Increasing the Operation Efficiency of Air Conditioning System for Integrated Power Plant on the Base of Its Monitoring

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Abstract. The efficiency of reciprocating gas engines of integrated energy systems (IES) for combined electricity, heat and refrigeration generation is strictly influenced by their cyclic air temperatures. To evaluate the effect of gas engine cyclic air deep cooling, compared with conventional its cooling, the data on dependence of fuel consumption and power output of gas engine JMS 420 GS-N.L on its inlet air temperature at varying ambient air temperatures at the entrance of the radiator for scavenge air cooling were received. The results of treatment of gas engine efficiency monitoring proved non-effective operation of conventional chilling all the ambient air, coming into the engine room, because of increased air temperature at the inlet of turbocharger (TC), caused by heat influx from surroundings in the engine room. A new method of gas engine inlet air two-stage cooling at increased ambient air temperatures and advanced cyclic air cooling system with absorption lithium-bromide chiller and refrigerant ejector chiller was proposed. With this chilled water from absorption lithium-bromide chiller is used as a coolant in the first high-temperature stage of engine inlet air cooler and boiling refrigerant of ejector chiller in the second low-temperature stage.

Keywords: Gas engine · Integrated energy system · Fuel consumption · Air cooling · Chiller

1 Introduction

Reciprocating gas engines (GE) found a widespread application in integrated energy systems (IES), or so called trigeneration systems [1–4], for combined electricity, heat and refrigeration generation [5–9]. For application in plants of combined energy supply the engine manufacturers developed gas engines (GE) as cogeneration engine modules equipped with heat exchangers for producing hot water or steam by using heat of exhaust gas, charged gas-air mixture (scavenge air), engine jacket and lubricant oil cooling water [10].

With rise in intake air temperature a thermodynamic efficiency of gas engines and, respectively, power plants essentially decreases: electric power output decreases and

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specific fuel consumption increases. A cold, generated by absorption chiller, that recovers the heat released from the engine, could be used for cooling engine intake air. Application of the received cold for cooling demands of the engine itself (in-cycle trigeneration) would provide not only improvement of its fuel efficiency and a higher ratio of electric power to byproduct heat, but also prolong the time of efficient operation of trigeneration plant, since cooling demands for technological needs have, as a rule, periodic character.

The most of well-known concepts of increasing the efficiency of trigeneration plant are limited to engine out-cycle use of a cold (for external consumers) [9–15], and owing to this do not provide realization of the additional reserves through conversing heat, released from the engine, in its working cycle. A realization of in-cycle trigeneration concept would broaden the applicability of trigeneration systems due to their applications even without enough heat and cooling demands.

A conventional method of chilling all the ambient air, coming into the engine room, from were it is sucked by engine turbocharger (TC), is non-effective because of heat influx from surroundings to the air stream sucked, that results in increased air temperature at the inlet of turbocharger and enlarged cooling capacity required for chilling all the ambient air coming into the engine room. The problem of engine cyclic air cooling arises especially actually for increasing ambient air temperature above 25…30 °C.

To solve this problem a new method of gas engine inlet air two-stage cooling to stabilize its inlet temperature at increased ambient air temperatures with absorption lithium-bromide chiller and refrigerant ejector chiller was proposed. With this chilled water from absorption lithium-bromide chiller is used as a coolant in the first high-temperature stage of engine inlet air cooler and boiling refrigerant of ejector chiller in the second low-temperature stage.

The problem of engine cyclic air cooling arises especially actually when ambient air temperature increases above 25…30 °C. If scavenge air temperature exceeds the maximum temperature restriction of 50 °C the engine efficiency drops sharp. For protection of engine from negative impact of high scavenge air temperature on the thermal conditions in the combustion cylinders the scavenge air temperature of about 40 °C is maintained automatically by reducing gas supply to engine and, accordingly, engine load.

The purpose of the research is to estimate the enhancement of fuel efficiency of gas engine in integrated energy system due to cooling engine inlet air at increased ambient temperatures with using the monitoring data of actual gas engine performance.

2 Literature Review

An enhancement of fuel efficiency of combustion engines is possible by cooling inlet air in vapour-compression and waste heat recovery chillers. The absorption lithium-bromide chillers (ACh) are the most widely used and provide cooling air to the temperature of around 15 °C with a high coefficient of performance (COP = 0.7–0.8) [16–23, 27–29]. Vapour-compression chillers consume electrical energy to drive compressors and provide cooling air practically to any low temperature [3, 31]. The most simple refrigerant ejector chillers, which convert the exhaust heat of engine into a cold, provide cooling air to the temperature of 5 °C but with low efficiency: COP = 0.2–0.3 [4, 26, 30].

The efficiency of cooling systems and refrigeration machines can be improved through intensification of heat transfer processes in heat exchangers and by application of advanced scheme decisions [4, 24, 30] and energy conserving technologies like booster ambient air precooling by using an excess of refrigeration capacity, accumulated at decreased cooling loads, to cover peak heat loads [17, 25].

Various methodological approaches has been proposed for designing engine inlet air cooling systems and first of all for the choice of their rational cooling capacities [2, 5–8, 11, 13, 16, 18, 19, 21, 25, 32–36]. Some of them are based on the annular fuel savings due to engine inlet air cooling and is conducted by using the summarized annular fuel savings of the engine dependence on a design cooling capacity of the to choose its rational value, that provides closed to maximum annual fuel savings of the engine or maximum rate of the annual fuel saving increment due to increasing a design cooling capacity [25, 36].

Many researches deal with improving the performance efficiency of trigeneration systems for combined electricity, heat and refrigeration generation for space conditioning and technological and other needs [5–8, 11, 20, 22, 27, 28].

The most of well-known concepts of increasing the efficiency of trigeneration plants are limited to application for external consumers of cold [10, 12, 22] and owing to this do not provide realization of the additional reserves through conversing the heat released from the engine in its working cycle. A realization of in-cycle trigeneration concept would broaden the applicability of trigeneration systems due to their applications even without stable heat and cooling needs.

3 Research Methodology

A fuel efficiency of gas engine of integrated energy system for combined electricity, heat and cooling generation was investigated to analyze the influence of chilling air at the inlet of engine on its efficiency. A cold, generated by absorption lithium-bromide chiller (ACh), that recovers the heat released from the engine, was used for cooling intake air of engine.

To evaluate the effect of gas engine inlet air deep cooling, compared with conventional its procession in the central air conditioner for conditioning ambient air coming into the engine room, data on the dependence of fuel consumption and power output of gas engine on its inlet air temperature at varying ambient air temperatures at the entrance of the radiator for scavenge air cooling water were received by treating the results of gas engine JMS 420 GS-N.L efficiency monitoring.

A method for treatment of the monitoring data on fuel consumption and power output of gas engine was developed [23]. The results of monitoring of gas engine fuel efficiency were presented in the form of data sets on dependence of fuel consumption $B_e = f(t_{in})$ and engine power output $P_e = f(t_{in})$ upon the air temperatures t_{in} at the inlet of the turbocharger for the various ambient air temperature t_{amb} at the entrance to the radiator of scavenge air cooling.

The goal of monitoring data sets $P_e = f(t_{in})$ and $B_e = f(t_{in})$ treatment was to calculate the magnitude of the change in power ΔP_e and fuel consumption ΔB_e, caused by the change in the engine inlet air temperature t_{in} by 1 °C, that is $\Delta P_e/\Delta t_{in}$ and $\Delta B_e/\Delta t_{in}$, to evaluate the effect of the application of developed air cooling system.

A treatment of monitoring data of gas engine JMS 420 GS-N.L in integrated energy system for combined electricity, heat and cooling has proved a non-effective operation of conventional chilling all the ambient air, coming into engine room, because of increased air temperature at the inlet of engine turbocharger (TC), caused by heat influx from the engine room.

The two-stage cooling system of gas engine inlet air by chilled water from the absorption lithium-bromide chiller (ACh) as a coolant in the first high-temperature stage AC_{HT} of engine inlet air cooler (AC) and boiling refrigerant of ejector chiller (ECh) in the second low-temperature stage AC_{LT} was developed. To prove its efficiency the current values of air temperature at the inlet of gas engine turbocharger t_{in}, air temperature at the exit of central air conditioner CAC t_{AC2}, air temperature drop in the air cooler of CAC $\Delta t_{AC} = t_{amb} - t_{AC2}$, air temperature increase in the engine room $\Delta t_{ER} = t_{in} - t_{AC2}$ were compared with their values for the high-temperature stage AC_{HT} t_{HT2} and low-temperature stage AC_{LT} t_{LT2}, reduction of air temperature in the high-temperature stage AC_{LT} Δt_{HT} and low-temperature stage AC_{LT} Δt_{LT} and full temperature reduction in the proposed two-stage air cooler $\Delta t_{AC} = t_{amb} - t_{LT2}$, and corresponding heat loads on the high-temperature stage AC_{HT} $Q_{0.HT}$ and low-temperature stage AC_{LT} $Q_{0.LT}$ of the air cooler.

4 Results

4.1 Investigating the Efficiency of Typical Gas Engine Inlet Air Cooling System

The efficiency of cooling air at the inlet of gas engine was investigated for IES of combined energy supply at the factory "Sandora"–"PepsiCo Ukraine" (Nikolaev, Ukraine). The integrated energy system is equipped with 2 cogeneration Jenbacher gas engines JMS 420 GS-N.LC (rated electric power P_{eISO} = 1400 kW, heat power Q_h = 1500 kW) and absorption lithium-bromide chiller.

The heath taken away from exhaust gas by waste heat recovery boiler (economizer), from charged gas-air mixture in a high-temperature stage of an intercooler (IC_{HT}), from engine jacket and lubricant oil cooling water in corresponding coolant radiators, is used by absorption chiller for producing a chilled water with temperature of around 11…12 °C. Chilled water is used for technological process cooling and by central conditioners for cooling engine room intake air, from where cooled air is sucked by engine turbochargers (Fig. 1).

A typical scheme of gas engine inlet air cooling system is presented in Fig. 2. The engine room intake air is cooled in the central conditioner by chilled water from absorption lithium-bromide chiller and the engine turbocharger sucks the air from engine room.

a b

Fig. 1. Cogeneration gas engine module JMS GE Jenbacher (a) and waste heat recovery central conditioner for cooling engine room intake air (b)

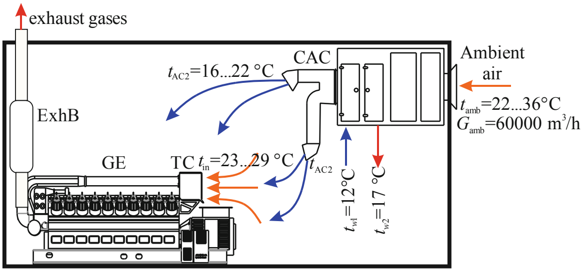

Fig. 2. A typical scheme of gas engine inlet air system with cooling the engine room intake air in the central conditioner by chilled water from the ACh and sucking the chilled air by the engine turbocharger from engine room: ExhB – exhaust heat boiler; GE – gas engine; CAC – central air conditioner; TC – turbocharger;

Because of heat influx from the engine room the temperature of engine intake air t_{in} is higher than its value at the outlet of central air conditioner (CAC) t_{AC2} (Fig. 3).

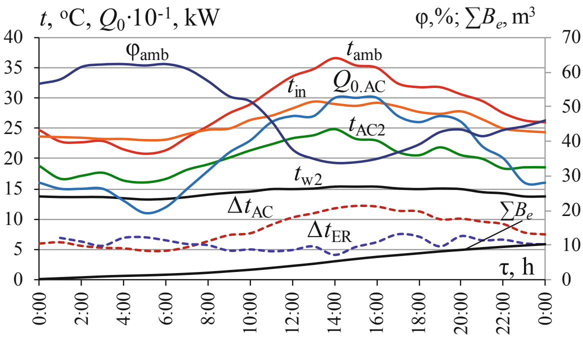

Fig. 3. Daily variation of temperature t_{amb} and relative humidity φ_{amb} of ambient air, temperature of air at the inlet of gas engine turbocharger t_{in}, air at the outlet of central air conditioner CAC t_{AC2}, cooling water at the outlet of air cooler of CAC t_{w2}, air temperature drop in the air cooler of CAC $\Delta t_{AC} = t_{amb} - t_{AC2}$, air temperature increase in the engine room $\Delta t_{ER} = t_{in} - t_{AC2}$, cooling capacity of air conditioner $Q_{0.AC}$ with air flow G_a = 60000 m³/h, $\Sigma \Delta B_e$ – full daily savings of natural gas due to cooling of air of ER, m³

4.2 Investigating the Efficiency of Improved Gas Engine Inlet Air Cooling System

The scheme of two-stage cooling system of gas engine inlet air by chilled water from the absorption lithium-bromide chiller (ACh) as a coolant in the first high-temperature stage AC_{HT} of engine inlet air cooler (AC) and boiling refrigerant of ejector chiller (ECh) in the second low-temperature stage AC_{LT} is presented in Fig. 4.

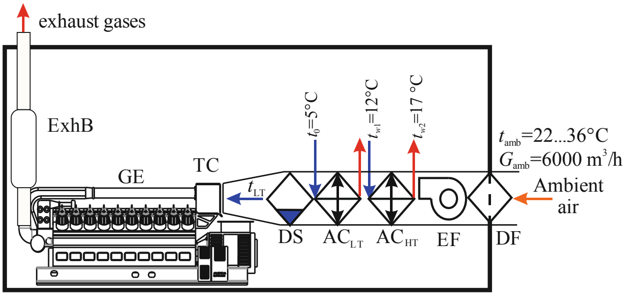

Fig. 4. The scheme of two-stage cooling system of gas engine inlet air by chilled water from the ACh in the first high-temperature stage AC_{HT} of engine inlet air cooler (AC) and boiling refrigerant of ejector chiller (ECh) in the second low-temperature stage AC_{LT}: ExhB – exhaust heat boiler; GE – gas engine; EF – electric fan; DF – dust filter; DS – droplet separator; TC – turbocharger; AC_{LT} and AC_{HT} – low- and high-temperature air coolers

Current values of air temperature at the exit from the high-temperature stage AC_{HT} t_{HT2} and low-temperature stage AC_{LT} t_{LT2} of two-stage air cooler, reduction of air temperature in the high-temperature stage AC_{HT} Δt_{HT} and low-temperature stage AC_{LT} Δt_{LT} and full temperature reduction in the air cooler $\Delta t_{AC} = t_{amb} - t_{LT2}$, heat load on the high-temperature stage AC_{HT} $Q_{0.HT}$ and low-temperature stage AC_{LT} $Q_{0.LT}$ and full heat load on the whole air cooler $Q_{0.AC}$, corresponding current reduction of specific fuel consumption due to cooling engine cyclic air in the high-temperature $\Delta b_{e.HT}$ and low-temperature $\Delta b_{e.LT}$ stages and in the whole air cooler Δb_e and the total daily reduction of fuel consumption ΣB_e are presented in Figs. 5 and 6.

A proposed two-stage cooling system of gas engine inlet air by chilled water from the absorption lithium-bromide chiller (ACh) in the first high-temperature stage AC_{HT} of engine inlet air cooler (AC) and boiling refrigerant of ejector chiller (ECh) in the second low-temperature stage AC_{LT} can provide decreasing engine inlet air temperature by about 20…25 °C compared with a typical scheme of gas engine inlet air system with cooling the engine room intake air in the central conditioner by chilled water from the ACh and sucking the chilled air by the engine turbocharger from engine room, that results in reduction of engine specific fuel consumption by about $\Delta b_e = (1\ldots2)$ g/(kW•h), i.e. about 2…3% decrease in specific fuel consumption at increased ambient air temperatures t_{amb} = 30…35 °C.

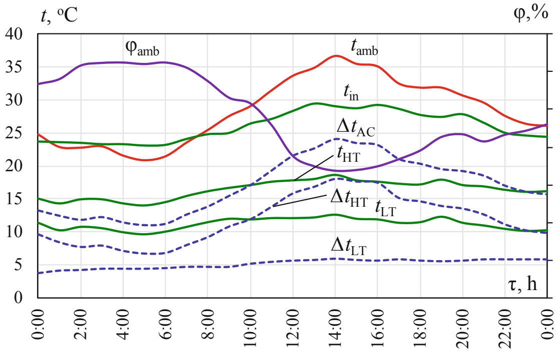

Fig. 5. Current values of temperature t_{amb} and relative humidity φ_{amb} of ambient air, temperature of air at the inlet of gas engine turbocharger t_{in} in basic version with central conditioner (Fig. 3), air temperature at the exit from the high-temperature stage AC_{HT} t_{HT} and low-temperature stage AC_{LT} t_{LT} of air cooler, reduction of air temperature in the high-temperature stage AC_{HT} Δt_{HT} and low-temperature stage AC_{LT} Δt_{LT} of air cooler and full temperature reduction in the air cooler $\Delta t_{AC} = t_{amb} - t_{LT}$ with air flow $G_a = 6000$ m^3/h

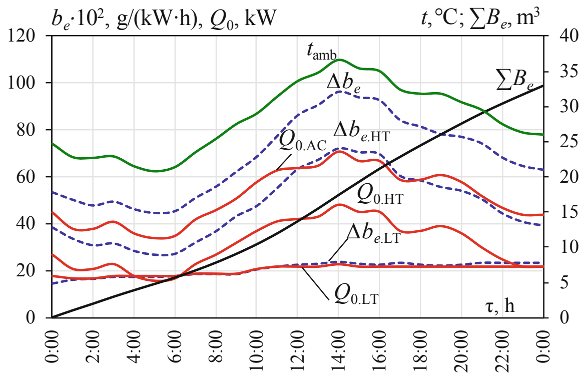

Fig. 6. Current values of ambient temperature t_{amb}, heat load on the high-temperature stage $Q_{0.HT}$ and low-temperature stage $Q_{0.LT}$ and full heat load on the air cooler $Q_{0.AC}$, current reduction of specific fuel consumption due to cooling air in the high-temperature $\Delta b_{e.HT}$ and low-temperature $\Delta b_{e.LT}$ stages and in the whole air cooler Δb_e and the total daily reduction of fuel consumption ΣB_e: air flow $G_a = 6000$ m^3/h

5 Conclusions

To evaluate the effect of gas engine inlet air deep cooling, compared with conventional its procession in the central air conditioner for conditioning ambient air coming into the engine room, data on the dependence of fuel consumption and electrical power output of gas engine on its inlet air temperature at varying ambient air temperatures at the entrance of the radiator for scavenge air cooling water were received by treating the results of gas engine JMS 420 GS-N.L efficiency monitoring in integrated energy system for combined electricity, heat and cooling generation in absorption lithium-bromide chiller.

The results of monitoring of gas engine fuel efficiency were presented in the form of data sets on dependence of fuel consumption $B_e = f(t_{in})$ and engine electrical power output $P_e = f(t_{in})$ on the air temperatures t_{in} at the inlet of the turbocharger for the various ambient air temperature t_{amb} at the entrance to the radiator of scavenge air cooling.

The monitoring data sets $P_e = f(t_{in})$ and $B_e = f(t_{in})$ were treated to calculate the magnitude of the change in electrical power ΔP_e and fuel consumption ΔB_e, caused by the change in the engine inlet air temperature t_{in} by 1 °C, that is $\Delta P_e/\Delta t_{in}$ and $\Delta B_e/\Delta t_{in}$, to evaluate the effect of the application of developed air cooling system.

A treatment of monitoring data on electrical power output and fuel consumption of gas engine JMS 420 GS-N.L in integrated energy system for combined electricity, heat and cooling generation in absorption lithium-bromide chiller has proved non-effective conventional method of chilling all the ambient air, coming into the engine room, from were it is sucked by engine turbocharger, is non-effective because of heat influx from surroundings to the air stream sucked, that results in increased air temperature at the inlet of turbocharger and enlarged cooling capacity required for chilling all the ambient air coming into the engine room.

A new method of gas engine inlet air two-stage cooling to stabilize its inlet temperature at increased ambient air temperatures with absorption lithium-bromide chiller and refrigerant ejector chiller was proposed. With this chilled water from absorption lithium-bromide chiller is used as a coolant in the first high-temperature stage of engine inlet air cooler and boiling refrigerant of ejector chiller in the second low-temperature stage.

An advanced gas engine inlet air cooling system with two-stage absorption-ejector chiller conversing waste heat of gas engine was proposed.

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