Enhancing the Utilization of Gas Engine Module Exhaust Heat by Two-stage Chillers for Combined Electricity, Heat and Refrigeration

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Abstract – **The efficiency of utilization of cogeneration gas engine module exhaust heat into the cold by the absorption Li-Br chiller was analized. The presence of significant heat losses caused by contradictory conditions of joint performance of absorption Li-Br chiller and cogenerative gas engine module on the temperature of return heat fluid (heating water) at the outlet of absorption Li-Br chiller and its temperature at the inlet of cooling system of cogenerative gas engine was revealed. The two-stage chillers with absorption Li-Br chiller as a high-temperature stage and adsorption chiller or refrigerant ejector chiller as a low-temperature stage of heat utilization (according to the temperature of heating water) was considered. Using of an adsorption chiller for the transformation of heat of return heating water after the absorption Li-Br chiler was proposed.**

The possibility of applying a refrigerant ejector chiller to transform a low potential heat of return heating water after the absorption Li-Br chiller is considered. A two-stage transformation of heat by refrigerant ejector and absorption chillers was proposed.

Keywords- Trigeneration; gas engine; adsorption chiller; absorption Li-Br chiller; ejector chiller; heat transformation

I. Introduction

The installations of combined electricity, heat and cooling supply are becoming widespread use following to worldwide trend of decentralization of energy supply. Gas engines that operate on natural gas and alternative gaseous fuels (biogas, etc.) are increasingly used in such integrated power installations [1-3]. Leading manufacturers produce combustion engines as cogeneration modules with standard heat exchangers to produce hot water through the use of exhaust gas heat, charged air or gas-air mixture, of engine jacket cooling water and lubricating oil. The exhaust heat of gas engines is usually transformed into the cold by absorption lithium-bromide (Li-Br) chiller, and the cold is used for technological needs and air conditioning [3, 4].

Although the cogeneration modules are easy to be integrated into the heat and cold supply systems, the analysis of the energy efficiency of such trigeneration systems shows the presence of significant heat losses during conversion of cogeneration gas engine module exhaust heat into the cold by the absorption lithium-bromide (Li-Br) chiller caused by a mismatch in the hot water temperature conditions of the absorption Li-Br chiller effective operation and cogeneration gas engine module performance with using the return heat water as a coolant.

So, a thermal state of gas engine is ensured by maintaining the temperature of return (cooled) hot water at its inlet not higher than 70 °C. At the same time, the temperature of hot water is reduced in absorption Li-Br chiller by no more than 10…15 °C, that is, down to 75...80 °C if its temperature at the exit of gas engine (at the inlet of absorption Li-Br chiller) is 90 °C. Because of contradictory requirements for effective operation of the gas engine and the absorption Li-Br chiller on the temperature of return hot water it is cooled in the emergency cooling tower of dry type after Li-Br chiller to keep its temperature at the inlet of gas engine at a safe level of 70 °C. But this leads to heat losses of about 30% and drop in the overall efficiency (electrical and thermal) of cogeneration gas engine module as a result [4, 5].

II. Research Results

The solution of the problem of increasing the efficiency of the transformation of gas engine exhaust heat into the cold was considered for the trigeneration plant of integrated electric, heat and cooling supply of the "Sandora"–"PepsiCo Ukraine" plant in Nikolaev, Ukraine [4, 5]. The trigeneration plant includes 2 cogeneration gas engines JMS 420 GS-N.LC GE Jenbacher (electric power of one engine is 1400 kW, thermal power is 1500 kW), in which the heat of the exhaust gases, of the charge air-gas mixture, of the engine jacket cooling water and lubricating oil is used for heating water. The heat of hot water is transformed by the AR-D500L2 Century absorption Li-Br chiller into a cold (2000 kW refrigeration capacity), which is spent for technological needs and for the operation of central air conditioners that provide ambient air cooling in the engine room, from which it is sucked into the engine turbocharger (Fig. 1).

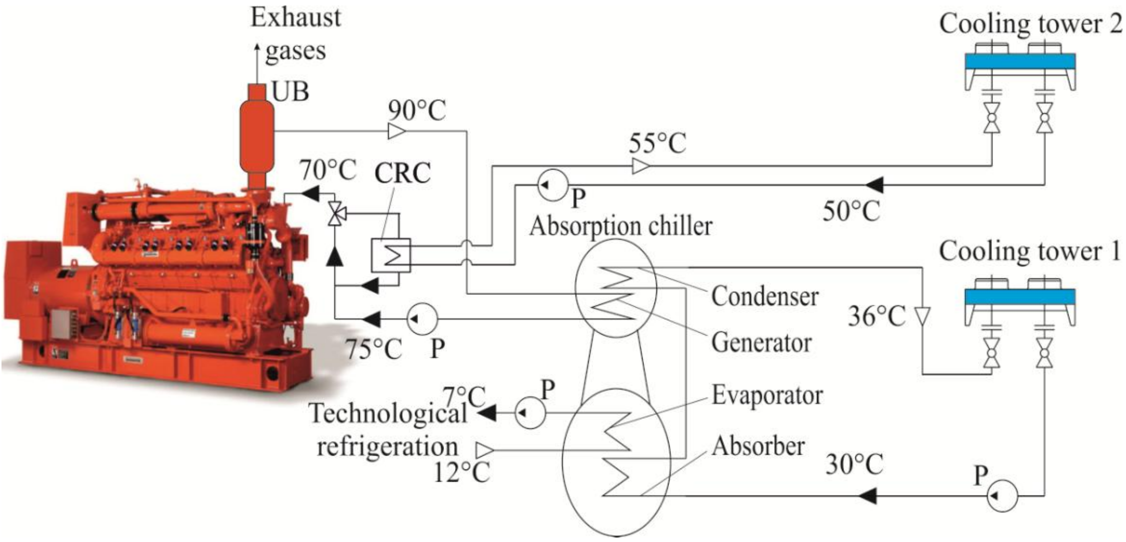

Figure 1. Scheme of a typical system for transformation of waste heat of the gas engine cogeneration module JMS 420 GS in the absorption Li-Br chiller: UB - utilization boiler; CRC - cooler of the return coolant; P - pump; cooling tower 2 of dry type for emergency heat release

In accordance with the existing scheme, at a return water temperature at the outlet from absorption lithium-bromide (Li-Br) chiller, for example 75...80 °C, i.e. above its specification value t = 70 °C for the inlet of the gas engine heat exchangers ensuring the optimum thermal state of the gas engine, some of the return water is cooled in the cooler of the return coolant CRC with the removal of excess heat into the atmosphere through the cooling tower 2 of dry type. It is not advisable to return the excess heat to absorption Li-Br chiller, because of its lower temperature level 75...80 °C in comparison with the specification temperature of the hot water at the inlet of absorption Li-Br chiller about 90 °C, since the decrease in the temperature of the hot water at the inlet of absorption Li-Br chiller causes falling the efficiency of heat transformation into the cold - reducing the coefficient of performance ζ, which is a ratio of the cooling capacity generated to the heat used.

The decrease in the temperature Δt of heating water in absorption Li-Br chiller is usually not more than Δt = 15 °C, at which the temperature of return hot water after the chiller is not lower than 75 °C (with the temperature of hot water at the outlet of gas engine module of 90 °C) that is higher than the required temperature of coolant at the gas engine inlet t = 70 °C, which maintains the thermal state of the gas engine at the safe level. So this needs to discharge the excess heat into the atmosphere by the emergency cooling tower 2 of dry type. Due to the heat losses corresponding to the heat extracted into the atmosphere, the thermal coefficients of the heat recovery system of the gas engine are significantly lower than the coefficient of performance of the absorption Li-Br chiller, which causes a substantial decrease in the cooling capacity.

At the same time, using the absorption Li-Br chiller as a low-temperature stage for hot water deep cooling is not advisable, since when the temperature of the heating water is significantly lowered, the cooling capacity of the chiller is greatly decrease (Fig. 2).

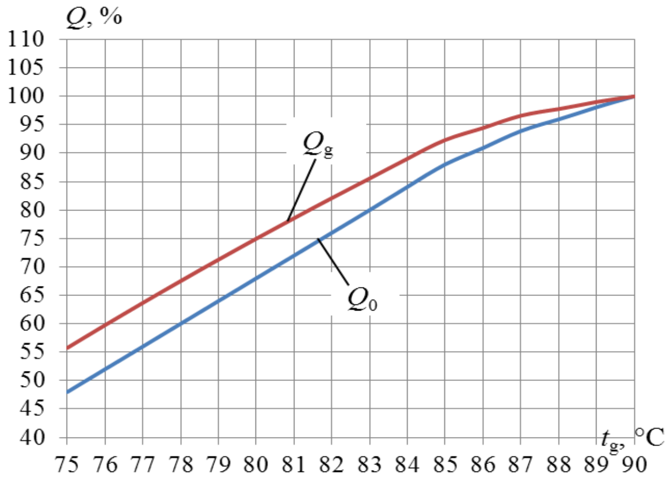

Figure 2. The percentage of the values of heating water heat Q_g and of the cooling capacity of the absorption Li-Br chiller Q_0 depending on the temperature of the heating water t_g

Therefore, in order to exclude these heat losses, an adsorption chiller can be applied as a low-temperature stage thermotransformer after the existing absorption Li-Br chiller. According to manufacturer's data, their adsorption chillers are quite effective at the temperature of the heating water of 68 °C [6]. The scheme of the proposed two-stage absorption-adsorption system of heat utilization is shown in Fig. 3.

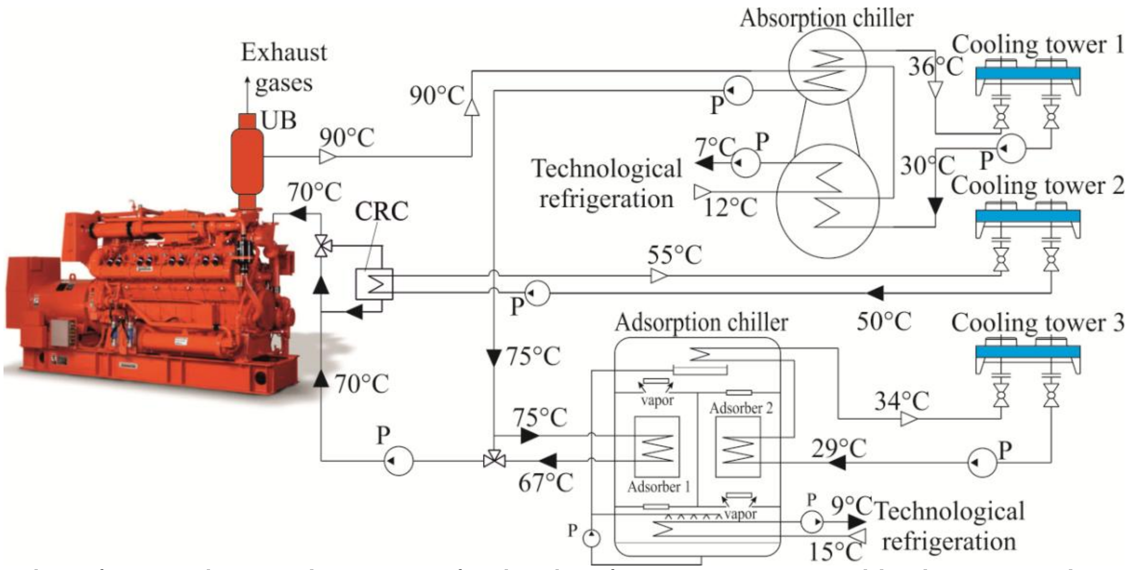

Figure 3. Scheme of two-stage absorption-adsorption system for exhaust heat of gas engine cogeneration module utilization: UB - utilization boiler; CRC - cooler of the return coolant; P - pump; cooling tower 2 of dry type for emergency heat release

According to this scheme, a part of the heat of hot water from the gas engine cogeneration module is transformed into a cold in absorption Li-Br chiller, as in the basic scheme, with lowering its temperature to about 75 °C. Then, a hot water with a temperature of about 75 °C is cooled in adsorption chiller with its temperature drop of about 8 °C, that results in lowering its temperature to about 67 °C. Using in the adsorption chiller a part of about 69% of the total hot water flow rate, two return water streams with temperatures of 75 °C after absorption Li-Br chiller and 67 °C after adsorption chiller are formed. Their mixing results in the temperature of joint return flow of about 70 °C at the inlet of gas engine cogeneration module.

The values of the coefficients of performance for the adsorption and absorption refrigeration machines, as well as the basic and proposed heat utilization systems, are shown in Fig. 4.

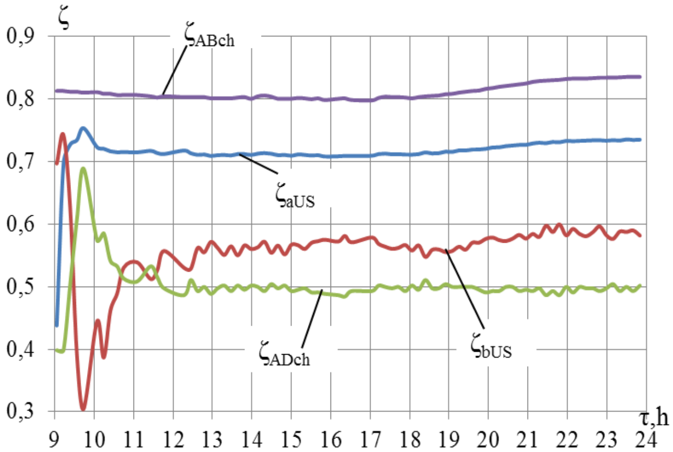

Figure 4. The values of the coefficients of performance for adsorption chiller ζ_{ADch} , for absorption Li-Br chiller ζ_{ABch} , for the basic utilization system with an absorption Li-Br chiller ζ_{bUS} and for the advanced utilization system with two-stage absorption-adsorption chiller ζ_{aUS}

Knowing the amount of heat of the hot water used in the chillers, as well as their coefficients of performance, the cooling capacities of both chillers were calculated, as well as their total value for the advanced heat utilization system with two-stage absorption-adsorption chiller (Fig. 5).

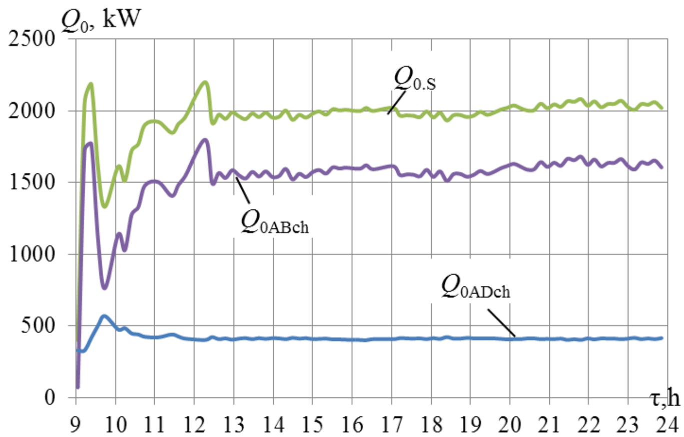

Figure 5. The values of the total cooling capacity $Q_{0.S}$ of the advanced gas engine heat utilization system with two-stage absorption-adsorption chiller and absorption Li-Br chiller of the first stage Q_{0ABch} (t_g = 90 °C) and absorption Li-Br chiller of the second stage Q_{0ADch} (t_g = 75 °C)

As another solution, to exclude these heat losses the use of a refrigerant ejector chiller has been proposed [7-11]. Refrigerant ejector chillers are simple in design, but their efficiency depends strongly on the temperature of heating water at the inlet. A slight decrease in the hot water temperature leads to a significant drop in the coefficient of performance of refrigerant ejector chiller. Therefore, the refrigerant ejector chiller is suggested to be used before the absorption Li-Br chiller in order to consume a high-potential heat of the hot water in the ejector chiller generator.

The scheme of the system for conversing the waste heat of gas engine in refrigerant ejector and absorption Li-Br chillers is shown in Fig. 6.

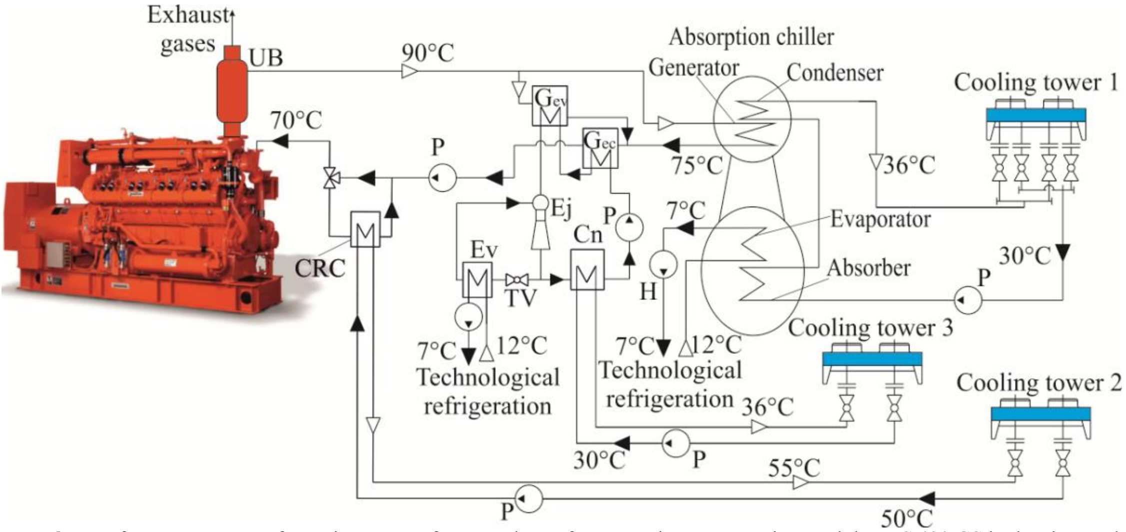

Figure 6. Scheme of a two-stage transformation system for waste heat of a gas engine cogeneration module JMS 420 GS in the ejector chiller and the absorption Li-Br chiller: UB - utilization boiler; CRC - cooler of the return hot water; TV - throttle valve; Ev, Cn, Ej - evaporator, condenser and ejector of refrigerant ejector chiller; G_{ev}, G_{ec} – evaporative and economizer sections of refrigerant ejector chiller generator; P - pump; Cooling tower 2 - emergency heat release

According to this scheme, the heat of hot water with temperature t_g = 90 °C is used in the evaporative section of the refrigerant ejector chiller generator. Then, with a temperature lowered to 85 °C, the hot water is fed to the absorption Li-Br chiller and leaves the absorption Li-Br chiller at a temperature of about 72 °C at the outlet. In order to maintain the temperature of the return hot water at the inlet of the gas engine not higher than 70 °C, the remaining part of the excessive hot water heat is discharged in the economizer part of the ejector chiller generator for addition heating of liquid refrigerant at the inlet of the evaporative section of generator.

The cooling capacities of the basic typical absorption Li-Br chiller heat conversion system $Q_{0(b)}$ and proposed advanced two-stage heat transformation system with refrigerant ejector and absorption chillers $Q_{0(ad)}$, as well as of its components – refrigerant ejector chiller $Q_{0(ej.ch)}$ (t_g = 90 °C) and absorption chiller $Q_{0(ab.ch)}$ (t_g = 85 °C) are shown in Fig. 7.

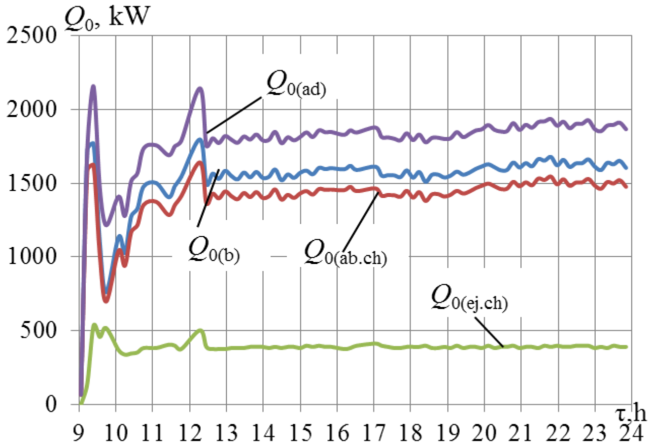

Figure 7. The values of cooling capacity of the basic absorption Li-Br chiller heat conversion system $Q_{0(b)}$ and advanced two-stage heat transformation system with refrigerant ejector and absorption chillers $Q_{0(ad)}$, and refrigerant ejector chiller $Q_{0(ej.ch)}$ (t_g = 90 °C) and the absorption Li-Br chiller $Q_{0(ab.ch)}$ (t_g = 85 °C)

When the hot water temperature at the inlet of absorption Li-Br chiller decreases, the amount of heat transformed into the cooling capacity is reduced as shown in Fig. 2.

An increament in cooling capacity of the proposed ejector-absorption system for transformation of gas engine waste heat compared with a typical absorption lithium bromide system in dependence of the value of refrigerant ejector chiller coefficient of performance is presented in Fig. 8.

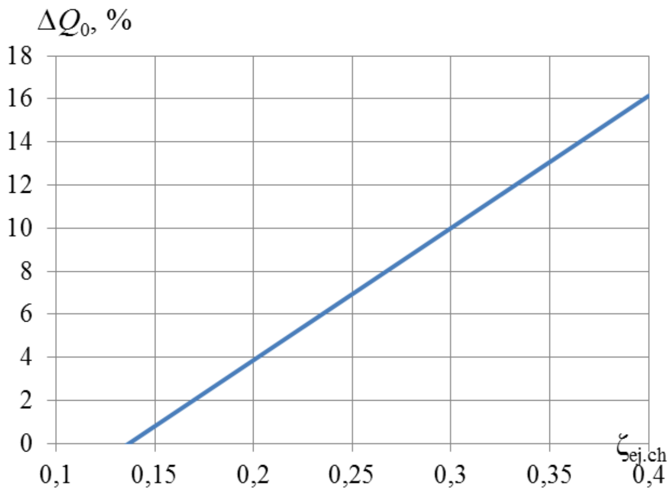

Figure 7. An increament in cooling capacity of the proposed ejector-absorption system compared with typical absorption lithium bromide system in dependence of the value of refrigerant ejector chiller coefficient of performance

Proceeding from the data given in Fig. 8, the use of refrigerant ejector chiller for transformation of the waste heat of gas engine into cooling capacity is expedient if its coefficient of performance is higher than 0.15. So, the application of refrigerant ejector chiller with coefficient of performance of 0.4 provides 18% increment in cooling capacity of the proposed ejector-absorption system compared with typical absorption lithium bromide system.

III. CONCLUSIONS

By utilizing the excess heat of gas engine cogeneration module, that is normally discharged into the atmosphere, in the advanced heat utilization system with two-stage absorption-adsorption chiller, an increament of about 20 % in the cooling capacity is obtained. Besides, using the adsorption chiller for utilization of low-potential heat of the return hot water after absorption Li-Br chiller provides an increase of the coefficient of performance for the whole heat utilization system from $\zeta = 0.5$ for the basic system to $\zeta = 0.7$ for the advanced utilization system with two-stage absorption-adsorption chiller.

A two-stage ejector-absorption chiller system with refrigerant ejector chiller for transforming the excessiv low potential waste heat of gas engine that is left unused by absorption lithium bromide chiller and normally discharged into the atmosphere is developed for combined electricity, heat and cooling plant too. It was shown that the application of refrigerant ejector chiller with coefficient of performance of 0.4 provides 18% increment in cooling capacity of the proposed ejector-absorption chiller system compared with typical absorption lithium bromide chiller system.

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