Exhaust Heat Recovery in Integrated Energy Plant

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Abstract. The combined refrigeration, heat, and power generation (trigeneration) gained widespread application. The reciprocating combustion gas engines are used as drive engines. They are the most adapted to match the actual refrigeration, heat, and electricity needs and manufactured as cogenerative engine modules equipped with heat exchangers to release the heat of exhaust gas, scavenge gas-air mixture, engine jacket, and lubricant oil cooling water to produce hot water converted to refrigeration for technological, space conditioning and heating duties. The efficiency of recovering the heat released from gas engines in a typical integrated energy plant with an absorption lithium-bromide chiller has been analyzed. Issuing from monitoring data on the parameters of heat utilization circuit, the reserves for utilizing the heat usually not recovered by absorption chiller and removed to the atmosphere by radiator are revealed. The advanced heat recovery system that transforms the heat, typically extracted to the atmosphere, by ejector chiller to generate supplementary refrigeration for gas engine intake air cooling was developed as the simplest and expedient solution for implementation at a typical integrated power plant.

Keywords: Energy efficiency · Gas engine · Waste heat · Utilization · Absorption chiller · Ejector chiller · Industrial innovation

1 Introduction

The combined refrigeration, heat, and power generation (trigeneration) achieved wide application [1, 2]. The reciprocating combustion gas engines are used as drive engines [3, 4]. The gas engines are the most adapted to matching the actual refrigeration, heat, and electricity needs [5, 6]. They are manufactured as cogenerative engines equipped with heat exchangers to release exhaust gas heat, scavenge gas-air mixture, engine jacket, and lubricant oil cooling water to produce hot water converted to refrigeration for technological space conditioning and heating duties [7, 8].

Rising gas engines' air temperature reduces their thermodynamic efficiency: electrical power decreases, and fuel efficiency falls [9]. Issuing from this, the heat released from the engines is reasonable to be used for cooling engine intake air through its converting to refrigeration [10, 11].

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2 Literature Review

The advanced technologies for the utilization of combustion engine exhaust are used to increase the heat released [12, 13].

The absorption lithium-bromide chillers (ACh) are mainly applied for converting waste heat to refrigeration [14, 15]. They can produce chilled with the temperature of about 7 ºC and cool the air to the temperature of about 15 ºC accordingly with an increased coefficient of performance (COP) of 0.7 to 0.8.

The jet devices using water [16, 17] or refrigerant [18, 19] as coolants such as thermopressors [20, 21] and ejector chillers (ECh) are the most simple in design and cheap. The ECh has less COP of about 0.3 but can cool the air to 10 ºC and lower [18, 19]. They include heat exchangers with a two-phase flow of refrigerant [22, 23]. Their efficiency can be enhanced by heat transfer intensification in evaporators [24] and improving refrigerant distribution [25, 26] in minichannels with advanced circuits of refrigerant circulation [27, 28]. Applying modern simulation methods as ANSYS [29, 30] provides their rational design to match actual operation conditions [31, 32]. Deep utilization of engine exhaust heat is achieved by applying, for instance, low-temperature condensing surfaces [33, 34]. Various techniques increase the heat released [35, 36] and convert it to refrigeration [37, 38]. All of them are accompanied by considerable ecological effects [39, 40].

The enlarged waste heat and heat losses caused by conflicting temperature conditions for the effective operation of ACh and gas engines were revealed in the typically integrated energy plants (IEP). Thus, to provide the condition of safe engine operation at the required thermal level, the temperature of a return hot water from ACh at the exit of engine heat removing contour is limited to 70 °C. In the opposite case, the excessive heat of return hot water is removed to the atmosphere through the so-called emergency radiator.

The general approach of the present research is to convert the heat of return hot water not used by ACh and removed to the atmosphere in typical IEP to refrigeration by ECh for engine intake air cooling.

The work focuses on enhancing the utilization of gas engine released heat through converting the waste heat not used by ACh to refrigeration in ECh to provide the effective operation of the engine.

3 Research Methodology

The efficiency integrated energy plants of the factory “Sandora”–“PepsiCo Ukraine” (Mykolayiv, Ukraine) was investigated. The IEP consists of two GE JMS 420 GS (electric power output $P_e = 1400$ kW, heat power output $Q_h = 1500$ kW) and ACh.

The ACh recovers the heat of exhaust gas, scavenging gas-air mixture, and the water cooling engine jacket and lubricant oil to receive hot water and convert the latter to refrigeration for technological and space conditioning and heating duties.

The circuit of the typical system for converting gas engine released heat to refrigeration by ACh is presented in Fig. 1.

In the typical IEP (Fig. 1), the temperature of return hot water after ACh t_{wA2} is 75 to 80 °C, that is more higher than 70 °C at the inlet to cogenerative engine module to

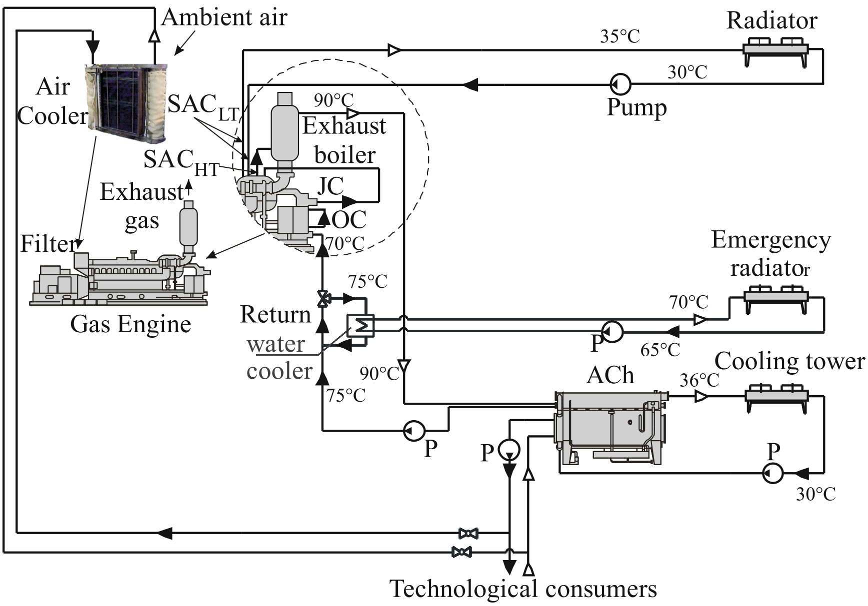

Fig. 1. The circuit of the typical system for converting gas engine released heat to refrigeration by ACh: OC – oil cooler; JC – engine jacket cooler; SAC_{LT} and SAC_{HT} – low- and high-temperature stages of scavenging air cooler

provide its safe thermal rate. Therefore, the excessive heat of return water after ACh is removed through the return water cooler and emergency radiator to the atmosphere.

So as the temperature of return water after ACh t_{wA2} = 75…80 °C is much less than its values 90 to 95 °C that might provide the efficient operation of a single-stage ACh with a high COP of about 0.7, it is impossible to use its heat again in ACh. The use of supply hot water with such lowered temperature would cause falling the COP of ACh from its rated value of about 0.7 to 0.5 and lower.

The analyses of monitoring data on the temperatures of hot water from the gas engine during converting its heat were done to estimate the value of the rest of the heat removed to the atmosphere and convert it to additional refrigeration.

The temperatures of hot water from the engine at the inlet of ACh t_{wA1} and outlet of ACh t_{wA2} and return water t_{wEin} at the inlet of engine previously cold in the emergency radiator through removing excessive heat to the atmosphere are shown in Fig. 2.

As Fig. 2 shows, the temperature depression $t_{wA1} - t_{wA2}$ of hot water in ACh due to converting its heat to refrigeration is a bit less than 15 °C. Accordingly, a temperature decrease of return water after ACh $t_{wA2} - t_{wEin}$ is more than 5 °C, and the heat losses to the atmosphere caused by removing the excessive heat not converted to refrigeration by ACh are quite considerable.

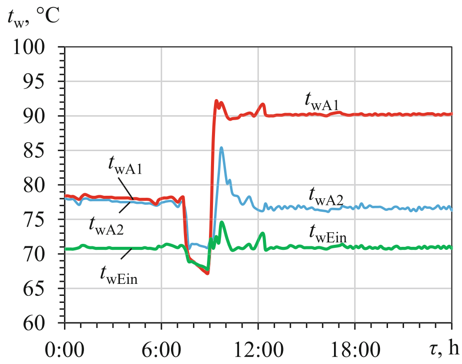

Fig. 2. Temperatures of hot water at the inlet of ACh t_{wA1} and outlet of ACh t_{wA2} and return water t_{wEin} at the inlet of engine cold in the emergency radiator

4 Results

The values of the waste heat Q_{hw} not converted to refrigeration by ACh and the heat Q_{hA} used by ACh calculated according to monitoring data on the temperatures of hot water (Fig. 2) are presented in Fig. 3.

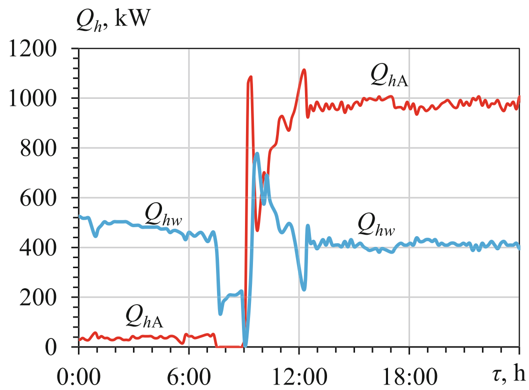

Fig. 3. Values of heat converted to refrigeration by ACh Q_{hA} and the waste heat Q_{hw}

As Fig. 3 shows, the waste heat Q_{hw} as a lost heat removed to the atmosphere by the emergency radiator to keep the temperature of return hot water at the inlet of the gas engine not higher than 70 °C, is about 40% of the heat converted by ACh to refrigeration or 30% of the engine heat capacity (1400 kW).

Therefore, the waste heat recovery system was developed to utilize the heat of return hot water after ACh (usually removed to the atmosphere) to generate additional refrigeration for gas engine intake air cooling. Its efficiency was estimated proceeding from monitoring data.

To increase the temperature of return hot water from 75 °C to 90 °C providing the operation of ACh with a high COP of 0.7 to 0.8, a booster gas boiler available at any factory can be applied. In this case, the additional refrigeration capacities Q_{0l} might be generated due to the use of the lost waste heat besides the basic refrigeration capacities of ACh $Q_{0\mathrm{A}}$ converting the originally available heat $Q_{h\mathrm{A}}$ (Fig. 3) as it is shown in Fig. 4.

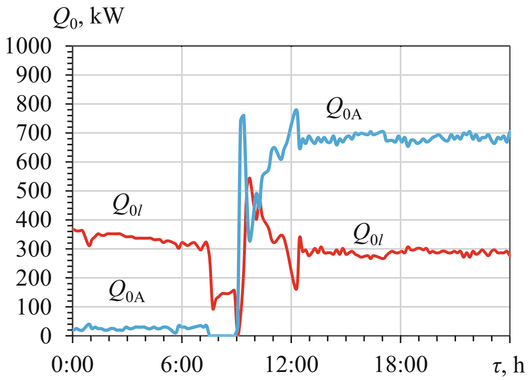

Fig. 4. Refrigeration capacities of ACh $Q_{0\mathrm{A}}$ due to converting the available heat of high rate Q_{hA} (Fig. 3) and additional refrigeration Q_{0l} received by recovering the lost heat Q_{w}

As Fig. 4 shows, due to recovering waste heat $Q_{h\mathrm{w}}$, conventionally lost through removing to the atmosphere, it is possible to increase the basic refrigeration capacity by about 300 kW for trigeneration plant based on gas engine JMS 420 GS-N.LC.

It should be mentioned that the application of a boost gas boiler to raise heat potential of waste heat of return hot water left from the ACh can be efficient for multi engines trigeneration plant with two and more ACh. The additional boosted heat is used to feed the other ACh, thereby improving the operational flexibility of the overall trigeneration plant.

To recover the waste heat of return hot water after ACh, the simplest in design ECh is applied. It operates as a boost low-temperature stage of combined absorption-ejector chiller (AECh).

The refrigeration capacity, received by recovering the waste heat of return hot water, can be used for engine intake air cooling by chilled water from ACh preliminary subcooled by boiling refrigerant of ECh (Fig. 5).

The use of increased refrigeration capacity for gas engine intake air cooling enables to enlarge the engine electricity production with reduced specific fuel consumption. Thus, such deep utilization of the heat released from gas engines enhances engine fuel efficiency and prolongs the duration of trigeneration plant efficient operation even within periodic cooling and heating demands.

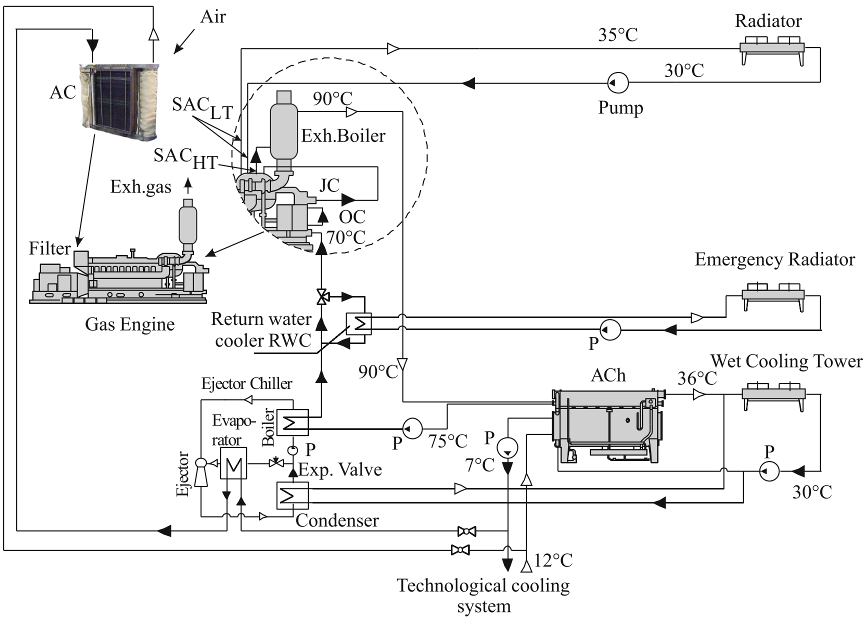

Fig. 5. The circuit of deep utilization of the heat released from gas engine in AECh

5 Conclusions

The analysis of converting the heat released from gas engine to refrigeration by ACh in typical IEP, proceeding from monitoring data on the temperatures of hot water during utilization of its heat, revealed the heat losses of about 40% of the heat converted in ACh. This is caused by conflicting requirements to temperature conditions for the effective operation of ACh and gas engine. To provide the condition of safe engine operation at the required thermal level, the temperature of return hot water after ACh at the entry of engine heat removing circuit is limited to 70 °C. Therefore in the typical IEP the return hot water excessive heat is removed to the atmosphere through an emergency radiator.

The innovative waste heat recovery system for IEP through converting the rest of heat (not used by ACh and usually removed to the atmosphere) in ECh to generate addition refrigeration for gas engine intake air cooling is developed as the simplest solution to be implemented at the typical IEP.

The absorption-ejector chiller (AECh) with a low-temperature ECh stage and a high-temperature absorption stage for the deep waste heat recovery system of IEP is proposed.

Such a deep waste heat recovery system makes it possible to enhance engine fuel efficiency due to intake air cooling and prolong the time of IEP performance even within periodical technological cooling needs.

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