American Journal of Physics and Applications
2018; 6(6): 162-168
http://www.sciencepublishinggroup.com/j/ajpa
doi: 10.11648/j.ajpa.20180606.14
ISSN: 2330-4286 (Print); ISSN: 2330-4308 (Online)

Study on Application of Waste Heat Recovery in Ammonia Refrigerator

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To cite this article:
Tong Xie. Study on Application of Waste Heat Recovery in Ammonia Refrigerator. *American Journal of Physics and Applications*. Vol. 6, No. 6, 2018, pp. 162-168. doi: 10.11648/j.ajpa.20180606.14

Received: November 5, 2018; **Accepted**: December 8, 2018; **Published**: January 15, 2018

Abstract: Large ammonia chillers are widely used in the food production industry. Ammonia refrigerators generate a large amount of exhaust heat energy while cooling work. Traditionally, these exhaust heat energy is used as waste heat and discharged to the atmosphere through a condenser cooling fan. In this paper, the exhaust heat energy of ammonia refrigerator is analyzed. The exhaust energy is divided into two parts: sensible heat and latent heat. The sensible heat energy recovery and latent heat energy recovery and utilization schemes are studied respectively, and a aquatic product processing in Qingdao area is selected. The enterprise carried out the actual chiller heat recovery and recovery test. After three years of actual operation, the results show that the ammonia chiller exhaust heat energy and sensible heat recovery can obtain 40-70 degrees hot water for employee bathing and Production of sanitary cleaning, etc., and the cost of heat recovery is almost zero; the latent heat is partially recovered, the cooling water of the ammonia refrigerator is used as the water source, and the heat source is used to extract heat energy from the cooling water. The unit operates in winter, is not affected by the ambient temperature, and the heating efficiency is not Will decay, the energy efficiency ratio is maintained at more than 5 times.

Keywords: Exhaust Heat, Waste Heat Recovery, Sensible Heat, Latent Heat, Water Source Heat Pump

1. Introduction

Ammonia refrigerators are widely used in large food processing enterprises and are important equipment for food processing.

Ammonia refrigerators generate a large amount of exhaust heat energy while cooling. Traditionally, these heats have been treated as waste heat and passed through a condenser or cooling tower to the atmosphere [1]. At the same time, in the food processing process, there are many places that need warm water, such as carcass cleaning, sanitation in the processing of meat, thawing of raw materials in the processing of aquatic products, melting of frost in freezing equipment, etc. Hot water. Especially in winter, the tap water temperature is relatively low, the ability to hydrolyze and melt the frost is very weak, and the winter uses the self-hydrolyzed frozen raw materials, or the freezing equipment melts the frost, which not only consumes a large amount of water, but also has a slow speed, which affects the production efficiency.

Food processing enterprises have stricter hygiene requirements. They usually require employees to bathe no less than 2 times a week. Due to the large number of processing workers, the amount of hot water required for bathing is large. If fuel or gas is used to provide bathing hot water, the annual fuel gas the fee is not a small amount.

In the winter, another big energy consumption for food companies is the heating of workshops and staff quarters. In order to reduce the production cost of food enterprises and rationally use energy, based on the analysis of the working principle of ammonia refrigeration machine, we studied the feasibility of recycling the exhaust heat energy of ammonia refrigeration machine by food enterprises, and conducted experimental research and achieved good results. expected result.

2. Thermal Energy Composition Analysis

The exhaust heat energy of the ammonia chiller is manifested on the one hand, and the ammonia chiller using the piston compressor has a higher exhaust temperature. Take the Qingdao area as an example, the summer can reach about 110°C, and the spring and autumn can reach about 100°C. Up to 90°C, the temperature value is much higher than the temperature of production and processing, bath water. On the other hand, the theoretical calculation of the ammonia refrigeration cycle shows that the exhaust heat of the ammonia refrigerator is not less than twice the power consumption of the refrigerator even under normal food freezing conditions. When the ammonia refrigerator is in normal operation, the high temperature ammonia gas discharged is overheated. After the end of the exhaust, ammonia gas enters the condenser and releases a large amount of heat. Careful analysis of the process by which ammonia releases heat can be divided into two parts [2]:

2.1. Sensible Heat

The sensible heat energy is the heat energy released by the ammonia gas being cooled from a superheated state to a saturated state. This part of the heat is characterized by a higher temperature, but not much heat (the sensible heat is only about 15% of the total heat of the heat).

2.2. Latent Heat

The latent heat is the heat released by ammonia gas cooled from saturated gas to saturated liquid. this part of the heat energy is characterized by low temperature, but the heat is huge (the latent heat is about 85% of the total heat)[3].

It should be noted that when the ammonia refrigeration system adopts the screw compressor, the fuel injection cooling during the operation of the screw compressor will greatly reduce the sensible heat in the exhaust heat energy (the sensible heat is only about 7% of the total heat output). The reduced sensible heat energy is eventually transferred to the cooling water along with the latent heat energy in the condenser.

When designing waste heat recovery, the required heat cannot be greater than the total heat rejection of the ammonia refrigerator. In order to ensure demand, It is recommended that the required heat should account for up to 60% of the total calorific capacity of the chiller, and the heat that the waste heat recovery system cannot absorb is still discharged by the condenser of the refrigeration system.

3. Thermal Recovery Program

3.1. Sensible Heat

Although the proportion of sensible heat energy in the total heat output is not much, but the temperature is relatively high, the sensible heat energy can be continuously absorbed by the circulating water of the water storage tank, and a certain amount of water can be heated to 45 degrees or more to meet the employee's bathing requirements.

To recover sensible heat, it is necessary to install a heat exchange device on the exhaust manifold of the ammonia refrigerator [4]. This device is similar to a plate heat exchanger, but it is different.

The sensible heat recovery system is shown in Figure 1.

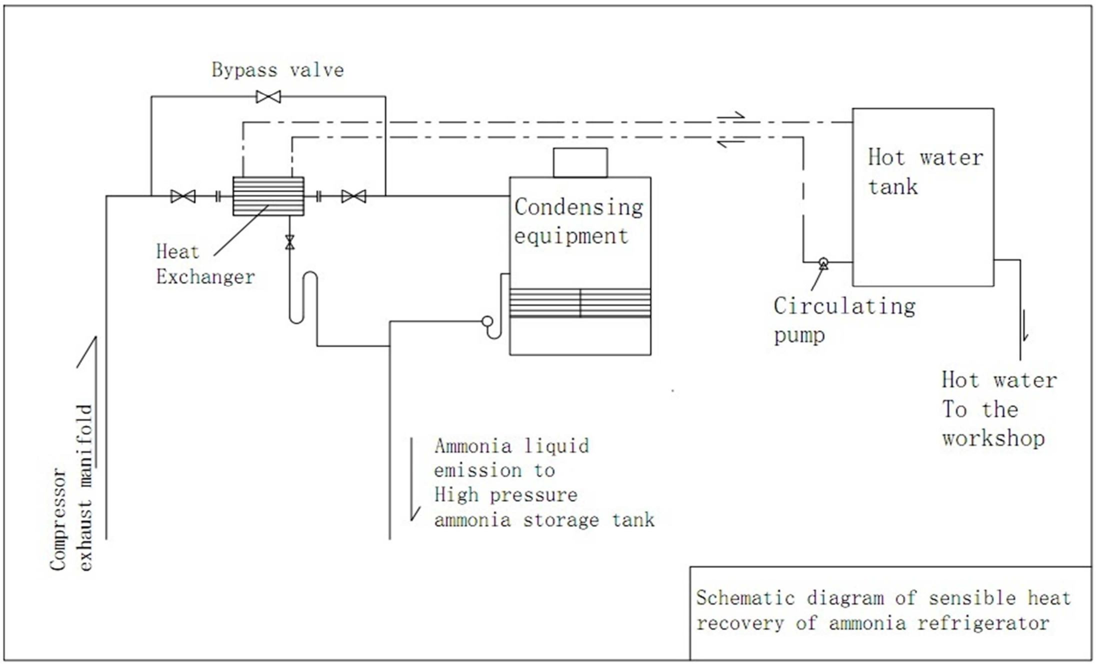

Figure 1. *Schematic diagram of sensible heat recovery scheme.*

In Figure 1, the bypass valve is a backup valve. When the heat recovery is normal, the bypass valve is closed, and the superheated ammonia gas in the compressor exhaust manifold passes through the sensible heat recovery heat exchanger and enters the condenser. When the sensible heat recovery heat exchanger needs to be repaired, the valves at both ends of the sensible heat recovery heat exchanger are turned off, and the bypass valve is opened at the same time to maintain the normal operation of the refrigeration system.

In order to reduce the natural loss of sensible heat energy, the exhaust pipe and equipment between the compressor exhaust manifold and the sensible heat recovery heat exchanger can be insulated. The sensible heat recovery heat exchanger is made of stainless steel, all welded structure, with high pressure resistance, high heat exchange efficiency and small equipment volume. The sensible heat recovery heat exchange equipment is produced by a professional enterprise, and the pressure test is carried out according to the standard of ammonia refrigeration equipment.

It should be pointed out that when the water temperature of the water tank is lower than the condensation temperature, the ammonia gas in the sensible heat exchanger will condense and produce condensed ammonia liquid [5]. Therefore, the sensible heat exchanger must have an ammonia liquid discharge pipe. When the water temperature of the water tank is higher than the condensation temperature, the condensed ammonia liquid is no longer generated in the sensible heat exchanger. In order to prevent the high pressure here and affect the discharge of the condenser, a U-shaped liquid column must be established to compensate the pressure difference [6]. The heat energy of sensible heat recovery continues to increase the temperature of the water in the water storage tank through the operation of the circulating water pump of the water storage tank for application.

3.2. Latent Heat Energy

The total amount of latent heat energy accounts for about 85% of the total heat output, and the volume is huge. When the ammonia refrigerator is in normal operation, the latent heat energy is mainly released in the circulating cooling water of the condenser [7].

The scheme is designed to recover these latent heat energy from the cooling water of the ammonia condenser. In the ammonia condenser, the temperature of the cooling water that absorbs the latent heat energy is only slightly higher than the ambient temperature in summer; it is about 10-15 degrees higher than the ambient temperature in winter. Taking Qingdao, China as an example, the outdoor temperature in winter is about 0 degrees, and the temperature of the cooling water in the ammonia condenser is about 15 degrees. In the cold winter, the steady 15 degrees of water is a rare heat resource.

Combine the ammonia refrigeration system with the water source heat pump technology to use the cooling water in the ammonia refrigeration condenser as the water source for the water source heat pump system to extract heat from the cooling water of the ammonia condenser for winter heating [8].

In the ammonia refrigeration condenser, the temperature of the cooling water is about 15 degrees, which is very suitable for the operation of the water source heat pump. After the water source heat pump absorbs heat, the water temperature is reduced from 15 degrees to about 10 degrees, and then returned to the ammonia condenser to participate in the ammonia condensation cycle. Since part of the heat is absorbed by the water source heat pump, the condenser cooling fan can reduce operation;

The cooling fan of the ammonia condenser can be automatically controlled by the temperature of the cooling water of the ammonia condenser.

The schematic diagram of the latent heat recovery system of ammonia refrigeration exhaust is shown in Figure 2.

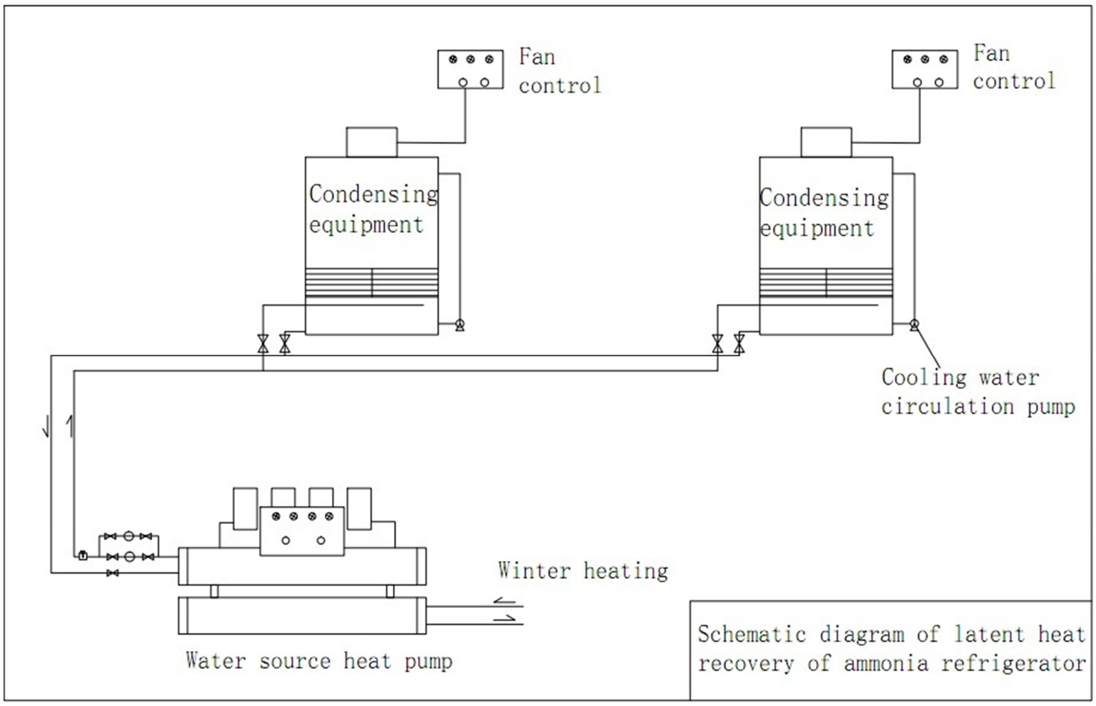

Figure 2. *Schematic diagram of latent heat recovery scheme.*

By selecting an appropriate water source heat pump, the temperature of the heating and hot water in winter can be maintained at 45-55 degrees to meet the heating requirements of the workshop or dormitory.

4. Sensible Heat Recovery Test and Results

4.1. Overview of the Test Company

The test company is located in Qingdao, China (36°10'15.8"N 120°27'35.6"E). The company has 520 processing personnel and 5 piston ammonia chillers with a total cooling capacity of 800kw. In winter, the number of ammonia refrigeration compressors will be less than other seasons. Operate 2 sets of winter chillers, 320ww of winter cooling capacity, 640kw of ammonia chiller, sensible heat of 96kw, and latent heat 540kw.

Before the regenerative heat recovery of the chiller, the company used steam boilers to produce steam, steamed water in 10 tons of stainless steel water tanks, provided bathing water for employees, and bathed four times a week. Ten thousand yuan (Note: Yuan - China's currency unit).

4.2. Sensible Heat Recovery Implementation

We analyzed the production process of the company, and needed hot water during the production process, including employee bathing, freezing equipment melting frost, sanitary cleaning of production equipment, and thawing of raw materials. Among these links, the water temperature is higher in the employee's bathing requirements, and the water in other links can be mixed with hot water and tap water to meet different temperature needs.

According to these circumstances, The scheme proposes the sensible heat energy of the exhaust ammonia refrigerator, instead of the oil-fired boiler, for the heating of water in a 10-ton water tank.

After the actual renovation project is completed, the main equipment is shown in Figure 3.

Figure 3. *The main equipment for sensible heat recovery in the test - heat exchanger.*

On the ammonia exhaust manifold, a sensible heat recovery heat exchanger device is installed. When the refrigerator operates, the superheated ammonia gas discharged from the compressor exchanges heat with the circulating water in the heat exchanger, and the superheated steam is cooled, and the water is cooled. Get heated.

In order to reduce the consumption of sensible heat in the winter low temperature, It is recommended to keep the pipeline between the compressor and the heat exchanger insulated.

4.3. Sensible Heat Recovery Test Results

The waste heat recovery and renovation project was completed on September 30, 2015. It has been in normal operation for more than three years, which satisfies the production needs of the company.

The three-year operation proves that after 10 hours of continuous operation, 10 tons of tap water can be raised to about 45 degrees in winter, and 8 tons can be raised to 70 degrees in summer, which satisfies the needs of enterprises.

After the transformation was completed and put into use, the company has stopped the boiler operation, saving costs:

Direct cost: Previously, the boiler heated 10 tons of water to 70 degrees, it needed to run for 1 hour, and consumed 85 liters of fuel diesel. According to the oil price of 6 yuan / liter, the cost was 510 yuan, while the waste heat recovery of the refrigerator was 10 hours, only 15 degrees (kwh). The cost is about 15 yuan, which is 2.3% of the fuel cost of the boiler, and the direct cost is reduced by 97.7%.

Management expenses: Due to the requirements of environmental protection and safe production, the government is becoming more and more strict on boiler control, which directly leads to an increase in boiler management costs. It requires not only professional furnace personnel and water quality inspection personnel to carry out certification work, but also environmental protection, safety and equipment. The comprehensive management cost such as regular inspection is high, and the refrigeration waste heat recovery equipment works automatically, no personnel management is required, and only one labor cost is saved.

The total investment of the project transformation is 127,000 yuan, and the investment recovery period is about 6 months.

After the modification of the sensible heat recovery technology of the ammonia chiller, no change is required for the operation of the chiller. No matter whether the heat recovery equipment is operated or not, it will not adversely affect the refrigeration system, and the waste heat recovery equipment will absorb part of the refrigeration when it is running. The machine exhausts heat, reduces the heat load of the refrigeration condenser, and has a positive impact on the energy saving of the refrigeration system.

The heat energy recovered by the sensible heat recovery heat exchanger accounts for about 50% of the sensible heat energy of the ammonia refrigerator. In the actual sensible heat recovery process, as the temperature of the circulating water for absorbing heat energy increases, the sensible heat of ammonia gas lower than the water temperature cannot be absorbed and utilized, so it is impossible to completely recover all the heat energy. The sensible heat energy that is not absorbed is eventually released into the cooling water in the ammonia condenser.

5. Latent Heat Recovery Test and Results

After completing the sensible heat recovery of the exhaust gas, the company saw obvious energy-saving effects after running for two months. On this basis, consult us whether it is possible to recover the heat energy of the refrigerator and use it for heating in winter workshops and dormitory [9].

The production workshop of the enterprise requires 800 square meters of processing area for heating in winter and 1,260 square meters of heating area for staff quarters, totaling 2060 square meters of total heating area, and the calculated heating load is 206kw, which is smaller than the aforementioned winter refrigerator exhaust. The latent heat is 510kw, so we think it is feasible.

After the actual latent heat recovery and reconstruction project is completed, the photo of the host water source heat pump is shown in Figure 4.

Figure 4. *The main equipment for latent heat recovery in the test--water source heat pump.*

The water source heat pump using Freon (R-22) is selected in the scheme. The heating conditions of the heat pump are:

Hot water inlet temperature 40 degrees, hot water outlet temperature 45 degrees, water source inlet temperature 15 degrees, water source outlet temperature 7 degrees, input power 50.2kw, heat production 220.8kw

The water source heat pump extracts heat from the 15 degree cooling water in the ammonia condenser. When the water temperature is lowered to 7 degrees, it returns to the ammonia condenser. The temperature of the heating water supplied by the water source heat pump reaches 45 degrees, which satisfies the heating needs of the workshop and dormitory [10].

Heat pump heating is a clean and energy-saving method that has been widely promoted in recent years. According to the source of thermal energy, heat pumps are commonly divided into two categories: air source heat pumps and water source heat pumps. The heat energy produced by the air source heat pump is mainly derived from ambient air. Because air is ubiquitous, air sources are widely used, but in winter, the heating efficiency of air source heat pumps will drop significantly. The heat energy produced by the water source heat pump is mainly derived from surface water or groundwater. The heat efficiency of the water source heat pump is higher than that of the air source heat pump, but due to the current water resources, the application of the water source heat pump is not much.

In Qingdao, the average temperature in winter is about 0 degrees. When cold air comes, the temperature will be close to minus 10 degrees. If air source heat pump is used for heating, the heat pump operating efficiency will decrease in winter due to low temperature. Especially when cold air comes, the heat capacity of the air source heat pump unit can only reach about 60%, and the auxiliary electric heating function has to be activated.

In this aquaculture factory, the water source of the water source heat pump is used because of the clever use of the condensate of the refrigerator. The temperature of the source water is stable and controllable. The heat pump has high operating efficiency in winter and is almost unaffected by the cold air of the environment.

This latent heat recovery project was completed in December 2015 and has been running for three years in the winter. The energy-saving effect company is very satisfied. In this latent heat recovery project, latent heat recovery heat energy accounts for only about 40% of the total latent heat of the refrigerator. The actual operation proves that after the operation of the latent heat recovery equipment, the cooling fan of the ammonia condenser has a significantly reduced running time, which saves the cost of operating the fan.

6. Discussion

In order to recover as much heat as possible, the sensible heat recovery in the scheme uses a plate heat exchanger. The plate heat exchanger has higher heat exchange efficiency and corrosion resistance than the conventional heat exchanger, but in the process of use, attention should be paid to water. The hardness and timely removal of scale.

In the latent heat recovery scheme, the energy efficiency ratio (cop) of the water source heat pump is always maintained at a high level due to the provision of a stable and controllable water temperature, which is not susceptible to environmental influences. However, during use, attention should be paid to the cooling water salt concentration of the refrigeration condenser to prevent the salt concentration from being too high due to evaporation and concentration, resulting in scaling and corrosion of the water source heat pump. It is recommended to clean at least once a month to completely drain the condenser's cooling water, rinse and remove impurities from the cooling water tank, and then reheat the new water quality, which is good for the operation of the equipment.

7. Conclusion

After three years of operation test, the sensible heat recovery and latent heat recovery of the ammonia refrigerator have achieved good results.

The sensible heat recovery heat energy will change with the seasons, according to the annual average of 50kw / h, 20 hours a day, 300 days a year, the total heat recovery of sensible heat reaches 300,000 kWh per year.

The latent heat recovery is operated at 206kw/h for 20 hours per day, and the annual heating period is 120 days. The total heat recovery from latent heat recovery reaches 494,400 kWh per year.

The waste heat recovery system does not have any adverse effect on the operation of the ammonia refrigeration system, and the beneficial effect is to reduce the load on the condenser of the refrigeration system. In food industry enterprises, the total heat required can be calculated according to production demand and heating demand. When the total heat demand is less than the total heat output of the refrigerator, the exhaust heat energy of the refrigerator can be recovered to meet the production needs.

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Biography

Tong Xie (1965-), male, 1985 Shandong Business School (Jinan, China) food refrigeration major, 1989 Tianjin University of Commerce (Tianjin, China) refrigeration and air conditioning engineering major, university degree. He has worked in refrigeration and air conditioning and food freezing for more than 30 years. He is currently a director of Qingdao Refrigeration Society and a research and development engineer of Qingdao Chengheya Refrigeration and Air Conditioning Co., Ltd. The main research direction: food freezing technology, refrigeration and air conditioning energy-saving technology.