

# Increasing electrical power output and fuel efficiency of gas engines in integrated energy system by absorption chiller scavenge air cooling on the base of monitoring data treatment

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**Abstract.** An advanced scavenge air cooling system for reciprocating gas engines of integrated energy system for combined electricity, heat and refrigeration generation has been developed. New method of deep scavenge air cooling and stabilizing its temperature at increased ambient air temperatures and three-circuit scavenge air cooling system with absorption lithium-bromide chiller and wet-type cooling tower was proposed. Such cooling method does not require essential constructive changes in the existing scavenge air cooling system but only an addition heat exchanger for chilling scavenge air cooling water of scavenge air low-temperature intercooler closed contour by absorption chiller. A chilled water from absorption chiller is used as a coolant. To evaluate the effect of gas engine scavenge air deeper cooling compared with its typical radiator cooling, data on the dependence of fuel consumption and power output of gas engine on ambient air temperature at the inlet of the radiator are analyzed. The efficiency of engine scavenge air deep cooling at increased ambient air temperatures was estimated by reducing the gas fuel consumption compared with radiator cooling.

## 1 Introduction

Reciprocating gas engines (RGE) found a widespread application in integrated energy systems (IES) or so called trigeneration systems for combined electricity, heat and refrigeration generation. They are manufactured as cogeneration modules equipped with heat exchangers for producing hot water used also as a heat source for absorption chiller [1–3].

The specific fuel consumption of gas engines increases with arising turbocharger (TC) suction air and scavenge gas-air mixture temperatures at the inlet of engine cylinders. The cooling problem arises especially actually for scavenge air, which heat is rejected traditionally to surroundings by radiator (cooling tower of dry type) through intermediate water cooling contour of engine low-temperature intercooler. The efficiency of such heat rejecting system drops sharp with increasing ambient air temperature above 25...30 °C, when it becomes impossible to cool scavenge air to appropriate temperature of about 40 °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.

At high ambient air temperature the exceeding scavenge air temperature causes operation of gas engine

on increasing specific gas fuel consumption compared with rated load mode. So, for maintenance of gas engine on rated load or close modes it is necessary more decrease in temperature of cooling water in intermediate cooling contour of low-temperature intercooler. For this purpose a chilled water received in absorption chiller might be used.

To evaluate the effect of gas engine scavenge air deeper cooling compared with its typical radiator cooling, data on the dependence of fuel consumption and power output of gas engine on ambient air temperature at the inlet of the radiator are to be analyzed. A method for treatment of the monitoring data on fuel consumption and power output of gas engine was presented in [4].

**The goal** of the research is improving the fuel efficiency of IES on the base of reciprocating gas engines (RGE) while operation at increased ambient air temperatures through using an absorption lithium-bromide chiller (ABCh) for deeper scavenge air cooling in comparison with radiator cooling.

## 2 Investigating the efficiency of typical gas engine scavenge air cooling system

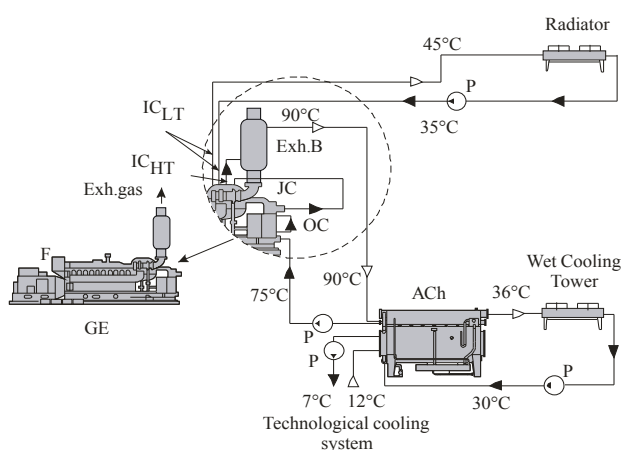
The efficiency of cooling gas engine scavenge air is investigated for IES of combined energy supply at the factory "Sandora"-"PepsiCo Ukraine" (Nikolaev, Ukraine). The integrated energy system is equipped with 2 cogeneration Jenbacher gas engines JMS 420 GS-N.LC (rated electric power  $P_{eISO} = 1400$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

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$P_h = 1500$  kW) and absorption lithium-bromide chiller, designed and assembled by "Sinapse"—"GE Energy" (Kiev) and "Khladotechnika" (Nikolaev). The heat of engine scavenge air is rejected to the environment by radiator as cooling tower of dry type.

The absorption chiller utilizes the heat of engine exhaust gas, high temperature scavenge air, engine jacket and lubricant oil cooling water to produce a chilled water with temperature of about  $7^\circ\text{C}$  for technology process cooling and conditioning of air in engine room by central conditioners.

The scheme of conventional integrated energy system of factory "Sandora"—"PepsiCo Ukraine" is presented in Fig. 1. The engine room intake air is cooled in the central conditioner by chilled water from absorption lithium-bromide chiller and the engine turbochargers take air from engine room.



**Fig. 1.** The scheme of integrated energy system (trigeneration system) of factory "Sandora"—"PepsiCo Ukraine": GE – gas engine; OC – oil cooler; JC – jacket cooler; ExhB – exhaust gas boiler; IC<sub>LT</sub> and IC<sub>HT</sub> – low- and high-temperature intercoolers of charged gas-air mixture; F – intake air filter; AC – intake air cooler; ACh – absorption chiller; P – pump.

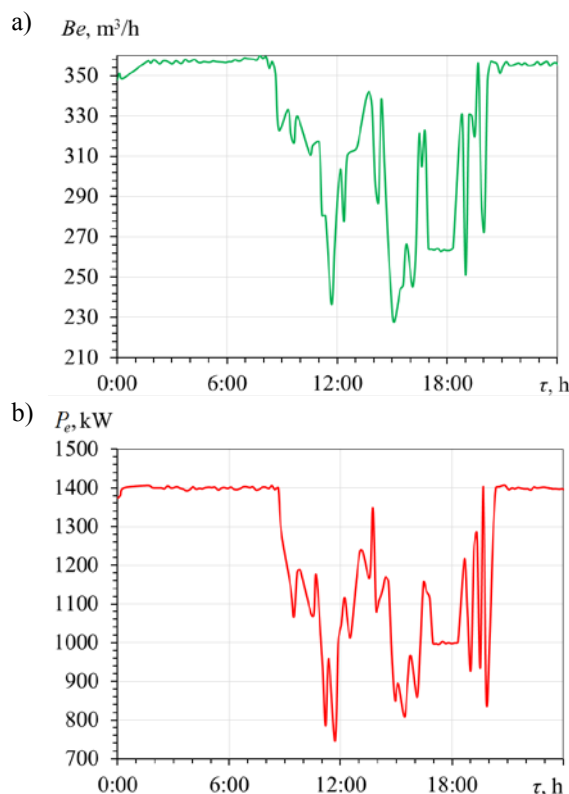
Intercooler of scavenge air consists of two stages: high-temperature stage (IC<sub>HT</sub>), in which cooling of scavenge air-gas mixture is followed by heating water for absorption chiller, and low-temperature stage (IC<sub>LT</sub>), from which the heat is rejected to the environment by radiator-cooling tower of dry type.

Some results of monitoring daily variation of volume gas supply  $B_e$  and electric power output  $P_e$  of gas engine JMS 420 GS-N.LC automatically changed to maintain a charged gas-air mixture temperature at the level of about  $40^\circ\text{C}$  are presented in Fig. 2 [5].

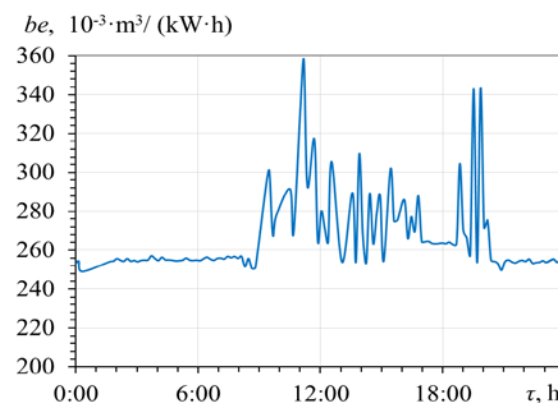
In summer hot day time interval  $\tau = 9 \dots 20$  h the ambient air temperatures are rather high:  $t_{\text{amb}} = 30 \dots 35^\circ\text{C}$ , that makes impossible reliable cooling of scavenge gas-air mixture by radiator to appropriate temperature level of  $40^\circ\text{C}$ . This results in automatically reducing gas supply to engine followed by decreasing load to maintain gas-air mixture temperature at the level of  $40^\circ\text{C}$  (Fig. 2).

A performance of gas engine on part load modes ( $\tau = 9 \dots 20$  h) is followed by increase in specific gas consumption  $b_e$  by  $(20 \dots 30) \cdot 10^{-3} \text{ m}^3 / (\text{kW} \cdot \text{h})$  (Fig. 3), i.e. 8...12 % compared with engine full loading at

temperatures  $t_{\text{amb}}$  and  $t_{\text{in}}$  more low  $25^\circ\text{C}$  ( $\tau = 2 \dots 9$  h).



**Fig. 2.** Daily variation of volume gas supply  $B_e$  (a) and electric power  $P_e$  (b) of gas engine with time  $\tau$  (July 17, 2011).



**Fig. 3.** Daily variation of engine specific volume gas consumption  $b_e$  with time  $\tau$  (July 17, 2011).

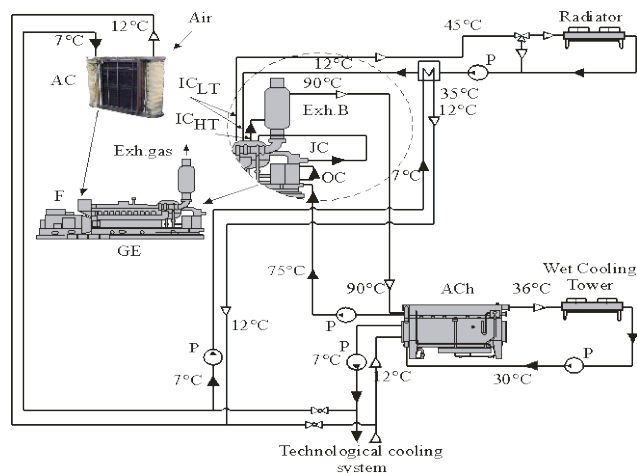
A reduction of time duration of engine performance at part load modes ( $\tau = 9 \dots 21$  h, Fig. 3) and decrease of specific gas consumption  $b_e$  is possible by addition decreasing temperature of scavenge air cooling water by absorption chiller before it entering the engine low-temperature intercooler IC<sub>LT</sub> to maintain a scavenge gas-air mixture temperature at the appropriate level of  $40^\circ\text{C}$  with variation of ambient temperatures  $t_{\text{amb}}$ .

### 3 Investigating the efficiency of improved gas engine scavenge air cooling system

A reduction of time duration of engine performance at part load modes ( $\tau = 9 \dots 21$  h, Fig. 3) and decrease of specific gas consumption  $b_e$  is possible by addition decreasing temperature of scavenge air cooling water by absorption chiller before it entering the engine low-temperature intercooler  $IC_{LT}$  to maintain a scavenge gas-air mixture temperature at the appropriate level of  $40^\circ\text{C}$  with variation of ambient temperatures  $t_{amb}$ .

A principal scheme of improved three-circuit scavenge air cooling system with absorption lithium-bromide chiller and wet-type cooling tower is presented in Fig. 4. Such cooling system does not require constructive changes in the scavenge air channel of gas engine and needs only an addition heat exchanger for heat transfer between the circuits connected to the closed water circuit of a traditional scavenge air cooler.

Thus chilled water with temperature  $t_c = 7^\circ\text{C}$  is directed from absorption chiller to addition plate water cooler, inserted into the current closed water cooling contour, to cool a cooling water at the inlet of the engine low-temperature intercooler  $IC_{LT}$  (Fig. 4).

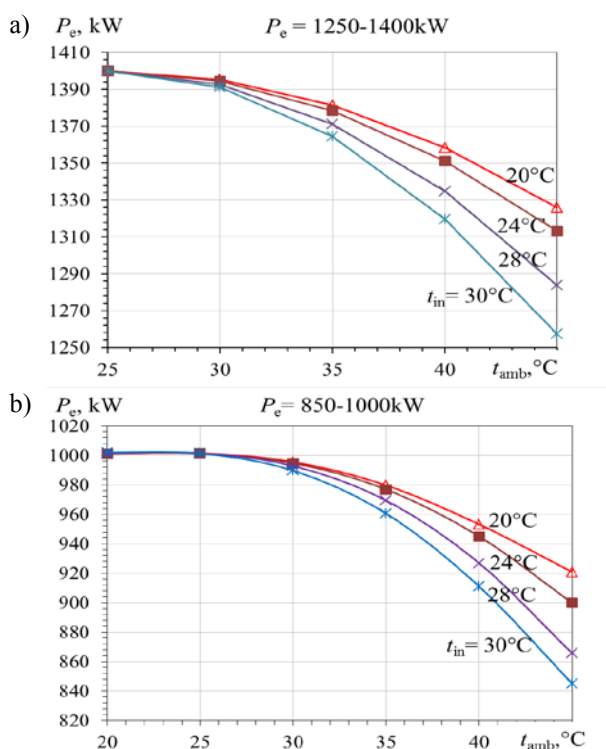


**Fig. 4.** The scheme of modified trigeneration system with addition cooling of cooling water for low-temperature intercooler of scavenge gas-air mixture: GE – gas engine; OC – oil cooler; JC – jacket cooler; ExhB – exhaust gas boiler;  $IC_{LT}$  and  $IC_{HT}$  – low- and high-temperature intercoolers of scavenge gas-air mixture; F – intake air filter; ACh – absorption chiller; P – pump; Heat Exh – heat exchanger.

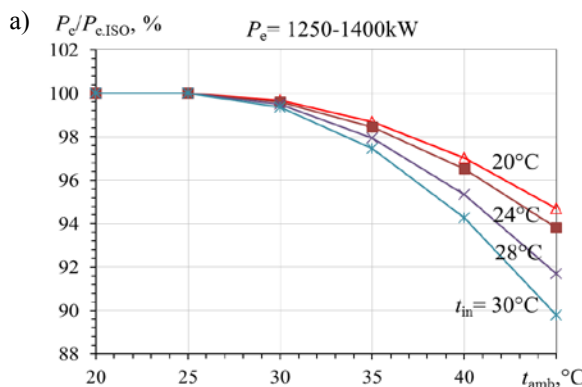
The results of monitoring of JMS 420 GS-N.L engine fuel efficiency were presented in the form of data sets on dependence of fuel consumption  $B_e = f(t_{amb})$  and engine power output  $P_e = f(t_{amb})$  upon the ambient air temperature  $t_{amb}$  at the entrance to the radiator of scavenge air cooling for the various air temperatures  $t_{in}$  at the inlet of the turbocharger. The goal of monitoring data sets  $P_e = f(t_{amb})$  and  $B_e = f(t_{amb})$  treatment is to calculate the magnitude of the change in power  $\Delta P_e$  and fuel consumption  $\Delta B_e$ , caused by the change in the ambient air temperature  $t_{amb}$  at the entrance to the radiator of scavenge air cooling by  $1^\circ\text{C}$ , that is  $\Delta P_e / \Delta t_{amb}$  and  $\Delta B_e / \Delta t_{amb}$ , to evaluate the effect of the application of

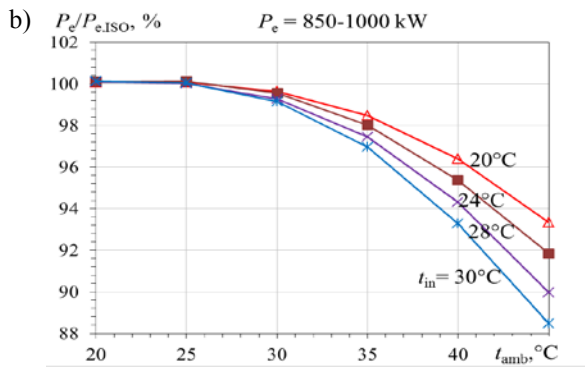
developed scavenge air cooling system.

The results of treatment of data for variation of electrical power output in absolute values  $P_e$  and relative values  $P_e / P_{eISO}$  compared to ISO value with changing ambient air temperature  $t_{amb}$  at the inlet of radiator for scavenge air cooling and also power output drops  $\Delta P_e / \Delta t_{amb} / P_{eISO}$  for  $1^\circ\text{C}$  increment of ambient air temperature  $\Delta t_{amb} = 1^\circ\text{C}$  at the inlet of radiator for scavenge air cooling at various air temperatures at the inlet of turbocharger  $t_{in} = 20 \dots 30^\circ\text{C}$  for Jenbacher gas engine JMS 420 GS-N.LC at about rated electrical power output  $P_e = 1250 \dots 1400$  kW ( $P_{eISO} = 1400$  kW) and at part loads  $P_e = 850 \dots 1000$  kW are presented below in Fig.5-8.

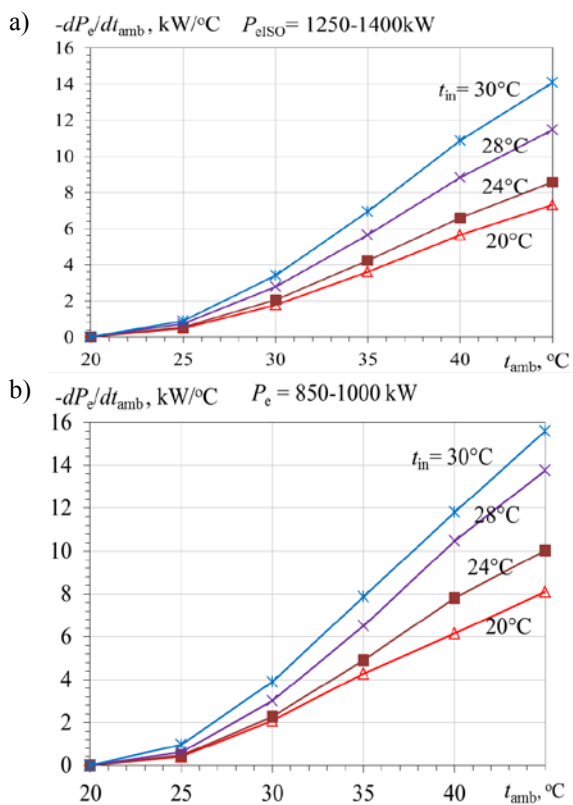


**Fig. 5.** Decrease of electrical power output  $P_e$  versus increasing ambient air temperature  $t_{amb}$  at the inlet of radiator for scavenge air cooling at various air temperatures at the inlet of turbocharger  $t_{in} = 20 \dots 30^\circ\text{C}$  for Jenbacher gas engine JMS 420 GS-N.LC at about rated electrical power output  $P_e = 1250 \dots 1400$  kW (a) and at part loads  $P_e = 850 \dots 1000$  kW (b).

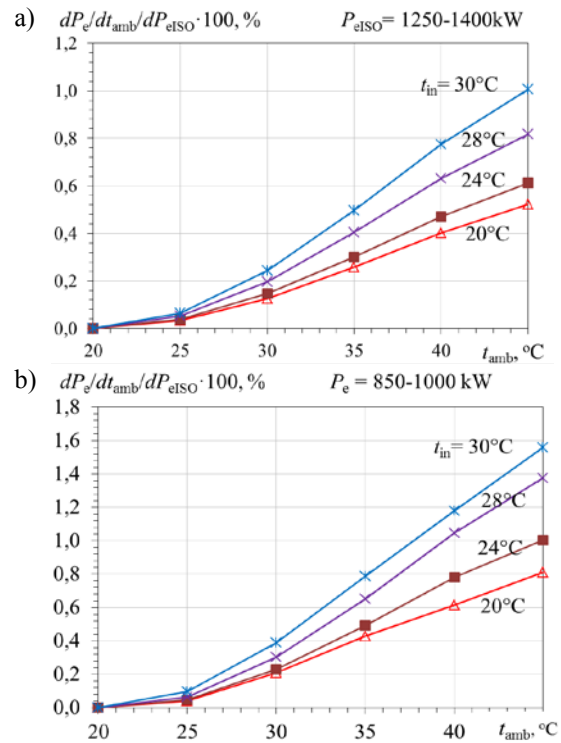




**Fig. 6.** Decrease of electrical power output in relative values  $P_e/P_{e,ISO}$  compared to ISO value versus increasing ambient air temperature  $t_{amb}$  at the inlet of radiator for scavenge air cooling at various air temperatures at the inlet of turbocharger  $t_{in} = 20...30$  °C for Jenbacher gas engine JMS 420 GS-N.LC at about rated electrical power output  $P_e = 1250...1400$  kW (a) and at part loads  $P_e = 850...1000$  kW (b).

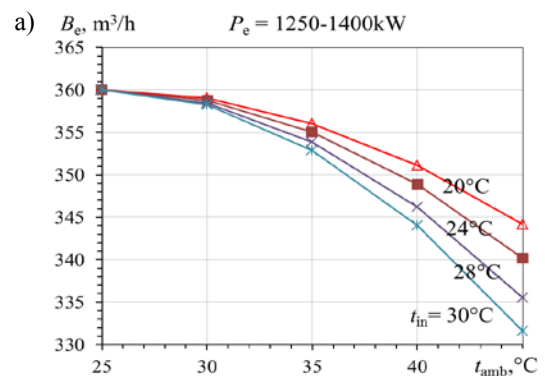


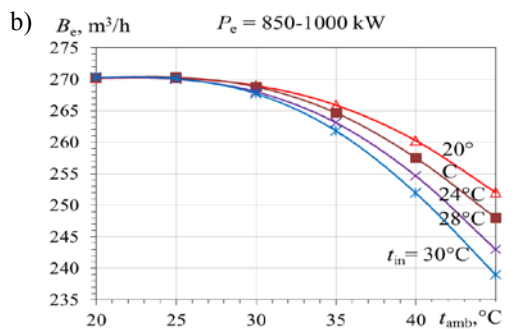
**Fig. 7.** Increase of electrical power output drop  $\Delta P_e/\Delta t$  for 1 °C increment of ambient air temperature  $\Delta t_{amb} = 1$  °C at the inlet of radiator for scavenge air cooling versus increasing ambient air temperature  $t_{amb}$  at the inlet of radiator at various air temperatures at the inlet of turbocharger  $t_{in} = 20...30$  °C for Jenbacher gas engine JMS 420 GS-N.LC at about rated electrical power output  $P_e = 1250...1400$  kW (a) and at part loads  $P_e = 850...1000$  kW (b).



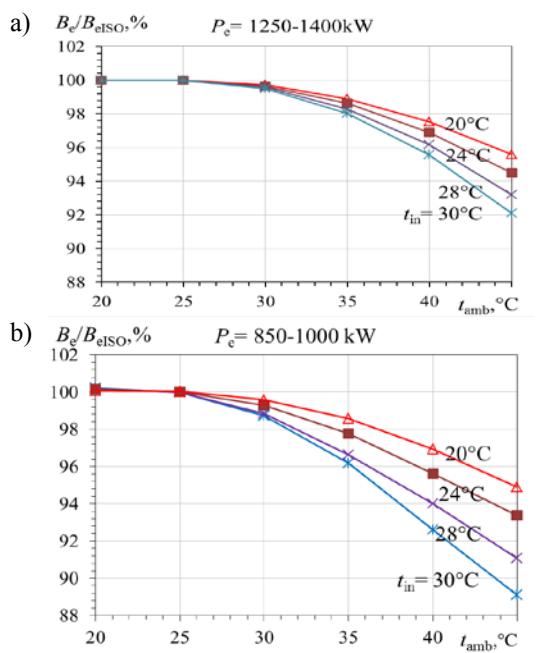
**Fig. 8.** Increase of electrical power output drop for 1 °C increment  $\Delta t$  of ambient air temperature  $\Delta t_{amb} = 1$  °C at the inlet of radiator for scavenge air cooling in relative values  $\Delta P_e/\Delta t/P_{e,ISO}$  compared to ISO value versus increasing ambient air temperature  $t_{amb}$  at the inlet of radiator at various air temperatures at the inlet of turbocharger  $t_{in} = 20...30$  °C for Jenbacher gas engine JMS 420 GS-N.LC at about rated electrical power output  $P_e = 1250...1400$  kW (a) and at part loads  $P_e = 850...1000$  kW (b).

The results of treatment of monitoring data on volume gas fuel consumption in absolute values  $B_e$  and relative values  $B_e/B_{e,ISO}$  compared to ISO value and also increase in volume gas fuel consumption  $B_e/\Delta t$  and increase in engine specific volume gas fuel consumption  $\Delta b_e/\Delta t$  for 1 °C increment  $\Delta t$  of ambient air temperature  $\Delta t = 1$  °C at the inlet of radiator for scavenge air cooling with changing ambient air temperature  $t_{amb}$  at the inlet of radiator are presented in Fig. 9-12.

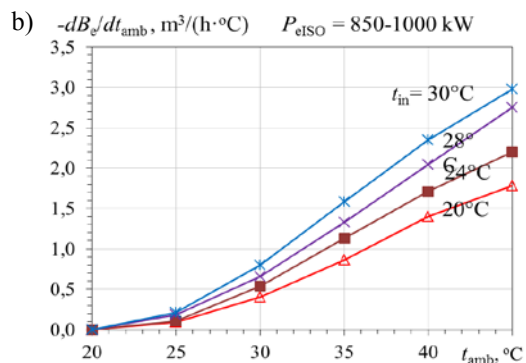
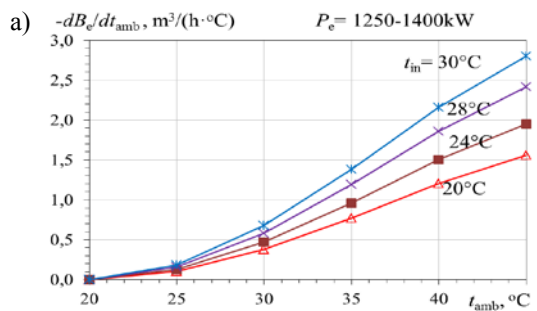




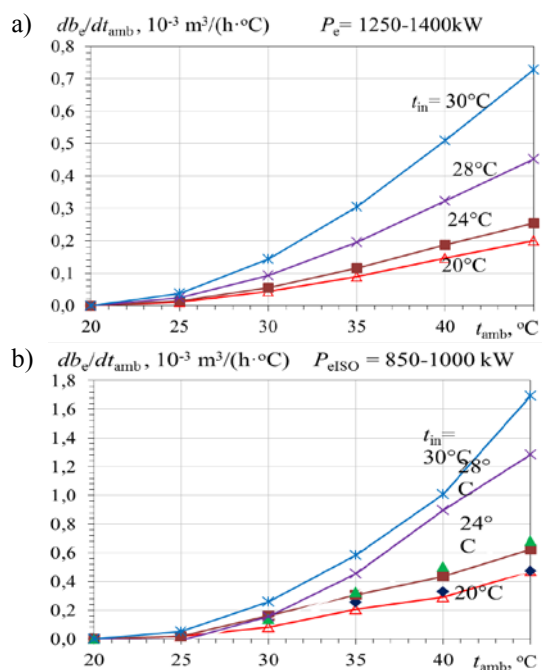
**Fig. 9.** Decrease of volume gas fuel consumption  $B_e$  versus increasing ambient air temperature  $t_{\text{amb}}$  at the inlet of radiator for scavange air cooling at various air temperatures at the inlet of turbocharger  $t_{\text{in}} = 20...30^\circ\text{C}$  for Jenbacher gas engine JMS 420 GS-N.LC at about rated electrical power output  $P_e = 1250...1400 \text{ kW}$  (a) and at part loads about  $P_e = 850...1000 \text{ kW}$  (b).



**Fig. 10.** Decrease of volume gas fuel consumption in relative values  $B_e/B_{\text{elSO}}$  compared to ISO value versus increasing ambient air temperature  $t_{\text{amb}}$  at the inlet of radiator for scavange air cooling at various air temperatures at the inlet of turbocharger  $t_{\text{in}} = 20...30^\circ\text{C}$  for Jenbacher gas engine JMS 420 GS-N.LC at about rated electrical power output  $P_e = 1250...1400 \text{ kW}$  (a) and at part loads about  $P_e = 850...1000 \text{ kW}$  (b).



**Fig. 11.** Increase of volume gas fuel consumption  $B_e/\Delta t$  for  $1^\circ\text{C}$  increment  $\Delta t$  of ambient air temperature  $\Delta t_{\text{amb}} = 1^\circ\text{C}$  at the inlet of radiator for scavange air cooling versus increasing ambient air temperature  $t_{\text{amb}}$  at the inlet of radiator at various air temperatures at the inlet of turbocharger  $t_{\text{in}} = 20...30^\circ\text{C}$  for Jenbacher gas engine JMS 420 GS-N.LC at about rated electrical power output  $P_e = 1250...1400 \text{ kW}$  (a) and at part loads about  $P_e = 850...1000 \text{ kW}$  (b).



**Fig. 12.** Increase of engine specific volume gas fuel consumption  $b_e/\Delta t$  for  $1^\circ\text{C}$  increment  $\Delta t$  of ambient air temperature  $\Delta t = 1^\circ\text{C}$  at the inlet of radiator for scavange air cooling versus increasing ambient air temperature  $t_{\text{amb}}$  at the inlet of radiator at various air temperatures at the inlet of turbocharger  $t_{\text{in}} = 20...30^\circ\text{C}$  for Jenbacher gas engine JMS 420 GS-N.LC at about rated electrical power output  $P_e = 1250...1400 \text{ kW}$  (a) and at part loads about  $P_e = 850...1000 \text{ kW}$  (b).

Thus, from Fig. 12,a, at operation of JMS 420 GS-N.L at about rated power (1200...1400 kW) and high ambient air temperatures  $t_{\text{amb}} = 30...35^\circ\text{C}$  at the inlet of radiator for scavange air cooling and at the TC intake air temperatures  $t_{\text{in}} = 25...30^\circ\text{C}$  the engine specific volume gas fuel consumption increase  $\Delta b_e/\Delta t$  for  $1^\circ\text{C}$  increment of ambient air temperature  $\Delta t = 1^\circ\text{C}$  at the inlet of radiator may be assumed of about  $(0.5...1.0) \cdot 10^{-3} \text{ m}^3/(\text{kW}\cdot\text{h})$ . A three-circuit scavange air cooling

system with ABCh (Fig.4) allows to maintain practically unchangeable scavenge air cooling water temperature of about  $t_{cw} = 10...12\text{ }^{\circ}\text{C}$  with the temperature of cooled water from ABCh of  $7\text{ }^{\circ}\text{C}$  and ambient air temperatures  $t_{amb} = 30...35\text{ }^{\circ}\text{C}$ . So such system can provide scavenge air cooling water temperature decrease of about  $20...25\text{ }^{\circ}\text{C}$  compared with conventional scavenge air cooling system with radiator, that results in reduction of engine specific fuel consumption by about  $\Delta b_e = (10...12) \cdot 10^{-3}\text{ m}^3 / (\text{kW} \cdot \text{h})$ , i.e. about 4...5% decrease in specific fuel consumption at increased ambient air temperatures  $t_{amb} = 30...35\text{ }^{\circ}\text{C}$ . At part loads 850...1000 kW a reduction of specific fuel consumption is nearly twice higher (Fig. 12,b).

The efficiency of deep scavenge air cooling by absorption chiller and stabilization of its temperature for JMS 420 GS-N.L results in reduction of the cost of 1 kW generated electricity by 5...7% compared with traditional radiator cooling.

## 4 Conclusions

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 refrigeration generation has proved non-effective performance of conventional scavenge air cooling by radiator at increased ambient temperatures. The improved gas engine scavenge air cooling system with absorption chiller conversing waste heat of engine into refrigeration was proposed.

An advanced scavenge air cooling system allows to maintain practically stable scavenge air cooling water temperature of about  $10...12\text{ }^{\circ}\text{C}$  with the temperature of cooled water from absorption chiller of  $7\text{ }^{\circ}\text{C}$  at high ambient air temperatures. This system provides an increase of engine electrical power output by 2...3% and decrease of specific fuel consumption by about 4...5% as compared with conventional radiator scavenge air cooling at increased ambient air temperatures 30...35  $^{\circ}\text{C}$ . At part loads the effect is much more.

For modernization of the existing traditional

scavenge air cooling system for gas engine of integrated energy system for combined electricity, heat and refrigeration generation such cooling method does not require essential constructive changes but only an addition heat exchanger for chilling scavenge air cooling water of scavenge air low-temperature intercooler closed contour by absorption chiller.

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