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Energy Saving in Trigeneration Plant for Food Industries †

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Abstract: The trigeneration plants for combined cooling, heating, and electricity supply, or integrated energy systems (IES), are mostly based on gas reciprocating engines. The fuel efficiency of gas reciprocating engines depends essentially on air intake temperatures. The transformation of the heat removed from the combustion engines into refrigeration is generally conducted by absorption lithium-bromide chillers (ACh). The peculiarity of refrigeration generation in food technologies is the use of chilled water of about 12 °C instead of 7 °C as the most typical for ACh. This leads to a considerable cooling potential not realized by ACh that could be used for cooling the engine intake air. A refrigerant ejector chiller (ECh) is the simplest in design, cheap, and can be applied as the low-temperature stage of a two-stage absorption-ejector chiller (AECh) to provide engine intake air cooling and increase engine fuel efficiency as result. The monitoring data on gas engine fuel consumption and power were analyzed in order to evaluate the effect of gas engine cyclic air cooling.

Keywords: trigeneration plant; gas reciprocating engine; engine cyclic air; two-stage cooling

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1. Introduction

Gas engines (GE) [1,2] are widely applied as drive engines in trigeneration systems, or integrated energy systems (IES), for combined cooling, heating, and power (CCHP) [3,4]. The thermodynamic efficiency of GE falls with increasing inlet air temperature: electric power drops and specific fuel consumption grows. The heat released from GE is mostly converted to refrigeration by absorption lithium-bromide chillers (ACh) and used for technological needs. So it is quite reasonable to use the refrigeration generated by ACh for engine inlet air cooling (EIAC), i.e., for in-cycle trigeneration [5,6]. In addition to enhancing engine fuel efficiency, this enables prolonging the duration of efficient trigeneration plant operation too [7,8]. It is of great importance that the refrigeration demands for technological duties have a periodic character as a rule.

In integrated energy systems for food technologies, chilled water with a temperature of about 12 °C is mostly used; this is higher than the 7 °C characterized for a typical ACh [9,10]. Thus, a significant cooling potential and the corresponding heat released from GE remains and is not realized by ACh. A refrigerant ejector chiller (ECh) might be applied as the low-temperature stage of a two-stage absorption-ejector chiller (AECh) to use the excessive thermal potential for engine intake air cooling that leads to enhanced engine fuel efficiency [11,12].

In a typical IES, all the ambient air coming into the engine room is cooled in the central conditioner [4]. Because of heat influx from the engine room surroundings to the air stream sucked by the engine turbocharger (TC), the temperature of the air at the suction of the turbocharger is increased and the required cooling capacity is enlarged.

Many pieces of research are aimed at enhancing the operational efficiency of trigeneration plants [13,14] based on combustion engines and designed for technological needs [15,16], space conditioning [17,18], and other duties. A lot of them are devoted to improving the fuel efficiency of engines [19,20] through cyclic air cooling in waste heat recovery chillers [21,22]. The ACh is mostly used for chilling air to about 15 °C with a high coefficient of performance (COP) of 0.7 to 0.8 [23,24]. The thermopressors [25,26] and ejector chillers (ECh) [27,28] are the simplest in design, generally consisting of heat exchangers [29,30]. The ejector chillers are able to cool the air down to 10 °C and lower, but with a lowered COP of 0.2 to 0.3.

The efficiency of chillers and cooling systems on the whole can be enhanced by an intensification of heat transfer in evaporators and condensers [31,32] by the application of advanced circulation contours [33,34] using the cooling potential of evaporated water [35,36], exhaust heat potential [37,38], and alternative fuels [39,40]. They enable deep exhaust heat utilization [41,42] with low temperature condensation [43,44]. Such technologies provide for the increasing heat potential to be converted by heat recovery chillers [45,46] for engine cyclic air cooling [47,48]. Many environment-friendly and waste heat conserving innovations might be applied in EIAC [49,50], including transport applications [51,52].

A lot of control optimization [53,54] and regulation [55,56] methods are used to optimize the thermal loads on air cooling systems in order to match actual varying climatic conditions and gain a maximum effect due to cooling. With this, in addition to fundamental exergy and exergoeconomic analysis [57], the widespread methods for estimating the effect gained due to cooling air modified for simplified calculations were developed [58–60].

The majority of well-known concepts to enhance the efficiency of trigeneration systems are focused on the engine out-cycle application of refrigeration and based on conventional heat conversion in ACh. A realization of the engine in-cycle concept of trigeneration based on EIAC would provide a widespread application of trigeneration even for the lack of cooling needs.

The application of combined cooling, heat, and power (CCHP) generation, or trigeneration, enables the COP to be increased by about 50% compared with their separate generation and practically twice increased yearly operation time compared with cogeneration; therefore, they are very prosperous in food industries to substitute vapor compression refrigeration with an electrically driven compressor.

The results of similar studies previously published issued from the most typical operation of ACh for the production of chilled water with a temperature of about 7 °C, but not the 12 °C required for technological needs in juice and other similar food industries where the cooling potential not realized by an ACh is considerably higher.

A new concept based on combined two-stage EIAC in ACh and ECh would enable the stabilization of the engine intake air at a low temperature. It could be realized by using chilled water from an ACh as a coolant in a high-temperature engine inlet air cooler and boiling refrigerant fed from an ECh—in a low-temperature air cooler [61].

The purpose of this research is to increase the fuel efficiency of a gas engine by combining two-stage inlet air cooling and estimate engine fuel efficiency enhancement on the basis of monitoring data.

2. Materials and Methods

2.1. General Assumptions and Hypothesis

So far as proposed, AECh systems are the advanced versions of traditional basic ACh systems, the economic comparison with the last might be done taking by into account only the cost of extra heat exchangers of ECh (refrigerant evaporator-air cooler, refrigerant condenser, refrigerant pump, and ejector) with an unchanged maintenance cost, personnel, etc. Because of variations in the cost of heat exchangers of different manufacturers and fuel especially, the economic analysis is to be conducted for the concrete case. Thus, the proposed method of designing the ACh system focuses on providing just initial basic data as rational technical characteristics further complicate a detailed economic analysis.

The hypotheses accepted to prove novel approaches to the principles of the proposed innovative AECh engine intake air cooling system operation are the following.

The heat influx to the engine room from heat exchangers (HExch) for the production of hot water through the removing of heat from gas engine cooling water, oil, scavenge air, exhaust gas, and heat influx to the engine room from surroundings causes, by insolation and heat transfer, a considerably (twice and more) increased thermal load on the typical engine intake air cooling (EIAC) system with intake air sucked by turbocharger from the engine room. Issuing from this point, it is not reasonable to cool all the ambient air coming into the engine room as in a typical central air conditioner, but just the engine turbocharger intake air or increasing its volume in account with the alternator cooling needs.

The assumptions adopted for the comparative analysis of the fuel efficiency of the basic types and developed EIAC systems are as follows:

The lowest temperature of air cooled in the ACh of a basic EIAC system is assumed to be t_{a2} = 20 °C and limited by the minimum temperature difference of 8 °C between cooled air and chilled water, leaving the ACh at t_w = 12 °C (water at the inlet of air cooler): $t_{a2} = t_w + 8$ °C.

In the case of using a refrigerant as a coolant in the low-temperature stage of the two-stage air cooler, the temperature difference between the air being cooled and boiling refrigerant is lower, 4 or 5 °C. Proceeding from this, the values of minimum temperature t_{a2} of air cooled in refrigerant chiller might be 10 °C and lower: $t_{a2} = t_0 + (4 \text{ or } 5)$ °C.

The annual fuel reduction $\sum B$ is used as a primary criterion.

2.2. Calculation Procedure

The annual fuel reduction $\sum B$ gained due to cooling gas engine intake air at varying loading on the EIAC system in response to actual climatic conditions was calculated by summarizing current values of fuel reduction increments through the "hour-by-hour" procedure.

The real input data of on-site actual ambient air temperature t_{amb} were taken by using the program "meteomanz".

The current values of total fuel reduction per an hour were

$$B = \Delta t \cdot (\Delta b_e / \Delta t) \cdot P_e \tag{1}$$

where a specific fuel reduction (for 1 kW gas engine power output) for every 1 °C drop in engine intake air temperature is $\Delta b_e/\Delta t$, engine intake air temperature depression in the air cooler is $\Delta t = t_{a1} - t_{a2}$, and engine power output P_e, is taken according to monitoring data.

The annual fuel reduction was

$$\Sigma B = \Sigma \Delta t \cdot \tau \ (\Delta b_e / \Delta t) \cdot P_e \tag{2}$$

The values of annual emission reduction were calculated proceeding from a reduction in CO_2 emissions by 428.7 g and NO_X by 2.78 g for each 1 m^3 gas fuel reduction [62].

The heat of hot water (with a temperature of about 90 °C) produced by a cogenerative gas engine module, converted by the ACh of a simple cycle is limited by the hot water temperature drop, not more than 15 °C, in order to keep the COP of the ACh at a high level of about 0.7. As a result, the temperature of heating water at the outlet of the ACh is not lower than 75 °C. Meanwhile, the temperature of return cooled water at the inlet of the cogenerative gas engine module, used as a coolant to remove the heat from the engine, should not be higher than 70 °C in order to keep the engine at a safe thermal level. The excess of return warm water heat is traditionally extracted into the atmosphere by an emergency radiator (Figure 1). Thus, about 25% of hot water heat released from the gas engine can be converted into additional refrigeration capacity by refrigerant ECh as the simplest in design for further deeper cooling engine intake air precooled in ACh.

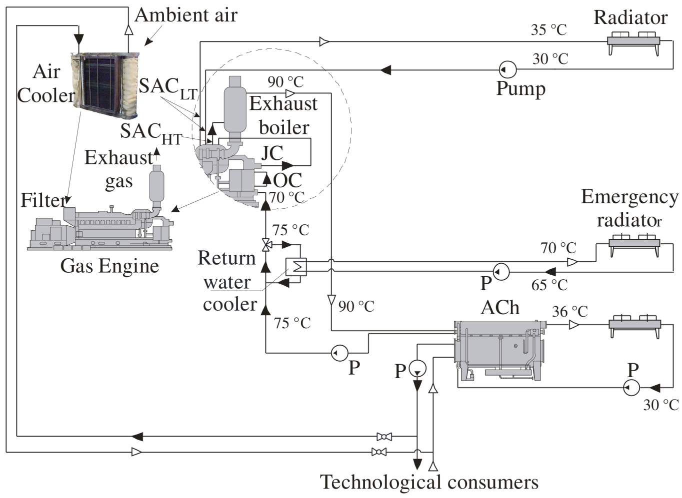
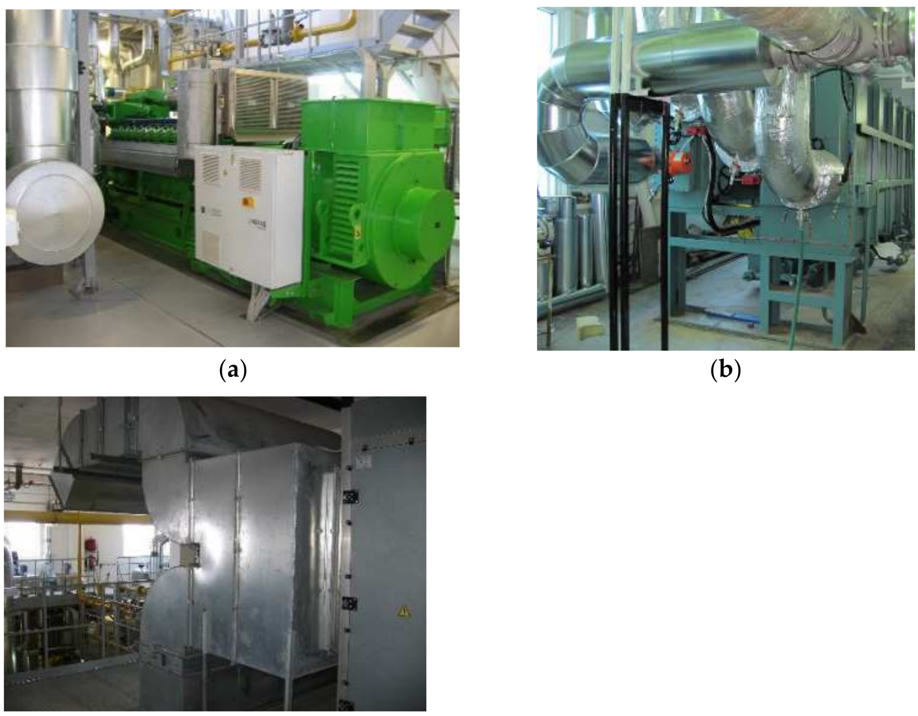


Figure 1. A schema of a typical system of cogenerative gas engine heat conversion by ACh with engine intake air cooling in the air cooler of the central conditioner by chilled water from the ACh: OC-oil cooler; JC-jacket cooler; SAC_{LT} and SAC_{HT} -low- and high-temperature scavenge air coolers.

The efficiency of gas engine inlet air cooling is investigated for the trigeneration plant of "Sandora"–"PepsiCo Ukraine" (Mykolayiv, Ukraine). The trigeneration plant is equipped with two Jenbacher gas engines JMS 420 GS-N.LC (rated electric power P_{eISO} = 1400 kW and heat Q_h = 1500 kW) and ACh AR-D500L2 Century (Figure 2).



(**a**) (**b**)

(**c**)

Figure 2. Gas engine module JMS GE Jenbacher (**a**), absorption chiller AR-D500L2 (**b**), and central conditioner for engine room incoming air cooling (**c**).

A typical scheme of gas engine inlet air cooling system is presented in Figure 3.

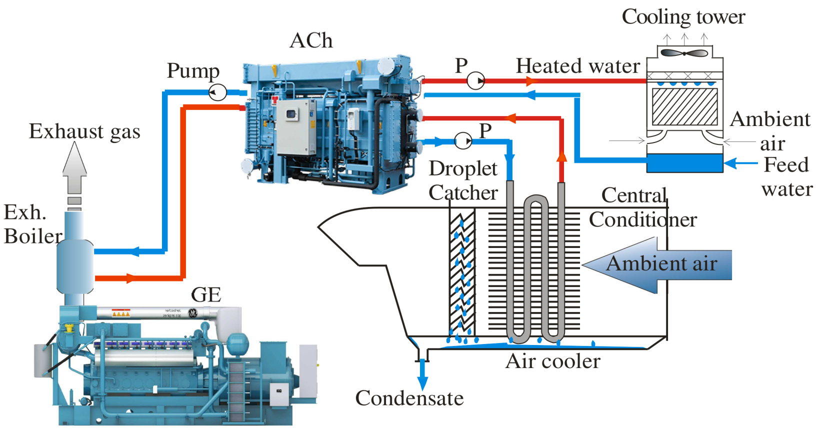


Figure 3. A scheme of a typical system of gas engine inlet air cooling in the central conditioner by chilled water from an ACh.

Because of the heat influx to cooled air stems from the engine room environment, the temperature of the air t_{in} at the inlet of the engine is higher than its value t_{HT} at the outlet of high-temperature air cooler AC_{HT} of the central conditioner by air temperature increment Δt_{ER} caused by heat influx: $t_{in} = t_{HT} + \Delta t_{ER}$ (Figure 4).

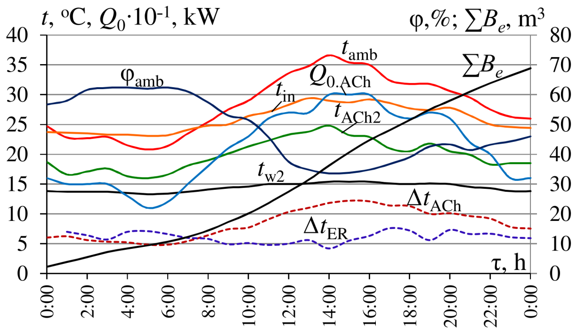


Figure 4. Daily variations in temperature t_{amb} and relative humidity φ_{amb} of ambient air, temperature of air at the gas engine inlet t_{in}, and at the high-temperature air cooler outlet $t_{ACh2} = t_{HT}$, $\Delta t_{ACh} = \Delta t_{HT} = t_{amb} - t_{HT}$; $\Delta t_{ER} = t_{in} - t_{HT}$.

A considerably increased temperature of the air at the inlet of engine t_{in} proves a non-effective operation of the conventional EIAC system by chilled water from an ACh with a temperature of 12 °C.

3. Results

In order to evaluate the effect of GE inlet air two-stage cooling, compared with conventional conditioning all the ambient air coming into the engine room, the data of gas engine JMS 420 GS-N.L fuel efficiency monitoring were used.

The results of monitoring a gas engine fuel efficiency were presented in the form of data sets on the dependence of fuel consumption $B_e = f(t_{in})$, power output $P_e = f(t_{in})$, and specific fuel consumption $b_e = B_f/P_e$ upon the air temperatures t_{in} at the inlet of the engine turbocharger. A method for processing the monitoring data on fuel consumption and power output of the gas engine was developed [11,61].

The goal of processing the monitoring data sets $P_e = f(t_{in})$, $B_e = f(t_{in})$, and $b_e = f(t_{in})$ was to calculate the value of the change in specific fuel consumption Δb_e caused by the change in the engine inlet air temperature t_{in} by 1 °C, as $\Delta b_e/\Delta t_{in}$, to estimate the fuel-saving due to applying the advanced two-stage air cooling [48,61].

The daily variation of volume gas consumption B_e and electric power P_e of engine JMS 420 GS based on monitoring data are presented in Figures 5–7.

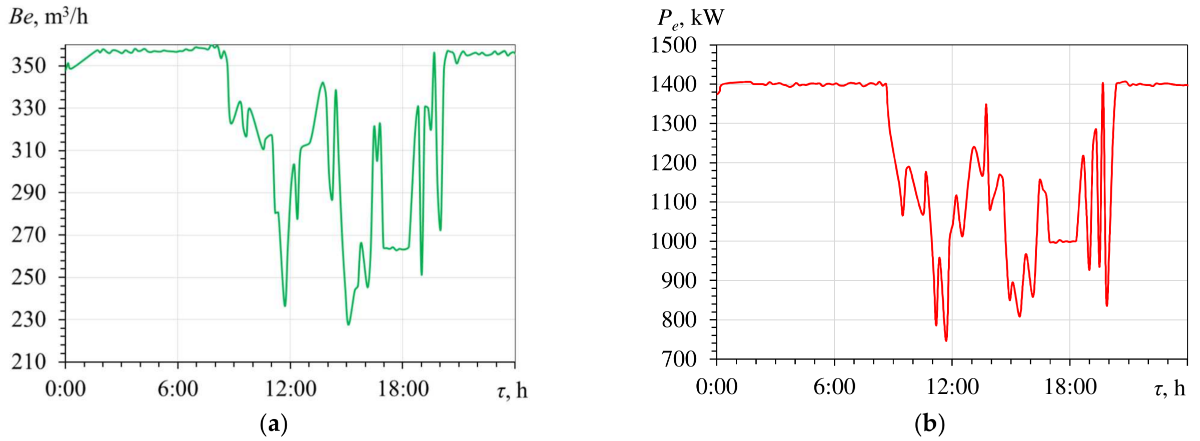


Figure 5. Daily variation of volume gas consumption B_e (**a**) and electric power P_e (**b**) of the gas engine against time τ.

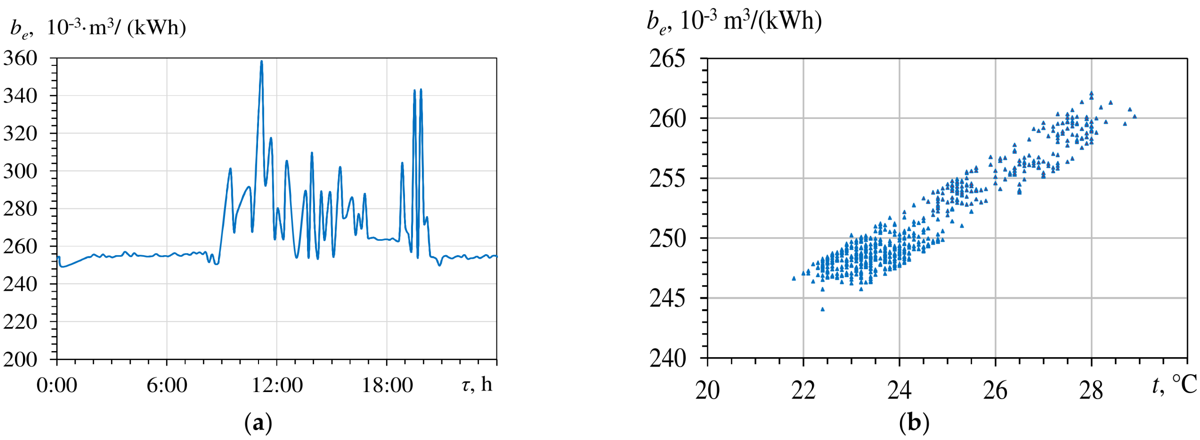


Figure 6. Specific volume gas consumption b_e aa a daily variation against time τ (**a**) and inlet air temperature t (**b**).

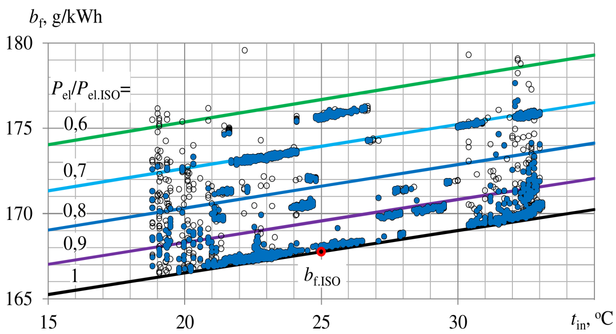


Figure 7. Variation of mass-specific fuel consumption b_f against inlet air temperature t_{in} at various loads $P_{el}/P_{el.ISO}$, P_{el}—electrical power as monitored data; $P_{el.ISO}$—rated electrical power at ISO ambient air parameters: t_{amb} = 25 °C, and relative humidity φ_{amb} = 30%.

During hot summer days at time interval τ = 9 . . . 20 h the ambient air temperatures are increased: t_{amb} = 30 . . . 35 °C, which makes it impossible to cool a charged gas-air mixture by the radiator to an appropriate level when the temperature is about 40 °C. This leads to an automatically decreasing gas supply to the engine and power output accordingly (Figure 5).

Performance of the gas engine at a raised intake air temperature t_{in} (τ = 9 . . . 20 h) is followed by an increase in specific gas consumption b_e by (20 . . . 30) × 10^{-3} $m^3/(kWh)$

(Figure 5a), i.e., 8 . . . 12% compared with engine full loading at ambient air temperatures t_{amb} and corresponding t_{in} lower than 25 °C (τ = 2 . . . 9 h).

As Figure 6 shows, arising intake air temperature t causes a considerable increase in specific volume gas consumption b_e.

As Figure 7 shows, with decreasing engine inlet air temperatures t_{in} the mass-specific fuel consumption b_f reduces by 0.25 to 0.27 g/(kWh) for 1 °C drop of engine inlet air temperature Δt_{in} = 1 °C.

A deviation of calculated values of mass-specific fuel consumption $b_{f.calc}$ from monitoring data $b_{f.monit}$ is within the range of 10% with a probability of 95% and within the range of 5% with a probability of 65% (Figure 8).

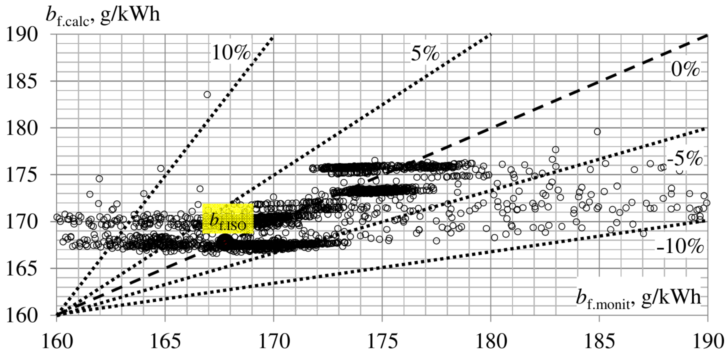


Figure 8. Mass specific fuel consumption calculated values $b_{f.calc}$ against monitoring data $b_{f.monit}$.

Issuing from a reduction in specific fuel consumption b_f with decreasing engine inlet air temperatures t_{in}, a concept of addition inlet air subcooling compared with its typical cooling by chilled water with a temperature of about 12 °C in ACh, used for technological cooling needs, is developed (Figure 9).

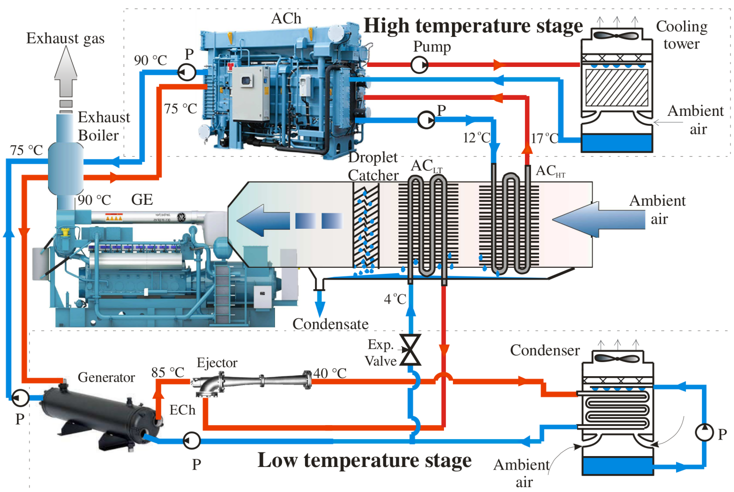


Figure 9. A two-stage absorption-ejector (AECh) system for chilling engine inlet air: AC_{HT} and AC_{LT}—high- and low-temperature air coolers; P—pump.

The calculation results of thermal loads $Q_{0.HT}$ and $Q_{0.LT}$ on high- and low-temperature air coolers and $Q_{0.AC}$ on the whole two-stage air cooler, based on the monitored air temperatures at the turbocharger inlet t_{in}, indicates current specific fuel consumption decreases Δb_e as well as daily summarized volume gas-saving ΣB_e due to engine inlet air cooling in high-temperature cooler AC_{HT} by ACh and low-temperature cooler AC_{LT} by ECh. The overall gas-saving results for two-stage AECh are presented in Figure 10.

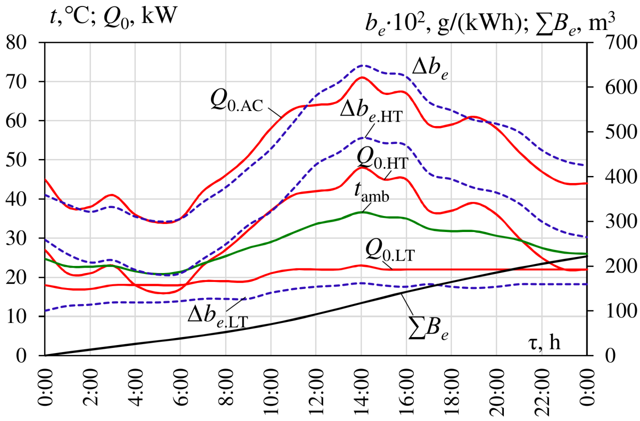


Figure 10. Daily variation of thermal loads $Q_{0.HT}$ and $Q_{0.LT}$ on high- and low-temperature air coolers and $Q_{0.AC}$ on the whole two-stage air cooler; $Q_{0.HT}$ and decreases of specific fuel consumption $\Delta b_{e.HT}$, $\Delta b_{e.LT}$, Δb_e, accordingly, and summarized volume gas-saving ΣB_e (Mykolayiv region, south of Ukraine, 2017).

Thus, the developed combined two-stage engine inlet air cooling system enables the operation of GE at a practically stabilized low sucked air temperatures at variable actual climatic conditions. This results in a reduction of specific fuel consumption by about 3 to 5 g/(kWh) or in 3% at raised ambient air temperatures t_{amb}.

4. Discussion

The application of a developed combined two-stage AECh engine inlet air cooling system enables the engine to operate at a practically stabilized low sucked air temperature at varying climatic conditions that result in monthly B and annual ΣB reduction of fuel consumption (Figure 11). With this, the annual fuel reduction ∑B is used as a primary criterion.

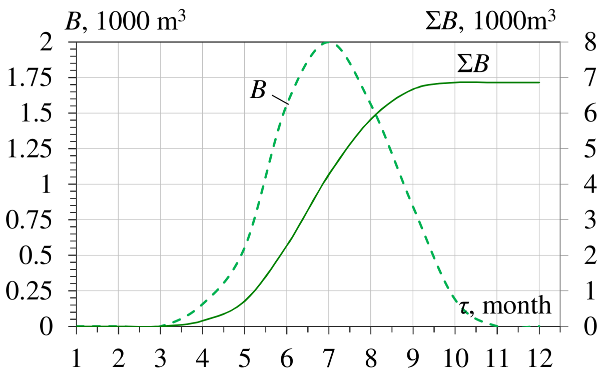


Figure 11. Monthly B and annual fuel saving ΣB for gas engine JMS 420 GS due to inlet air cooling in AECh (Mykolayiv region, south of Ukraine, 2017).

The annual fuel reduction ∑B gained due to cooling gas engine intake air at varying loading on the EIAC system in response to actual climatic conditions was calculated by summarizing the current values of fuel reduction increments through the "hour-by-hour" procedure.

The calculation results of the ecological effect due to engine intake air cooling in AECh in 2017 are presented in Figure 12. The values of the reduction in carbon dioxide ΣCO_2 emissions for GE (power output 1.4 MW) due to intake air cooling in AECh are presented in Figure 12a and the reduction in ΣNO_X emissions in Figure 12b.

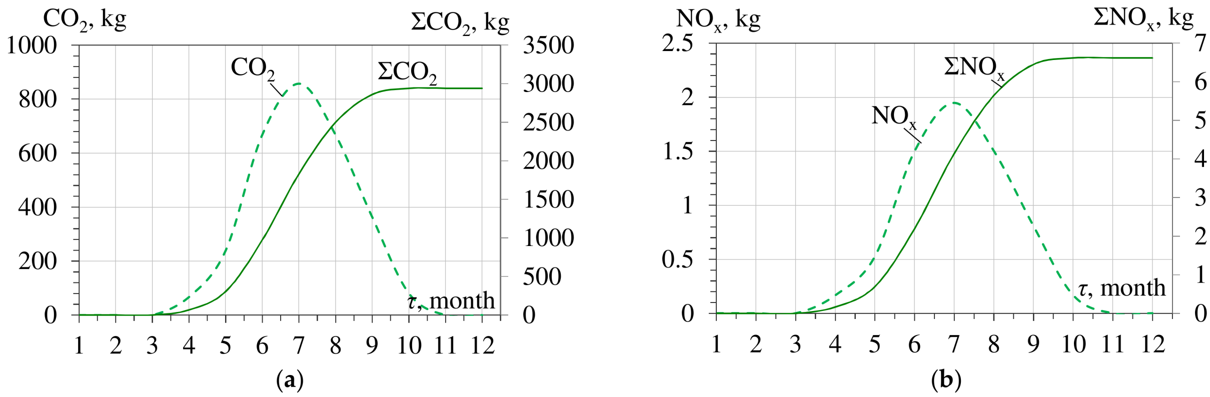


Figure 12. Monthly CO_2 and annual ΣCO_2 (**a**) and monthly NO_x and annual ΣNO_x (**b**) emission reduction due to engine inlet air cooling in AECh (Mykolayiv, southern Ukraine, 2017).

The values of the annual emission reduction were calculated issuing from a reduction in CO_2 emissions by 428.7 g and NO_X by 2.78 g for each 1 m^3 gas fuel reduction [62].

The system of TIAC in ACh and ECh consequently provides about 50% additional annual fuel saving compared with traditional air cooling in ACh for temperate climatic conditions (southern Ukraine) (Figure 13).

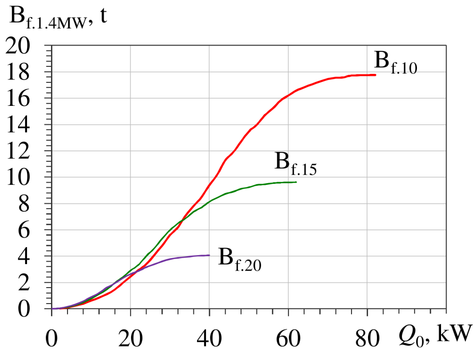


Figure 13. Annual fuel-saving ΣB B_f versus design cooling capacities Q_0 of chillers for engine intake air temperatures at 15 and 20 °C in ACh and 10 °C in AECh (Mykolayiv region, south of Ukraine, 2017).

Due to minimizing the heat influx of turbocharger suctioned air from the environment, the two-stage air cooling system enables engine performance at stabilized low intake air temperatures at varying climatic conditions.

So far as the proposed, the AECh system is the advanced version of the traditional basic ACh system. The economic comparison with the former might be done taking into account only the cost of extra heat exchangers of ECh (refrigerant evaporator-air cooler, refrigerant condenser, and ejector) with an unchanged maintenance cost, personnel, etc.

As a basic variant, the GE JMS 420 GS of the power output of 1.4 MW and air mass flow rate G_a =2 kg/s is accepted. According to Figure 10, $Q_{0.10}$ = 80 kW for EIAC system with AECh and $Q_{0.15}$ = 60 kW for the traditional ACh with corresponding annual fuel reduction $\sum B_{10}$ = 17.5 t and $\sum B_{15}$ = 9.4 t. Proceeding from these data, the value of the total cooling load on low-temperature ECh $Q_{0.10\text{-}15} = Q_{0.10} - Q_{0.15}$, i.e., 20 kW, provides additional annual fuel reduction $\sum B_{10\text{–}15} = \sum B_{10} - \sum B_{15}$ of about 8 t as compared with the traditional ACh system. Thus, the cooling capacity of a refrigerant evaporator-air cooler of ECh $Q_{0.10\text{–}15}$ = 20 kW and of refrigerant condenser $Q_{condenser} = Q_{0.10\text{–}15}$ (1 + COP), i.e., about 26 kW, where COP of ECh can be accepted as 0.3. Taking into account the cost of extra heat exchangers of ECh (about \$4420 according to [63]) and including its additional 10% increase for ejectors and 10% for mounting, the cost of additional equipment of ECh is about \$5300. On the other hand, the cost of gas fuel annually saved is about \$8000 (proceeding from the price of gas \$1000 per 1000 m^3) and the payback period is less than a year.

The application of a cheap ECh as a low-temperature stage of AECh is quite reasonable in contrast to applying the additional (quite expensive) ACh that is able to produce chilled water of about 7 °C and was able to cool air lower than 15 °C. Additionally, the ECh cools air to 10 °C and has about a 50% additional annual fuel savings compared with cooling the air to 15 °C with an ACh (Figure 13). Furthermore, the ECh with refrigerant boiling at a temperature lower than 5 °C might be used to produce chilled water accumulated at decreased ambient air temperature and the thermal load on the EIAC system to cover peaked cooling needs.

Because of the fluctuations in the cost of heat exchangers of different manufacturers and the price of the gas fuel especially, the economic analysis is to be conducted for the concrete case. Thus, the considered method of designing focuses to provide just initial basic data as rational technical characteristics for further complicated detailed economic analysis.

5. Conclusions

An analysis of monitoring data on the fuel consumption of gas engine JMS 420 GS-N.L has proved the typical cooling of the ambient air incoming into the engine room in ACh with a chilled water temperature of about 12 °C, required for technological duties, is inefficient.

A novel concept of two-stage engine inlet air cooling in trigeneration IES for food industries is proposed which issues from the monitoring data on the reduction in specific fuel consumption with lowering the temperatures of air at the inlet of the engine. An engine intake air cooling (EIAC) system is developed that includes an ACh as a high-temperature stage for cooling ambient air to about 20 °C by chilled water of about 12 °C (used for technological needs) and refrigerant ejector chiller as the second low-temperature stage of EIAC that uses a cooling potential (not realized by Ach) for further cooling of the air to about 10 °C by boiling refrigerant.

A refrigerant ejector chiller (ECh) is the simplest in design, cheap and can be applied as the low-temperature stage of a two-stage absorption-ejector chiller (AECh) to provide engine intake air cooling and increase engine fuel efficiency as result.

The combined two-stage waste heat recovery cooling system developed is practically independent of load modes of technological cold consumers due to using a cooling potential not realized by an ACh and enables a high fuel efficiency of GE − reduction of specific fuel consumption of GE JMS 420 GS by 3 to 5 g/(kWh), and even uses the an additional cooling capacity generated by an ECh for technological needs resulting in a design that is more adaptable to changeable thermal loads.

The combined two-stage waste heat conversion provides an increase in the annual fuel saving by about 50% for a temperate climate as compared with typical EIAC based on an ACh.

The application of a cheap ECh as a low-temperature stage of AECh is quite reasonable in contrast to applying the additional, quite expensive, ACh that is able to produce chilled water of about 7 °C and cools air lower than 15 °C. Additionally, the ECh provides cooled air of about 10 °C and about 50% additional annual fuel saving compared with cooling the air to 15 °C in an ACh (Figure 13). Furthermore, the ECh with refrigerant boiling at a temperature lower than 5 °C might be used to produce chilled water accumulated at decreased ambient air temperature and thermal load on the EIAC system to cover peaked cooling needs.

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Nomenclature and Units

AC	air cooler	
AC_{HT}	high-temperature air cooler	
AC_{LT}	low-temperature air cooler	
ACh	absorption lithium-bromide chiller	
AECh	absorption-ejector chiller	
COP	coefficient of performance	
ECh	ejector chiller	
EIAC	engine intake air cooling	
HExch	heat exchangers	
O	optimal point for maximum rate of annual fuel reduction increment	
R	rational point for closed to maximum annual fuel reduction	
Symbols and units		
B	total mass fuel consumption decrease, B = CDH ($\Delta b_e/\Delta t$)·P_e.	g, kg, t
b_e	specific fuel consumption	g/kWh
c_a	specific heat of humid air	kJ/(kg·K)
CDH	CDH = $\Delta t \cdot \tau$	K·h
d_{amb}	ambient air absolute humidity	g/kg
G_a	air mass flow rate	kg/s
P_e	power output	kW
Q_0	total cooling capacity, heat flow rate	kW
q_0	specific cooling capacity—per unit air mass flow rate	kW/(kg/s) or kJ/kg
t	temperature	°C
t_{amb}	ambient air temperature	°C
t_{a2}	outlet air temperature	°C
t_0	refrigerant boiling temperature	°C
ξ	specific heat ratio of the total heat (latent and sensible) rejected from air to its sensible heat	
τ	time interval	h
φ_{amb}	ambient air relative humidity	%
Δb_e	specific fuel consumption decrease	g/kWh
Δt	air temperature decrease	K, °C
$\sum B_{10,15,20}$	annual total fuel reduction due to cooling engine intake air to 10, 15, 20 °C	t
$\sum b_{10,15,20}$	annual specific fuel reduction (per 1 kW engine power output) due to cooling engine intake air to 10, 15, 20 °C	g, kg, t
Subscripts		
a	air	
amb	ambient	
max	maximum	
opt	optimal	
rat	rational	

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