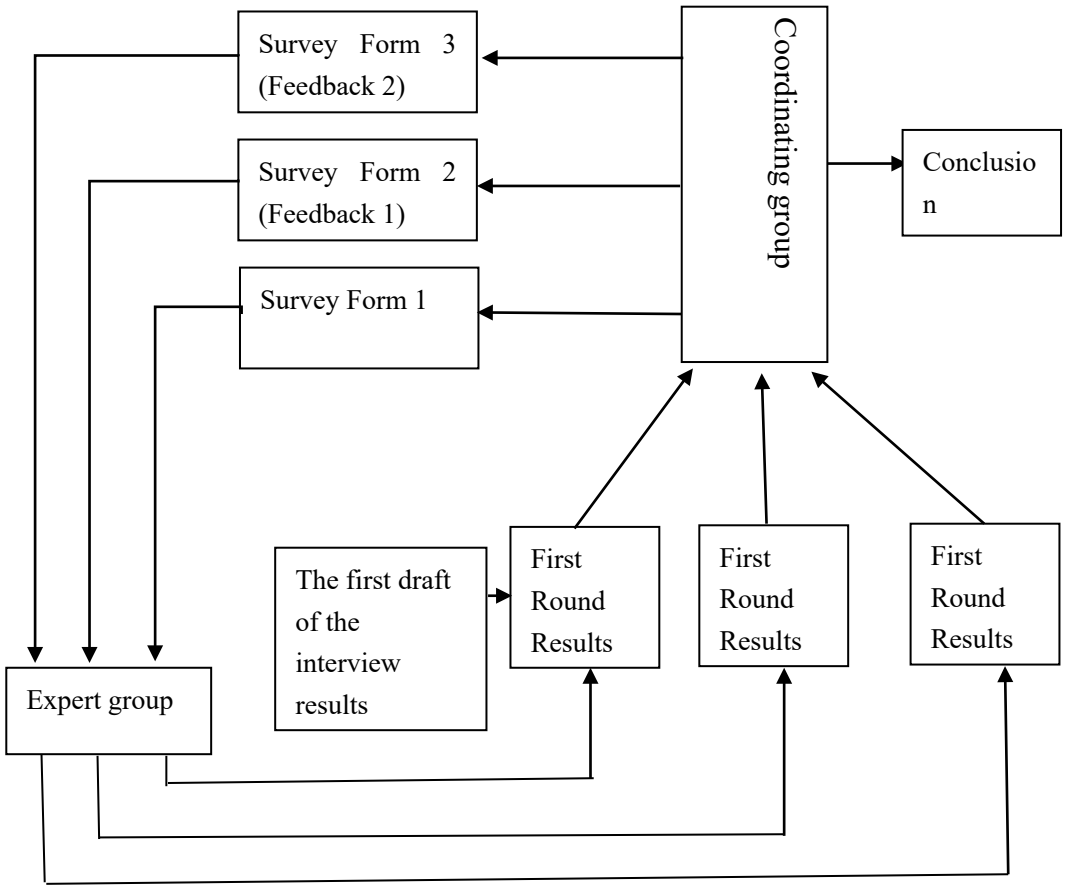


Figure18 Delphi method flow chart

Source: Wang, T. (2021). Application of Delphi Method in Risk Identification of Subway Line Upgrade Construction. PROJECT MANAGEMENT TECHNOLOGY, 4, 112-115.

4.3.2 The first round of open questionnaires

In order to obtain more accurate risk sources, the first round of questionnaires adopted an open questionnaire. The expert questionnaire (first round) is shown in Table 10. This round of survey did not provide the interview content to the experts in advance, and the whole process was anonymous. All the questionnaires collected by the coordination team were true and effective. The feedback results of the expert questionnaire (the first round) are shown in Table 11

Table10 Expert Questionnaire

Source: Wang, T. (2021). Application of Delphi Method in Risk Identification of Subway Line Upgrade Construction. PROJECT MANAGEMENT TECHNOLOGY, 4, 112-115.

Risk Factor Questionnaire for Methanol-Fueled Vessels	
Please fill in the risk factors of methanol-fueled ships and the reasons for them based on your own work experience	
Risk Factors	Causes of risks

Table11 Feedback results of the expert questionnaire (first round)

Source: Wang, T. (2021). Application of Delphi Method in Risk Identification of Subway Line Upgrade Construction. PROJECT MANAGEMENT TECHNOLOGY, 4, 112-115.

Risk Factors	The key content
Personnel risk	The construction personnel are not professional enough for using methanol fuel, they do not work seriously, they are prone to mood swings and physiological defects, the safety maintenance personnel are not careful in their maintenance, the staff of various departments are not cooperative enough, they operate against rules and regulations, and they miss inspections and repairs.

Equipment risk	Equipment failure, manufacturing defects, unqualified raw materials, quality inspection omissions during equipment production, and untimely disposal of defects and hidden dangers.
Environmental risk	Geological disasters, changes in national and local and other related industry policies, significant construction environment interactions, changes in the financial and economic environment, etc.
Management risk	The "double responsibility" is not clear, the dynamic revision of responsibilities is not timely, the phenomenon of subcontracting exists, the supervision coverage is not enough, the lack of supervision system, the failure to establish a database of hidden dangers at all levels, the failure to form a system of hidden danger investigation and management, and the unreasonable content of regulations.
Other categories of risk	Personnel in some positions are vulnerable to health problems due to the working environment

The results of the interviews were combined with the current round of questionnaires to compile 103 risk factors for methanol-fueled ship conversion design projects.

4.3.3 Round 2 Risk Factor Importance Determination

The coordinating team sorted through the risk factors completed by the experts and designed a second round of questionnaires based on this. First, the results of the first round were presented to the experts with explanations, and then the second round was distributed. This round of questionnaires focused on the importance of the personnel category of risk, and the importance of 25 risk factors was determined. The expert questionnaire (Round 2) is shown in Table 12, and the results of the expert questionnaire (Round 2) are shown in Table 13.

Table 12 Expert Questionnaire (Round 2)

Source: Wang, T. (2021). Application of Delphi Method in Risk Identification of Subway Line Upgrade Construction. PROJECT MANAGEMENT TECHNOLOGY, 4, 112-115.

Risk Factor Importance Questionnaire for Methanol Fueled Ship Modification Design Project		
Number	Risk Factors	Importance judgment
1	Weak ideological awareness among designers	A. very important, B. important, C. A little important D. general, E. unimportant
2	The ship's crew was unwilling to cooperate	A. very important, B. important, C. A little important D. general, E. unimportant
3	The ship's staff had no time to cooperate	A. very important, B. important, C. A little important D. general, E. unimportant

4	Dispatcher negligence	A. very important, B. important, C. A little important D. general, E. unimportant
5	Manufacturers debugging personnel excused each other	A. very important, B. important, C. A little important D. general, E. unimportant
6	Construction personnel do not work carefully	A. very important, B. important, C. A little important D. general, E. unimportant
7	Poor sense of cooperation among staff in various departments	A. very important, B. important, C. A little important D. general, E. unimportant
8	Color blindness, color weakness and other physical disabilities	A. very important, B. important, C. A little important D. general, E. unimportant
9	Long hours of fatigue work	A. very important, B. important, C. A little important D. general, E. unimportant
10	Part-time work during break time	A. very important, B. important, C. A little important

		D. general, E. unimportant
11	Drinking and working at work-hour	A. very important, B. important, C. A little important D. general, E. unimportant
12	Taking psychotropic drugs	A. very important, B. important, C. A little important D. general, E. unimportant
13	Working during illness or physiological period	A. very important, B. important, C. A little important D. general, E. unimportant
14	Inadequate self-efficacy	A. very important, B. important, C. A little important D. general, E. unimportant
15	Non-compliant operation	A. very important, B. important, C. A little important D. general, E. unimportant
16	Improper operation	A. very important, B. important, C. A little important D. general, E. unimportant
17	Command instruction error	A. very important, B. important,

		C. A little important D. general, E. unimportant
18	Leak detection and repair	A. very important, B. important, C. A little important D. general, E. unimportant
19	Someone vandalized the equipment	A. very important, B. important, C. A little important D. general, E. unimportant
20	Inadequate inspection by safety maintenance personnel	A. very important, B. important, C. A little important D. general, E. unimportant
21	Staff carrying prohibited items	A. very important, B. important, C. A little important D. general, E. unimportant
22	Over-aged staff	A. very important, B. important, C. A little important D. general, E. unimportant
23	Poor labor discipline	A. very important, B. important, C. A little important D. general, E. unimportant

24	Mood swings easily	A. very important, B. important, C. A little important D. general, E. unimportant
25	Lack of responsibility	A. very important, B. important, C. A little important D. general, E. unimportant
26	Other personnel enter the equipment operation area	A. very important, B. important, C. A little important D. general, E. unimportant
27	Staff mental problems caused by high construction noise	A. very important, B. important, C. A little important D. general, E. unimportant
Other comments		

Table 13 Feedback results of the expert questionnaire (Round 2)

Source: Wang, T. (2021). Application of Delphi Method in Risk Identification of Subway Line Upgrade Construction. PROJECT MANAGEMENT TECHNOLOGY, 4, 112-115.

Risk Factors	Highlights	Key Elements
Personnel risk	The team is young, the technical level is low, Low, mental quality is not	Technical ability, psychological quality

	strong, easy to panic when encountering problems	Mental quality, physical quality
Equipment Risk	Design compatibility needs to be improved, part of the quality of some products is not high, and the installation and maintenance workload is large	Product quality, equipment maintenance Installation issues, design issues
Environmental Health Risks	The construction environment interacts with each other significantly, and some positions are susceptible to health problems caused by the working environment.	Cross work, environmental injury Natural environment, policy changes
Managing Risk	There is a discrepancy between the construction of the system and the actual management, and the problem-solving lacks relevant basis and system support	System construction, double prevention Inadequate supervision, organizational structure

The coordination team collected and collated the results of the experts' judgments on the importance of risks, eliminated 42 risk factors that the experts considered unimportant, and identified the final 61 risk factors.

4.3.4 Round 3 Risk Factor Classification

The results of the 2nd round of survey were compiled and presented to the experts for feedback and explanation. Subsequently, a third round of expert questionnaire was distributed to classify the risk factors for methanol equipment modification. The expert questionnaire (Round 3) is shown in Table 14.

Table 14 Expert Questionnaire (Round 3)

Source: Wang, T. (2021). Application of Delphi Method in Risk Identification of Subway Line Upgrade Construction. PROJECT MANAGEMENT TECHNOLOGY, 4, 112-115.

Hierarchy of risk factors for equipment upgrade construction					
Major Categories		Medium category			
		1	2	3	4
A	Personnel risk	Technical Capabilities	Psychological quality	Quality of thought	Physical Fitness
B	Equipment Risk	Product Quality	Equipment Maintenance	Installation problems	Design issues
C	Environmental Health risks	Crossover Assignment	Environmental Injuries	Natural Environment	Policy Changes
D	Managing Risk	System construction	Double prevention	Inadequate regulation	Organizational Structure
Number		Risk Factors	Classify the category		
			Major Categories		Medium category

1	Inspection personnel thinking Weak ideological awareness	☐A ☐B ☐C ☐D	☐1 ☐2 ☐3 ☐4
2	Dispatcher Negligence neglect of duty	☐A ☐B ☐C ☐D	☐1 ☐2 ☐3 ☐4
3	Construction workers Not serious about work	☐A ☐B ☐C ☐D	☐1 ☐2 ☐3 ☐4
Other comments			

After completing the 3rd round of expert survey, the experts have formed a consensus on the Ningbo railroad equipment upgrade risk factors.

4.4 Risk factor identification results

Through multiple rounds of questionnaire research and feedback, a total of 3 levels, 4 major categories and 61 risk factors were selected. The risk mapping of the equipment upgrade project is shown in Figure 17.

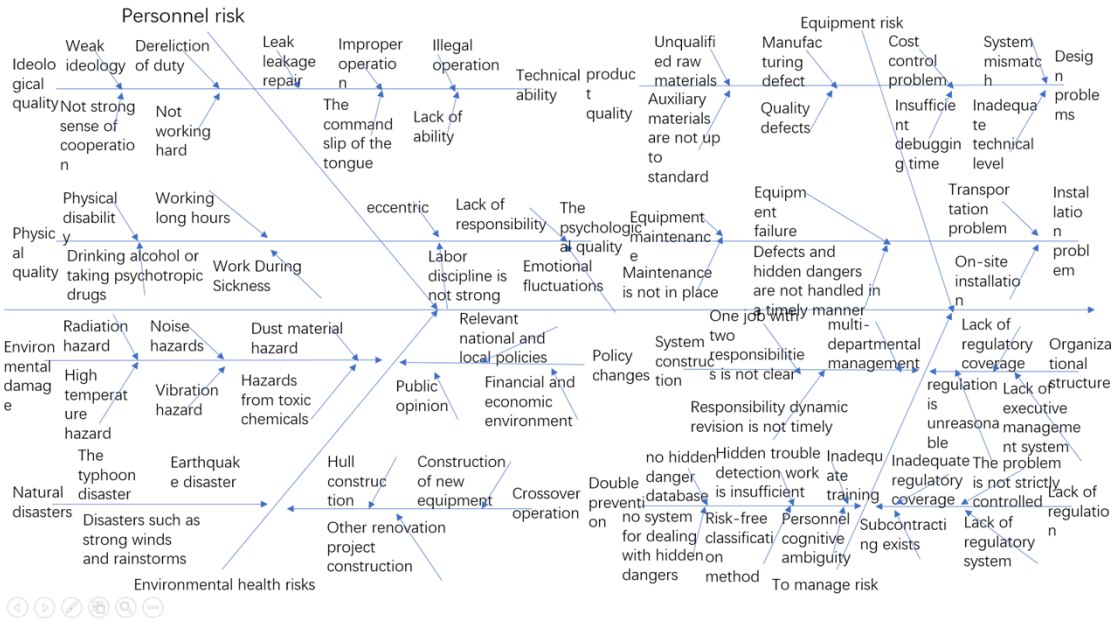


Figure 19 Risk mapping of the equipment upgrade project

Source: Wang, T. (2021). Application of Delphi Method in Risk Identification of Subway Line Upgrade Construction. *PROJECT MANAGEMENT TECHNOLOGY*, 4, 112-115.

Chapter 5 Suggestions on the development of methanol fuel

5.1 Marine methanol diesel engine

Like gasoline and diesel oil, methanol fuel is liquid fuel, that can be extracted from coal. At present, coal is one of the main raw materials of methanol in our country, Methanol can also be derived from natural gas, carbon dioxide and hydrogen, which makes it a kind of important renewable energy. Currently coal reserves still occupy a dominant position in China. Therefore, methanol is expected to become the backbone of liquid alternative fuel in China.

In the field of ship transportation, the limit requirements for internal combustion engine emissions are increasingly stringent. At present, the International Maritime Organization (IMO) and many international environmental protection authorities have issued a large number of regulations to reduce greenhouse gas emissions and reduce sea air pollution

Methanol fuel does not contain Sulphur and therefore meets the International Maritime Organization's Sulphur emission limits. At the same time, methanol fuel contains very few particles, so it also meets the particulate emission requirements of the International Maritime Organization. Methanol also has less NOx emissions than conventional Marine diesel, so it is indeed a clean fuel and has attracted worldwide attention in recent years.

Marine methanol diesel engine is more inclined to adopt the dual-fuel system mentioned above. It only needs a small improvement on the original diesel engine. The technology is relatively mature and the cost is relatively low. In a dual fuel injection system, methanol fuel can be fed to the accumulator through the high-pressure pump and to the methanol injector through the oil supply system, which is controlled by the control oil from the control valve. The fuel injection volume of diesel and methanol is controlled by the fuel management system of methanol diesel engine. A sealing oil system is usually used in a methanol injector. Methanol is fused

with water. When methanol is exposed to the air, it will absorb the water in the air, and methanol containing water is more corrosive, so it is essential to seal the methanol injection system.

Marine dual-fuel diesel-methanol engines borrow from mature diesel technology and require only minor improvements to the diesel engine. This combustion mode has no negative effect on the overall efficiency, power output and responsiveness of the diesel engine. Diesel engine emissions of NOx, Sox and particles are lower than traditional diesel engine, which is very suitable for ships in emission control areas or port berthing use. From the perspective of overall economy, if the methanol-diesel dual-fuel engine can be used in the whole process of shipping, the economy impact will be more significant, which can save more transportation costs for shipping.

5.2 Suggestions for ship design and arrangement

According to IGF CODE, some suggestions are put forward for the design of methanol fueled ships as shown in Table 15-

Table 15 Functional requirements

Source: IGF CODE 2015

Functional requirements
1.The fuel tank(s) shall be located in such a way that the probability for the tank(s) to be damaged following a collision or grounding is reduced to a minimum taking into account the safe operation of the ship and other hazards that may be relevant to the ship;
2.Fuel containment systems, fuel piping and other fuel sources of release shall be so located and arranged that released gas is led to a safe location in the open air;
3. The access or other openings to spaces containing fuel sources of release shall be so arranged that flammable, asphyxiating or toxic gas cannot escape to spaces that are not designed for the presence of such gases
4. Fuel piping shall be protected against mechanical damage;
5. The propulsion and fuel supply system shall be so designed that safety actions after any gas leakage do not lead to an unacceptable loss of power;
6. The probability of a gas explosion in a machinery space with gas or low-flashpoint fuelled machinery shall be minimized.

Table 16 Fuel storage

Source: IGF CODE 2015

Fuel storage
1. Fuel storage tanks and or equipment located on open deck shall be located to ensure sufficient natural ventilation, so as to prevent accumulation of escaped gas.
2. Fuel storage hold spaces shall be segregated from the sea by a double bottom;

Table 17 Regulations for location and protection of fuel piping

Source: IGF CODE 2015

Regulations for location and protection of fuel piping
1.Fuel pipes shall not be located less than 800 mm from the ship's side.
2. Fuel piping shall not be led directly through accommodation spaces, service spaces, electrical equipment rooms or control stations as defined in the SOLAS Convention.
3. Fuel pipes led through ro-ro spaces, special category spaces and on open decks shall be protected against mechanical damage.
4. Gas fuel piping in ESD protected machinery spaces shall be located as far as practicable from the electrical installations and tanks containing flammable liquids.
5. Gas fuel piping in ESD protected machinery spaces shall be protected against mechanical damage.

Table 18 Regulations for fuel preparation room design

Source: IGF CODE 2015

Regulations for fuel preparation room design
1.Fuel preparation rooms shall be located on an open deck, unless those rooms are arranged and fitted in accordance with the regulations of this Code for tank connection spaces.

Table 19 Regulations for bilge systems

Source: IGF CODE 2015

Regulations for bilge systems
1.Bilge systems installed in areas where fuel covered by this Code can be present shall be segregated from the bilge system of spaces where fuel cannot be present.
2. Where fuel is carried in a fuel containment system requiring a secondary barrier, suitable drainage arrangements for dealing with any leakage into the hold or insulation spaces through the adjacent ship structure shall be provided. The bilge system shall not lead to pumps in safe spaces. Means of detecting such leakage shall be provided.
3. The hold or interbarrier spaces of type A independent tanks for liquid gas shall be provided with a drainage system suitable for handling liquid fuel in the event of fuel tank leakage or rupture.

Table 20 Regulations for drip trays

Source: IGF CODE 2015

Regulations for drip trays
1. Drip trays shall be fitted where leakage may occur which can cause damage to the ship structure or where limitation of the area which is effected from a spill is necessary.
2. Drip trays shall be made of suitable material.
3. The drip tray shall be thermally insulated from the ship's structure so that the surrounding hull or deck structures are not exposed to unacceptable cooling, in case of leakage of liquid fuel.
4. Each tray shall be fitted with a drain valve to enable rain water to be drained over the ship's side.
5.Each tray shall have a sufficient capacity to ensure that the maximum amount of spill according to the risk assessment can be handled.

Table 21 Regulations for arrangement of entrances and other openings in enclosed spaces

Source: IGF CODE 2015

Regulations for arrangement of entrances and other openings in enclosed spaces
1. Direct access shall not be permitted from a non-hazardous area to a hazardous area. Where such openings are necessary for operational reasons, an airlock which complies with 5.12 shall be provided.
2. If the fuel preparation room is approved located below deck, the room shall, as far as practicable, have an independent access direct from the open deck. Where a separate access from deck is not practicable, an airlock which complies with 5.12 shall be provided.
3. Unless access to the tank connection space is independent and direct from open deck it shall be arranged as a bolted hatch. The space containing the bolted hatch will be a hazardous space.
4. If the access to an ESD-protected machinery space is from another enclosed space in the ship, the entrances shall be arranged with an airlock which complies with 5.12.
5. For inerted spaces access arrangements shall be such that unintended entry by personnel shall be prevented. If access to such spaces is not from an open deck, sealing arrangements shall ensure that leakages of inert gas to adjacent spaces are prevented.

Table 22 Regulations for airlocks

Source: IGF CODE 2015

Regulations for airlocks
1. An airlock is a space enclosed by gastight bulkheads with two substantially gastight doors spaced at least 1.5 m and not more than 2.5 m apart. Unless subject to the requirements of the International Convention on Load Lines, the door sill shall not be less than 300 mm in height. The doors shall be self-closing without any holding back arrangements.
2. Airlocks shall be mechanically ventilated at an overpressure relative to the adjacent hazardous area or space.
3. The airlock shall be designed in a way that no gas can be released to safe spaces in case of the most critical event in the gas dangerous space separated by the airlock. The events shall be evaluated in the risk analysis according to 4.2.
4. Airlocks shall have a simple geometrical form. They shall provide free and easy passage, and shall have a deck area not less than 1.5 m2. Airlocks shall not be used for other purposes, for instance as store rooms.
5. An audible and visual alarm system to give a warning on both sides of the airlock shall be provided to indicate if more than one door is moved from the closed position.
6. For non-hazardous spaces with access from hazardous spaces below deck where the access is protected by an airlock, upon loss of underpressure in the hazardous space access to the space is to be restricted until the ventilation has been reinstated. Audible and visual alarms shall be given at a manned location to indicate both loss of pressure and opening of the airlock doors when pressure is lost.
7. Essential equipment required for safety shall not be de-energized and shall be of a certified safe type. This may include lighting, fire detection, public address, general alarms systems.

5.3 Domestic methanol fuel industry system and the application prospect of Marine methanol diesel engine

From the first diesel engine at the beginning of the invention, after years of research and development and technology improvement, the efficiency of diesel engine, performance, reliability and emissions control have almost become perfect. And on a global scale, a huge industrial chain, formed a huge market, in the global economy, the dominant position in the field of power plant cannot be changed. Therefore, at present stage and in the foreseeable future, methanol diesel engine still can not completely replace the traditional diesel engine.

As mentioned above, the existing methanol diesel engines are not new models that are completely redesigned according to the combustion characteristics of methanol fuel, but are transformed through the replacement of fuel and fuel system on the basis of the existing diesel engines. Therefore, the advantages of mature diesel engines in technology, production line, spare parts, related systems, supply chain, dealers and maintenance and repair can be fully utilized and played.

Although the supply of methanol fuel in China is still not high, the promotion of this fuel and related power devices can effectively promote the development of relevant industrial systems and sales channels. The economy of methanol fuel is an important basis for the development of methanol ship market. Therefore, for methanol fuel, the challenge is not only to increase the production volume and sales volume of methanol, but also to produce methanol fuel more efficiently and quickly, and to reduce its actual production cost.

From the perspective of national policy, the development of national economy should not be overly dependent on a single type of fuel resource. Once the supply problem occurs, the industrial economic development will be interrupted and large-scale economic losses will be caused. Currently, China plays a leading role in energy consumption, so it is more necessary to adopt the effective strategy of energy diversification. Under the current environment, it is necessary to formulate relevant policies according to the relevant characteristics of energy distribution and geographical environment in China.

Considering the existing coal and oil reserves in China, methanol is bound to become an important part of China's energy diversification, especially in the areas where coal resources are relatively rich and oil resources are relatively poor. Methanol fuel provides a great opportunity for the development of China's energy industry, which can reduce the dependence on petroleum resources to a certain extent, and at the same time is beneficial to environmental protection. At the same time, the opposite equipment such as methanol diesel engine will have a broader space for development in this diversified era.

CONCLUSIONS

To sum up, methanol fuel is one of the most potential alternative fuels for internal combustion engines at present. At present, its industrial development system in China is in the ascended stage with a flourishing momentum.

At present, how the power performance, economic performance and emission performance of the matching methanol diesel engine will change after using methanol fuel, and whether there are unconventional emissions will be one of the key research contents in the future.

Although methanol diesel engine cannot replace the dominant position of traditional diesel engine at present, it can be said that it is a kind of power device full of potential in terms of its emission, the universality of fuel sources, the cost of complete modification and the operation economy, etc., and it will certainly have a good prospect in the field of Marine power plant.

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