Research on High Efficient Utilization of LNG Cold Energy

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Abstract. Liquefied natural gas (LNG) contains a large amount of cold energy.The development of cascade utilization of LNG cold energy has large economic benefits, and it is beneficial to reduce the cost of LNG. This paper designed a process and simulated the utilization system of LNG cold energy based on the software Aspen plusin order to utilize the cold energy reasonable. The simulation results show that the cascade utilization system is rationalwhich unites the process of cryogenic comminution of waste rubber, production of liquid CO_2 and dryice, and cold storage. The cascade utilization of LNG cold energy increases the utilization efficiency of LNG cold energy greatly, and it can also save energy.

Introduction

After the process of dehydration, desulfurization and cryogenic technology, the natural gas becomes the low temperature liquid mixture which named LNG. And LNG is colorless, odorless, non-toxic and transparent. Generallythe storage temperature of LNG is -162℃.The storage density is usually 430~470kg/m^3,which is one over six hundred and twenty-five of the standard state [1]. LNG needs to be gasified to normal temperature when it is used, and there will be plenty of cold exergy(about 830~860KJ/KG)releasein the gasification process[2].This part of cold energy is usually consumed by sea water or air in the gasification station, which cause huge energy waste and environmental pollution of the gasification station[3].

A detailed analysis of the cold energy is helpful to improve the cold recovery rate of LNG. The cold energy refers to the energy obtainedfrom the process that LNG is changing to the external balancing state.And it can be analyzedby using exerge method. Thereare temperature difference and pressure difference between LNG and outside world[4]. The exergy has two parts: the cold exergy which is caused by the heat unbalance at a certain pressure p, and the pressure exergy which is caused by the pressure unbalance at ambient temperature, that is:

$$e_x(T,p) = e_{x,th} + e_{x,p} \tag{1}$$

$$e_{x,th} = e_x(T,p) - e_x(T_0,p) \tag{2}$$

$$e_{x,p} = e_x(T_0,p) - e_x(T_0,p_0) \tag{3}$$

The main composition of LNG is methane, and LNGneeds to be purified before the liquidation. LNG has a large amount of cold exergy. It can be known that the large LNG gasification station is abundant in cold energy through the analysis.

Currently, the utilization of LNG cold energy is mainly in two forms: direct utilization and indirect utilization. Direct utilization includes cold energy power generation, cryogenic air separation, refrigerated warehouse, manufacturing liquid CO_2 and dryice, automobile refrigeration, automotive air conditioning and desalination of sea water. Indirect utilization includes cryogenic comminution and the treatment of water and pollutants.

Cascade utilization of LNG cold energy

There are lots of use patterns of LNG cold energy. But no matter which pattern is used alone, too much loss of cold energy causes the inefficient use of LNG cold energy. The utilization efficiency of cold energy is improved greatly when several utilization patterns are used jointly in order to use the different levels of cold energy. And this can be called the cascade utilization of LNG cold energy[5]. Li et al. [6] pointed out that the key factor of improving the utilization efficiency of LNG cold energy was the rational planning of LNG cold exergy.The integrated cascade utilization of LNG cold energy is an effective way to improve the cold energy utilization efficiency.Therefore, the cascade utilization is the development trend of LNG cold energy in the future. Wu et al. [7] analyzed the cascaded utilization of LNG cold energy, and found that use LNG third-level cold energy in the cold storage was a more reasonable way of the cascade utilization which has an obvious economic efficiency.

Waste rubber cryogenic comminution refers to that cool the rubber to make the temperature below the glass transition temperature firstly, and then crushe it into fine rubber particle[8]. The glass transition temperature of common rubber is above -105℃. Using LNG first-level cold energyto cool the waste rubber to -115℃, and then crushes it to make fine rubber particle. By this time, the temperature of LNG increases from -162℃ to -100℃, and the cryogenic exergy is been fully utilized. The temperature of dryice is about -78.5℃, and the second-level cold energy could be used to produce dryice. Then the temperature of LNG increases to -70℃, and it can be applied to the refrigerated warehouses.The temperature of refrigerated warehouse ranges from -45℃ to 0℃. The schematic of cascade utilization of LNG cold energy is shown in figure 1.

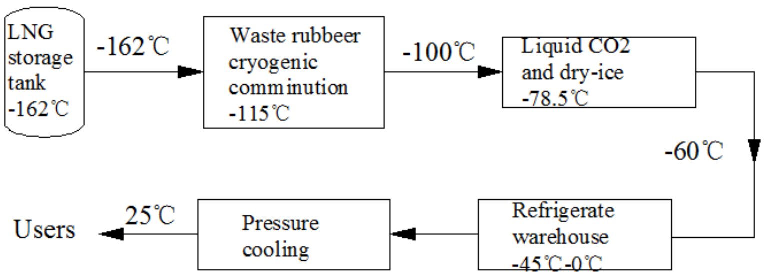

Fig .1. Flowsheet of cascade utilization of LNG cold energy

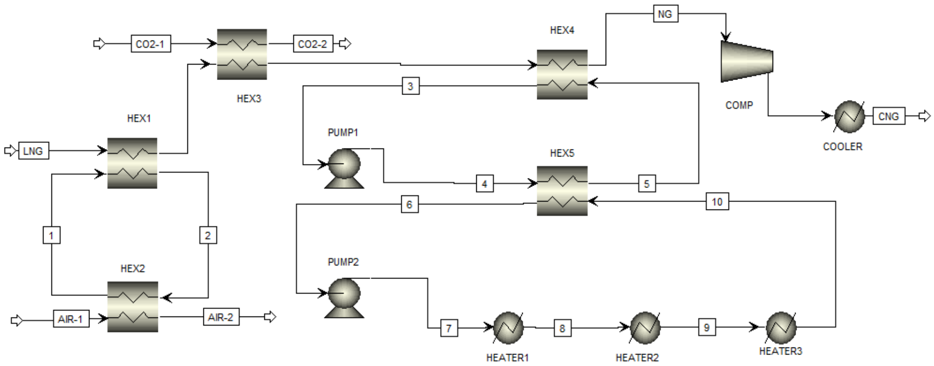

Fig .2. Flowsheet of cascade utilization of LNG cold energy

The process simulation software of aspen plus has been used to simulate this process.The flowsheet of cascade utilization of LNG cold energy is shown in figure 2. LNG transfers cooling quantity to refrigerant R22 in the heat exchanger HEX1, then refrigerant R22 transfers cooling quantity to the air in heat exchanger HEX2.The effect of refrigerant is to transfer the cold energy from LNG to the air. The cooled air is used in the waste rubber cryogenic comminution, and this is the first-level utilization of LNG cold energy. At this time, the temperature of LNG is still very low. The second-level of cold energy is used to produce liquid CO_2 and dryice, and this is the second-level utilization of LNG cold energy.Then the cooling quantity is transferred in heat exchanger HEX3. After that, LNG transfers cooling quantity to the ethylene glycol aqueous solution in the heat exchanger HEX4(the concentration of the ethylene glycol aqueous solution is 60%)[7].Then the natural gas is supplied to users after being compressed.At lastethylene glycol aqueous solution transfers cold quantity to ammonia in the heat exchanger HEX5 in order to producing cryogenic liquid ammonia, and then the cryogenic liquid ammonia is sent to freezing room, refrigerated room and cold storage room respectively to reduce their temperatures to -35℃, -18℃ and 0℃. The utilization rate of LNG cold energy is set as 60% because of the energy loss in the process.

Cascade utilization process of LNG cold energy

The application of LNG cold energy in cryogenic comminution of waste rubber. There are more and more waste tires producted every yearwith the development of the automobile industry. How to recycle the waste rubber effectively and prevent the damage to the environment are worldwide problems,and it is also a new project of China's recycling of renewable resources[9,10].

There are three main types of recycling waste rubber: thermal energy utilizing, reclaimed rubber and rubber powder. In order to avoid the secondary pollution,developed countries generally recycle the waste rubber by crushing it into fine rubber particle. Fine rubber particle has a broad application prospect. Generally the rubber powder is manufactured by three methods: the superfine grinding method (RAPRA), normal temperature crushing and cryogenic comminution.

When producing fine rubber particle, waste rubber was broken into a certain size of particle through coursecrusher firstly.Then the fibers and steel wirewere separated from the rubber particle. After sieving and being dried,the rubber particle was freezed in order to crushe the rubber particle into fine rubber particle in the low temperature pulverizer.The schematic of using LNG first-level cold energy in cryogenic comminution is shown in figure 3.

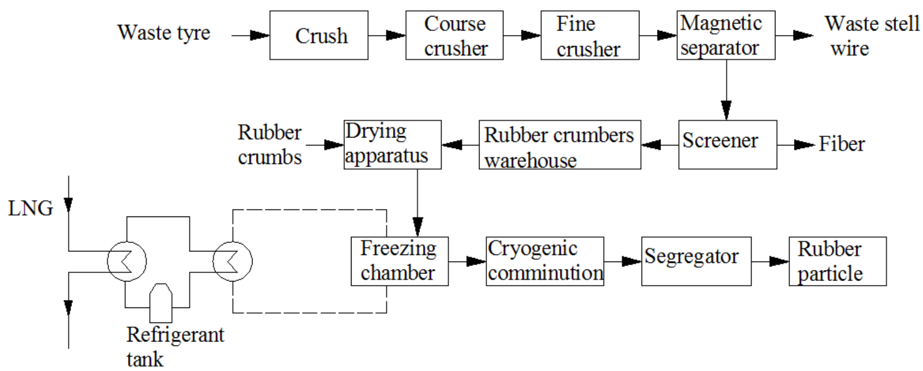

Fig .3. Schematic of using LNG first-level cold energy in cryogenic comminution

It can be supposed thatLNG is made up of methane entirely, and a gasification station supplies about 100 thousand m^3 LNG every day. The gasification rate is about 4166.7 m^3 per hour (about 2.8 t/h), and the utilization rate is set as 60%. The temperature of LNG increases to -100℃ after transferring the cold quantity to the air, and the temperature of air decreases to -115℃.The air flow rate is 7.1 t/h, and the cold energy which the air carried is 29MW. According to the present cryogenic commination in the world, 423.5MJ cold energy is consumed when crushing one ton waste rubber.The cold energy provided bythis gasification station can produce 197 thousand tons of fine rubber particle one yearwhen the annual operating time of the gasification station is 6000h.

The application of LNG cold energy to make liquid CO_2 and dry ice. This is the traditional way of generating liquid CO_2 and dryice: improve the pressure of CO_2, then cool and liquefies it. The low temperature of cooling and liquefying CO_2 is easily obtained from LNG.Therefore, the operating pressure of the liquefying device could be reduced. Compared to the traditional process, the load of the device reduces greatly, likewise the power consumption.

The temperature of dryice is -78.5℃[11], which matches the temperature of the second-level of LNG cold energy. The cold quantity is transferred from LNG to refrigerant Freon, then to CO_2.By this time, CO_2 is liquefied into liquid. The liquefied CO_2canbe sent into the machine to make dryice. It is easily to obtain the low temperature to make dryice from LNG, and the load is reduced greatly while the power consumption is reduced to 30%~40%. The dry ice can be used in industrial cleaning, aviation food preservation and artificial rainfall, etc. The schematic of using LNG second-level cold energy in making liquid CO_2 and dry ice is shown in figure 4.

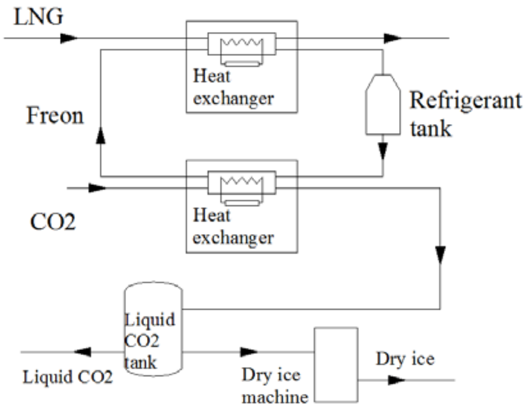

Fig .4. Schematic of using LNG second-level cold energy in making liquid CO_2 and dry ice

The application of LNG cold energy to the refrigerated warehouses. It is a very good way to use the LNG cold energy in refrigerated warehouses. The traditional refrigerated warehouses generally use two-stage vapor compression refrigeration device. The device consumes a lot of power, and the technology of the device is complex. The third-level cold energy of LNG can be used as the cold source of the refrigerated warehouses, that is, the third-level cold energy of LNG transfers cold energy to the refrigerant.After being cooled, the refrigerant will be sent into the pipes of the cold storage refrigeration system, and release cold energy through the cooling coil.The schematic of using LNG third-level cold energy in refrigerated warehouse is shown in figure 5.

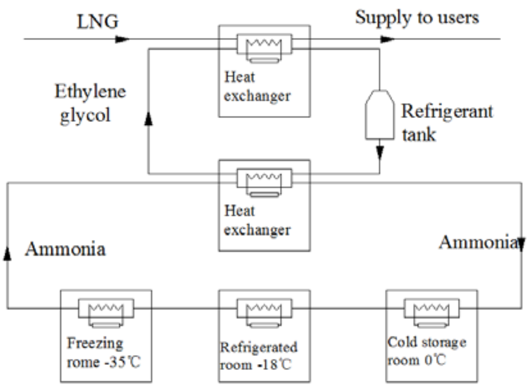

Fig .5. Schematic of refrigerated warehouse using LNG third-level cold energy

This system uses non phase-change cold storage mode. Ethylene glycol aqueousis chosen as cold storage medium. After being cooled,ethylene glycol aqueous will transfer the cold quantity to the secondary refrigerant. The cold energy of refrigerated warehouse is provided by the recycling of the secondaryrefrigerant. The secondary refrigerant should have high utilization efficiency and low operation cost, and it can guarantee the safe and stable operation of the system. Ammonia is chosen as the secondary refrigerantin the circulationbecause of its good thermodynamic properties, physicochemical propertiesand environmental friendly features[7].

After the calculation,it can be known that the total cold consumption of three refrigerated warehouses(freezing room, refrigerated room and cold storage room, the length, width and height are 100 meters, 60meters and 5meters respectively) is 15.3 MJ/h, and the third-level cold energy of LNG can provide 132.8 MJ/h.It is sufficient to provide the cold energy of 8 refrigerated warehouses.

The daily power consumption of each refrigerated warehouse is about 1000 degrees. That is to say, the power consumption of eight refrigerated warehouses is 240 thousand degrees. The average price of industrial electricity is one yuan per degree, and it can save 240 thousand yuan one month if this eight refrigerated warehouses use LNG cold energy completely.

Conclusions

（1）LNG contains a large amount of cold energy. Therecycleof the cold energy in the gasification process has considerable economic, environmental and social benefits, and ithas great significance to ease the growing tension of energy supply.

（2）Cascade utilization of LNG cold energy can make better use of LNG cold exergy, it can also reduce cold loss and improve the utilization efficiency.

（3）It can be supposed that a gasification station supplies about 100 thousand m^3 LNG every day, the first-level cold energy provided by thisgasification station can produce 197 thousand tons of fine rubber particle every year; and it can reduce energy consumption significantly when the second-level cold energy is used to produce liquid CO_2 and dryice; the third-level cold energy provided by this gasification can save 240 thousand degrees ofelectrical power every year when itis used in the refrigerated warehouses.

Acknowledgements

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