Analysis of processes that take place in absorber of absorption chiller

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ABSTRACT

Methods of using absorption chillers are presented based on the example of a mine air-conditioning system. This paper presents the application of the possibility of using thermal energy as a waste product that results from the combustion of gas (methane; CH_4) in gas engines and the process of its processing into the production of a cooling medium. The principle of the operation of an absorption chiller is described – the processes in the absorber, the physicochemical changes in the system, and the method of producing chilled water. The actual application of cascade-connected refrigeration devices is presented in order to achieve a final product with specific parameters.

Keywords: free cooling, thermodynamic cycles, cold production, compressors

1. Introduction

As a related system in the analyzed mine, the energy and cooling system consists of several technological lines that were built in stages. The installations were created in such a way that it was possible to increase the cooling capacity in the case of increased demand. The first two technological lines included a gas engine with an electric power of 3.2 MW_{el} and a thermal power of 3.7 MW_t, two absorption chillers, and a compressor chiller with a cooling capacity of 2.5 MW_{ch}. The total cooling capacity that the system could generate is 5 MW_{ch}. At individual stages of the installation expansion, a third gas engine was launched with electric and thermal power of 3.9 MW_{el} and 4.3 MW_t, respectively. The cooling system that is shown in Figure 1 was built on the basis of heat recovery from a gas engine – a heat-recovery system from exhaust gases, and a heat-recovery system from the engine body.

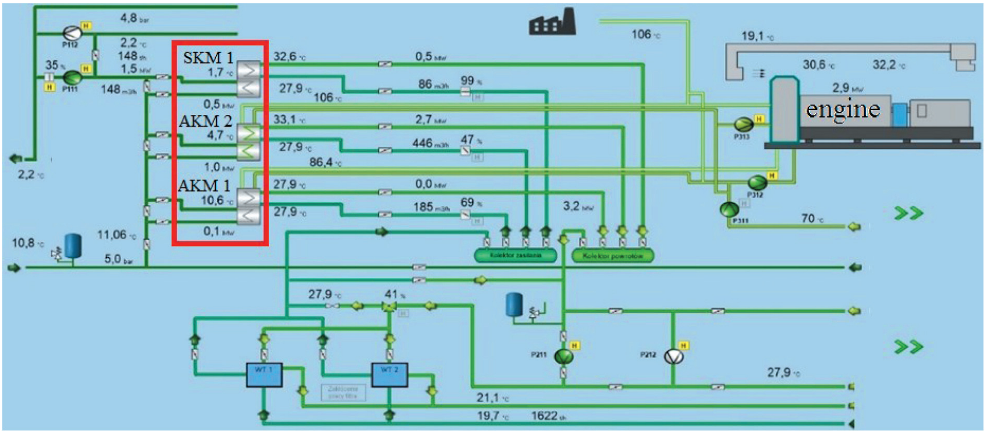

Fig. 1. Cooling system based on heat from gas engine

The heat exchange between the recovery systems is based on water heat exchangers (as shown in Figure 2). Heated water from the waste heat of a gas engine with a temperature of up to 130°C is used as an energy source in absorption chillers to produce cold water.

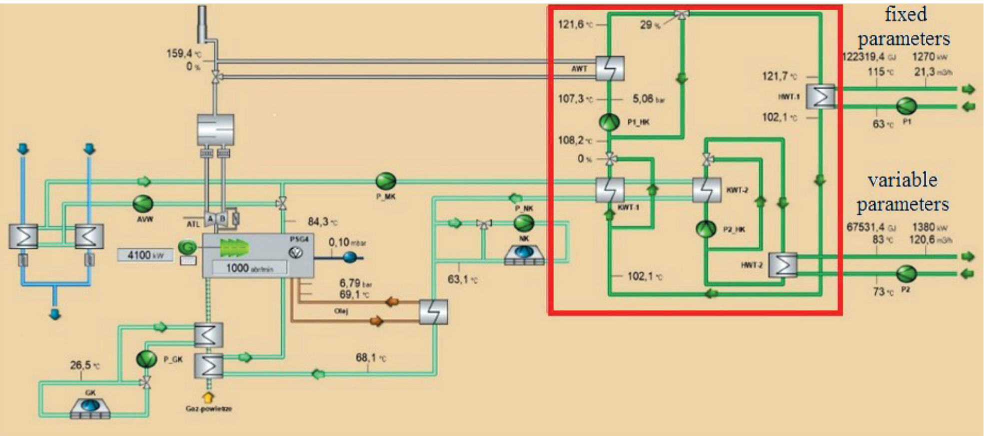

Fig. 2. Heat-recovery system from exhaust gas system and engine body: media distribution through heat exchangers in marked area

2. Cooling system

The general concept of the applied solution is to generate electricity in generators that are powered by gas piston engines using depleted methane from methane drainage in the mine, heat recovery from the engine body, and the exhaust gases of these engines; the transmission of cold with water at a temperature of approx. 1.5–2.0°C is produced in absorption refrigerators that are powered by the heat from gas engines and compressor refrigerators that are powered by electricity that is generated by generators. The chilled water that is sent down the mine after reducing the static pressure is directed to air coolers. The idea of the full association of the system provides for the priority of water cooling for the needs of the central mine air conditioning; therefore, the system is directly connected to the power and heating networks. In the absence of electricity generation or no heat being recovered from gas engines, the absorption chillers can be supplied from the district heating network, and the compressor chillers can be supplied from the power grid. However, with the proper operation of the system, it produces surplus electricity and heat (which are sold to power and heating networks).

The water-cooling system has three stages (as shown in Figure 1). Each segment uses different devices with different cooling powers. The first element of the system is the AKM1 refrigerator, followed by the AKM2, and then the SKM compressor refrigerator in the final stage. The use of such a combination of devices ensures the stable operation of the system and its flexibility depending on the temperature of the water in the circuit. The water temperature at the outlet from the underground part of the mine is about 18°C. It flows through the first chamber (AKM1) with a capacity of 600 kW, where its temperature is reduced to 14.5°C. The cooler is used to fuel hot water that is obtained from the waste heat of the heat and power plant processes. In the next stage, the cooled water goes to the second refrigerator (AKM2) with a capacity of 1730 kW, where it is cooled to a temperature of 4.5°C. The last stage through which the cooled medium flows is the compressor cooler (SKM), which ultimately cools the water to a temperature of 1.5°C. The refrigerators that are used in the refrigerator system are bromolite devices ($LiBr + H_2O$) in which the absorber is a lithium bromide solution, while the refrigerant is composed of water (which reaches a temperature of 3°C as a result of the physicochemical processes that take place in the refrigerator.

A compressor cooler is an ammonia machine in which the working medium is ammonia and the absorber is water. Due to the harmfulness of ammonia, these devices operate in a closed system in separate chambers under the supervision of an ammonia-detection system with the use of emergency ventilation.

3. Operational problems – crystallization

Crystallization may occur in all absorption chillers that use lithium bromide and water as its solution and refrigerant. This is due to the fact that certain concentration levels of the liquid solution in certain areas of the system can only be obtained above the normal ambient temperature. The solution in a single-stage absorption unit generator typically contains 64.3% lithium bromide (by weight). LiBr solutions start to crystallize at 43.3°C; this crystallization occurs when the temperature of the LiBr solution becomes too low or the concentration is too high (then, the LiBr solution thickens). The LiBr solution then cannot absorb any more water and starts to solidify (crystallize). Crystallization takes place in the heat exchanger; this phenomenon can also occur in the generator. In addition, crystallization can occur in pipes that are not properly insulated and are located in rooms where the temperature can affect the solution that flows through the pipes. Crystallization can be prevented by keeping the solution temperature high and the optimum concentration percentage below 64%. Since the temperature of the solution in the generator is usually high enough to avoid crystallization, it is important to keep the temperature high. Before turning off the refrigeration unit, the solution must be sufficiently diluted in all areas of the system. This action helps prevent crystallization during downtimes. Keep in mind that, after a while, the temperature of the solution will become equal to the ambient temperature. To avoid crystallization, a dilution cycle must be performed on this type of refrigeration equipment. Many chillers utilize a self-dilution system during a shutdown sequence to prevent crystallization during shutdowns. After carrying out the dilution cycle in an absorption chiller, the concentration of the solution will be less than 45% lithium bromide (by weight). Although the crystallization line (see graph) does not extend this far, it can be seen that a solution that is at a concentration of 45% will not crystallize at normal ambient temperatures.

The most common cause of crystallization is power failure. If the power supply to the full load chiller is disconnected for a sufficiently long time, the concentrated solution on the high-pressure side of the unit will cool down (Laskowski, Smyk 2020). As a dilution cycle is not possible, the concentration of the solution in some areas of the assembly will still be high. If the temperature of the concentrated solution drops sufficiently, it will reach the crystallization point. The time that is required for crystallization is influenced by the room temperature, the quality of the insulation, and the concentration of the solution (Moran et al. 2014).

4. Summary

Common engineering practices list several steps that should be followed in order to successfully decrystallize the lithium bromide solution of an absorption chiller. The final sequence and durations of the individual activities depend on the place and degree of the crystallization. The main activity is to force the refrigerant from the evaporator of the device to the absorber in order to reduce the concentration of the diluted solution that is pumped into the generator. This operation is also called refrigerant regeneration or purification, as it removes the small but harmful content of lithium bromide in the refrigerant (thus contributing to an increase in the cooling capacity of the unit). This procedure is also one of the simplest methods of decrystallization, as it only consists of the manual or automatic opening of an appropriate drain valve for a period that is necessary for pumping the entire amount of refrigerant (while the refrigerant pump is running at the same time). A significant reduction in the concentration of the working solution of a device as a result of the complete regeneration of the refrigerant in the absence of crystallization may cause the refrigerator to heat the cold water instead of cooling it for a period of several minutes after its completion. This phenomenon occurs most often in systems with low cold water inlet temperatures, where the condensation temperature of the refrigerant in the evaporator is higher than the cold water inlet temperature. The next stage after the pumping of the refrigerant is completed should be to start the lithium bromide pump in order to force the appropriate amount of it into the generator. In the next step, the feed medium (hot water) is opened in order to heat the lithium bromide to the appropriate temperature. These activities are performed with the cold water flow on and the cooling water flow stopped. When the required solution temperature in the generator is reached, the hot water supply is stopped, and the circulation of lithium bromide is stopped; this causes the hot solution to return from the generator to the absorber. After several times of starting, heating, and stopping the circulation of the solution, it is possible to heat the entire volume of the device in order to decrystallize it. The procedure that is described above is commonly used to remove the crystallization that is formed in the most likely place; i.e., inside the regenerative exchanger of the solution on its concentrated (concentrated) side. Failure to apply the above procedure means that the crystallization occurs over a wider area – also in the pipelines and pumps of the concentrated working solution that returns from the generator to the absorber of the device. In the case of crystallization inside a solution pump, an effective method of removing it is to dismantle its impeller and rinse its interior with hot water. In the case of the crystallization of the lithium bromide solution in its pipelines, it is necessary to heat them to the appropriate temperature by using an external heating medium.

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