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Review on Utilization Methods of LNG Cold Energy

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ABSTRACT

As an important unconventional natural gas resource, in-depth research on coalbed methane (CBM) is of great significance. By synthesizing relevant literature, this paper expounds the concept, genetic types, and accumulation mechanisms of CBM, conducts a detailed analysis of the characteristics and distribution laws of CBM reservoirs, discusses the current status and challenges of CBM exploration and development technologies, summarizes the environmental impacts of CBM development and corresponding response strategies, and looks forward to future research directions. The purpose is to comprehensively sort out the research progress in the field of CBM and provide a reference for subsequent in-depth research and development practices.

KEYWORDS

LNG Cold Energy Utilization; LNG Cold Energy Power Generation; Cold Recovery; Cold Energy Storage.

1. INTRODUCTION

In recent years, with the increasing global demand for energy and the pursuit of sustainable development, the utilization of clean energy has become a key issue. Liquefied Natural Gas (LNG) has emerged as an important clean energy source, and its global trade volume has been on the rise. When LNG is regasified, a large amount of cold energy is released, which, if not properly utilized, will not only cause energy waste but also have a negative impact on the environment. Therefore, the efficient utilization of LNG cold energy has attracted extensive attention from researchers and industry practitioners. This review article aims to comprehensively summarize and analyze the various utilization methods of LNG cold energy, providing a reference for further research and application in this field.

2. LNG COLD ENERGY CHARACTERISTICS

2.1. Cold Energy Quantity

LNG is mainly composed of methane, and its boiling point at normal pressure is about -162°C. When LNG is regasified to room temperature and normal pressure, a significant amount of cold energy is released. The cold energy of LNG can be calculated based on its physical properties and the temperature change during regasification. Generally, the cold energy of 1 kg of LNG is approximately 830 - 860 kJ, which is equivalent to the energy consumption of about 0.23 - 0.24 kWh of electricity. This large amount of cold energy has great potential for utilization.

2.2. Cold Energy Quality

The cold energy of LNG has high quality due to its low temperature. The low - temperature cold energy can be used to drive various thermodynamic processes that require low - temperature heat sources, such as power generation, air separation, and seawater desalination. The high - quality cold energy of LNG can be effectively matched with the energy - consuming processes in different industries, realizing the efficient conversion and utilization of energy.

3. UTILIZATION METHODS OF LNG COLD ENERGY

3.1. Power Generation

3.1.1. Rankine Cycle - based Power Generation

The Rankine cycle is one of the most common methods for LNG cold energy power generation. In this system, a working fluid (such as ammonia, propane, or a mixture of them) is cooled and liquefied by LNG cold energy. Then, the liquefied working fluid is heated and vaporized, and the high - pressure vapor expands in a turbine to drive a generator for power generation. For example, in an organic Rankine cycle (ORC) using propane as the working fluid, the low - temperature heat source of LNG can be well utilized. The efficiency of the Rankine cycle - based power generation system is affected by factors such as the type of working fluid, the temperature difference between the heat source and the cold source, and the system pressure. Some studies have shown that by optimizing the working fluid and system parameters, the power generation efficiency of the Rankine cycle system can reach up to 40% [1].

3.1.2. Stirling Engine - based Power Generation

The Stirling engine is also suitable for using LNG cold energy for power generation. It operates on the principle of a closed - cycle regenerative heat engine. LNG cold energy is used to cool the working gas in the Stirling engine, and then an external heat source (such as waste heat from industrial processes or solar energy) is used to heat the gas, causing it to expand and do work, thereby driving the generator. Stirling engines have the advantages of simple structure, high efficiency at low - temperature differences, and low emissions. Research indicates that the thermal efficiency of Stirling engines used in LNG cold energy power generation can reach about 30% - 35% [2].

3.1.3. Other Power Generation Methods

In addition to the above - mentioned methods, there are also power generation methods such as the Kalina cycle, Brayton cycle, and Allam cycle that can utilize LNG cold energy. The Kalina cycle uses a mixture of ammonia and water as the working fluid, which can adapt to a wider range of temperature differences and has higher efficiency in some cases. The Brayton cycle is mainly used in gas - turbine - based power generation systems, and by integrating LNG cold energy, the performance of the system can be improved. The Allam cycle is a new type of power generation cycle that can realize carbon capture while using LNG cold energy, which has good prospects for future development.

3.2. Air Separation

3.2.1. Principle and Process

The process of using LNG cold energy for air separation is based on the fact that the boiling points of different components in air (such as nitrogen, oxygen, and argon) are different. LNG cold energy is first used to cool and liquefy air. Then, through the process of distillation in a distillation column, different components in the liquefied air are separated according to their boiling points. For example, nitrogen with a lower boiling point is vaporized first, followed by oxygen and argon. This process can significantly reduce the energy consumption required for traditional air separation. In a typical

LNG - cold - energy - based air - separation plant, compared with the conventional air - separation method, the power consumption can be reduced by about 30% - 40% [3].

3.2.2. Industrial Applications

LNG - cold - energy - based air - separation technology has been widely applied in the industrial field. In the steel industry, a large amount of oxygen is needed for steelmaking processes. By using LNG cold energy for air separation, the cost of oxygen production can be effectively reduced, which improves the competitiveness of the steel enterprise. In addition, in the chemical industry, where nitrogen and argon are used as protective gases or raw materials in many chemical reactions, the application of this technology can also bring significant economic benefits.

3.3. Seawater Desalination

3.3.1. Freezing - based Seawater Desalination

One of the ways to use LNG cold energy for seawater desalination is the freezing - based method. In this process, LNG cold energy is used to lower the temperature of seawater to below its freezing point, causing seawater to freeze. When seawater freezes, the salt in it is separated from the ice crystals. After separating the ice from the brine, the ice is melted to obtain fresh water. This method has the advantages of low energy consumption and simple equipment. However, it also has some challenges, such as the need to solve the problem of ice separation and the influence of impurities in seawater on the freezing process. Some research shows that the energy consumption of this freezing - based seawater desalination method using LNG cold energy can be reduced by about 20% - 30% compared with traditional desalination methods [4].

3.3.2. Hybrid Seawater Desalination Systems

In addition to the pure freezing - based method, hybrid seawater desalination systems that combine LNG cold energy with other desalination technologies, such as reverse osmosis or multi - effect distillation, have also been developed. In a hybrid system, LNG cold energy can be used to pre - treat seawater, such as reducing the temperature of seawater to improve the efficiency of reverse osmosis membranes or assisting in the evaporation process in multi - effect distillation. This combination can give full play to the advantages of different desalination technologies and further improve the overall efficiency of seawater desalination.

3.4. Food Refrigeration and Freezing

3.4.1. Cold Storage Applications

LNG cold energy can be directly used for food cold storage. In large - scale cold storage facilities, using LNG cold energy to maintain the low - temperature environment can reduce the reliance on traditional mechanical refrigeration systems, thereby saving electricity. For example, in a fruit and vegetable cold storage, by using LNG cold energy, the temperature can be stably maintained at a suitable level for fruit and vegetable preservation, while reducing the energy consumption of the refrigeration system by about 30% - 40% [5]. This not only reduces operating costs but also helps to better preserve the quality of food.

3.4.2. Food Freezing

In the food - freezing process, LNG cold energy can also play an important role. Quick - freezing of food using LNG cold energy can quickly lower the temperature of food to below the freezing point, forming small ice crystals in the food, which helps to maintain the original texture and flavor of the food. Compared with traditional freezing methods, the food frozen by LNG cold energy has better quality in terms of taste, nutrition, and appearance. This technology has been gradually applied in the production of frozen foods such as seafood, meat, and ready - to - eat meals.

3.5. Other Utilization Methods

3.5.1. Liquefaction of Carbon Dioxide

LNG cold energy can be used to liquefy carbon dioxide. In some industrial processes, such as carbon capture and storage (CCS) projects, a large amount of carbon dioxide needs to be liquefied for transportation and storage. By using LNG cold energy, the temperature of carbon dioxide can be reduced to its liquefaction point, which reduces the energy consumption required for traditional compression - based liquefaction methods. This technology can not only contribute to the development of CCS technology but also help to reduce greenhouse gas emissions.[6]

3.5.2. Cryogenic Grinding

In the field of material processing, LNG cold energy can be used for cryogenic grinding. For some materials that are difficult to grind at normal temperature, such as rubber, plastics, and some metal alloys, by cooling them to a low temperature using LNG cold energy, their brittleness increases, making it easier to grind. Cryogenic grinding using LNG cold energy can improve the grinding efficiency, reduce the wear of grinding equipment, and obtain finer - particle - sized products, which is of great significance for the recycling and processing of waste materials.

4. CHALLENGES AND SOLUTIONS IN LNG COLD ENERGY UTILIZATION

4.1. Technical Challenges

4.1.1. Low - temperature Material Compatibility

In the process of using LNG cold energy, due to the extremely low temperature of LNG, the materials used in the equipment need to have good low - temperature resistance and compatibility. Some common materials may become brittle or have a significant change in their mechanical properties at low temperatures, which may lead to equipment failure. To solve this problem, researchers are constantly developing and screening new materials with excellent low - temperature performance, such as special stainless steels and composite materials. At the same time, improving the manufacturing process of equipment to ensure the quality of materials under low - temperature conditions is also an important measure.

4.1.2. System Integration and Optimization

Integrating LNG cold energy utilization systems with existing industrial processes or energy systems is a complex task. Different systems may have different operating parameters and requirements, and it is necessary to optimize the overall system to ensure the efficient utilization of cold energy.[7] For example, in a combined power generation and air - separation system using LNG cold energy, it is necessary to coordinate the energy supply and demand relationship between the power - generation part and the air - separation part. This requires the use of advanced system - simulation and optimization software to design and adjust the system to achieve the best overall performance.

4.2. Economic Challenges

4.2.1. High Initial Investment

The construction of LNG cold energy utilization projects usually requires a large amount of initial investment, including the purchase of equipment, the construction of pipelines, and the development of related technologies. This high initial investment may deter some investors, especially in the context of uncertain economic returns. To address this issue, the government can provide certain policy support, such as subsidies, tax incentives, and preferential loan policies, to reduce the financial pressure on investors. In addition, improving the economic evaluation model of LNG cold energy utilization projects and accurately predicting the long - term economic benefits can also help attract investment.

4.2.2. Unstable Cold Energy Supply

The supply of LNG cold energy may be affected by factors such as the production and transportation of LNG, resulting in unstable cold energy supply. For example, fluctuations in LNG import volume or problems in the operation of LNG receiving terminals may lead to changes in the amount of available cold energy. To solve this problem, energy storage technologies can be introduced, such as using cold - energy storage materials to store LNG cold energy during periods of high cold - energy supply and release it when the cold - energy supply is insufficient. At the same time, establishing a stable cooperation relationship between LNG suppliers and cold - energy users can also help to a certain extent to ensure the stable supply of cold energy.

4.3. Environmental Challenges

4.3.1. Potential Impact on Marine Ecosystems

If LNG cold energy is not properly utilized and a large amount of cold water is directly discharged into the ocean during the regasification process, it may have an impact on the marine ecosystem. The sudden drop in seawater temperature may affect the growth, reproduction, and distribution of marine organisms. To avoid this, it is necessary to design reasonable cold - energy utilization and discharge schemes. For example, using heat - exchange devices to gradually release cold energy to seawater, reducing the impact of temperature changes on the marine environment. In addition, strengthening environmental monitoring and assessment of LNG cold - energy - utilization projects can also help to timely discover and address potential environmental problems.[8]

4.3.2. Emission Reduction Requirements in the Whole Process

Although LNG is a relatively clean energy source, in the process of LNG cold - energy utilization, there are still some emissions, such as greenhouse gas emissions from power - generation systems using LNG cold energy. To meet the increasingly stringent emission - reduction requirements, it is necessary to continuously improve the energy - conversion efficiency of LNG cold - energy - utilization systems and adopt clean - energy - based auxiliary energy sources. For example, in power - generation systems, combining with renewable energy sources such as solar energy and wind energy can reduce the overall carbon footprint.

5. FUTURE DEVELOPMENT TRENDS

5.1. Multi - energy Complementary Utilization

In the future, the development of LNG cold energy utilization will tend to be multi - energy complementary. Combining LNG cold energy with other energy sources, such as solar energy, wind energy, and waste heat from industrial processes, can achieve a more comprehensive and efficient utilization of energy. For example, in a power - generation system, using LNG cold energy in combination with solar - thermal power generation can make up for the instability of solar energy and improve the overall power - generation efficiency. In addition, in industrial parks, integrating LNG cold energy with waste heat from various industrial processes can form a multi - energy - complementary integrated energy - supply system, which is conducive to the sustainable development of the park.

5.2. Smart Energy Management and Control

With the development of information technology, smart energy management and control systems will play an important role in LNG cold energy utilization. Through the use of sensors, the Internet of Things, and big - data analysis technology, real - time monitoring and intelligent control of LNG cold - energy - utilization systems can be realized. For example, according to the real - time demand for cold energy and electricity in different industries, the operation parameters of the system can be automatically adjusted to achieve the optimal allocation of energy. This not only improves the energy - utilization efficiency but also reduces the labor cost and operation risk of the system.

5.3. Expansion of Application Fields

The application fields of LNG cold energy will continue to expand in the future. In addition to the existing applications in power generation, air separation, seawater desalination, and food refrigeration, LNG cold energy may be applied in emerging fields such as the production of high - purity chemicals, the treatment of special waste, and the energy supply of data centers. For example, in data - center cooling, LNG cold energy can be used to replace traditional mechanical refrigeration systems, which can not only save energy but also improve the reliability of data - center operation.

6. CONCLUSION

The utilization of LNG cold energy has broad prospects and significant economic, environmental, and social benefits. Through various utilization methods such as power generation, air separation, seawater desalination, and food refrigeration, LNG cold energy can be effectively converted and used, reducing energy consumption and environmental pollution. However, there are still some challenges in the process of LNG cold energy utilization, including technical, economic, and environmental aspects. By addressing these challenges through continuous technological innovation, policy support, and improved management, the future development of LNG cold energy utilization will show a trend of multi - energy complementarity, smart management, and expanded application fields. This will contribute to the sustainable development of the global energy industry and the realization of carbon - neutral goals.

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