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Comparison of Fuel Saving For Air by Chiller at The Entrance to The Gas Turbine Between Two Areas in Libya

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Abstract.

This paper prepares the analysis of gas turbine (GT) and generator analysis as a basis for the climatic position of the power sector between two different Libyan cities, Tripoli in the north and Hon in the south Libya. It is therefore a system characterized by high intake air temperatures and reduced energy efficiency, requiring intake cooling air. Lithium bromide absorption coolers reduce gas turbine inlet air temperatures by up to 15°C and water-ammonia absorption coolers and refrigerant spray with air temperature reductions of up to 10°C and little use of heat from the turbine's exhaust gases are considered waste heat. Heat transformer. Fuel savings by cooling gas turbine inlet air to different temperatures using different types of heat converters have been evaluated in regions of Libya where electricity production is concentrated in generators. turbine. The gas turbine inlet cooling air reaches temperatures of up to 10 and 7°C via refrigerant injection coolers and water-ammonia absorption which have been shown to deliver annular fuel savings greater than 1, 3 to 1.5 times that of a lithium bromide absorption cooler supplying gas turbine inlet. Air temperature drops to 15 ° C. As a result, higher efficiency of deep cooling of gas turbine intake air to temperatures of 10 and 7°C through water-ammonia absorption and refrigerant injection coolers has been demonstrated. The possibility of annular fuel savings due to air cooling at the inlet of gas turbine generators using different types of thermal converters was evaluated for Libyan regions where electricity production is concentrated.

Keywords: gas turbine (GT), generator, fuel saving, absorption lithium-bromide chiller, refrigerant ejector chiller, absorption aqua-ammonia chiller, intake cooling air, exhaust gas waste heat recovery, climatic conditions.

1. INTRODUCTION

Gas turbine (GT) generators are the base of the electric power sector of Libya. The electricity production of the total amount of about 5000 MW is concentrated in six regions: Tripoli (32 %), Benghazi (15 %), West Region (20 %), Middle Region (18%), East Region (6%), South Region (9%) [1].

Gas turbine fuel efficiency essentially depends on the intake ambient air temperature t_{HB} and decreases with its increase. So, with the increase of ambient air temperature t_{HB} at the inlet of a simple cycle gas turbine LM2500+ "General Electric" (N_e = 27 MW at t_{HB} = 15 ºC) by 10 ºC the gas turbine efficiency drops by 2 % with a corresponding increase of specific fuel consumption b_e, and for LM1600 (N_e = 15 MW) – approximately by 1,6 % [2]. Because of the intake air temperature raising the electrical power output of GT is lower than its nominal value by 15–20% [1]. Therefore the problem of GT intake cooling air is particularly actual in the energy of Libya, especially Tripoli and Hon.

A climatic map of Libya is characterized by essential differences of ambient conditions (temperature t_{amb} and relative humidity φ of ambient air) in above mentioned six regions, where the electricity production by gas turbine electrical stations is concentrated.

A depth of gas turbine intake cooling air by the thermotransformers – waste heat recovery chillers, using the waste heat of exhaust gas, and consequently a decrease in gas turbine fuel consumption is limited by the temperature t_{x} of a coolant submitted to the air cooler at the suction of gas turbine compressor. So, if the ozone-safe refrigerants R142B and R600 are used as a coolant in an ejector thermotransformer (ETT) or ammonia in absorption aqua-ammonia thermotransformer (ALBTT) the gas turbine intake air can be chilled to the temperature t_{B2} = 10 ºC and even down to 7 ºC (with t_{x} = 2…3 ºC) [2, 3–6], but in the case of water applied as a coolant in absorption lithium-bromide thermotransformers (ALBTT) the temperature of chilled air is higher: t_{B2} = 15…17 ºC (t_{x} ≈ 7 ºC) [3, 4, 7, 8].

Ambient air parameters are characterized not only by seasonal, but also by daily fluctuations of temperature t_{HB}, and consequently, by changeable magnitudes of its depression $\Delta t_{B} = t_{HB} - t_{B2}$ during the cooling air process and corresponding values of decrease in fuel consumption. Therefore the estimation of efficiency of engine intake cooling air by fuel saving should be made taking into account the actual changing values of ambient air temperature t_{HB} and the temperatures of chilled air t_{B2}, depending on the type of thermotransformer.

The goal of the analysis is the estimation of fuel efficiency of simple cycle gas turbines with intake cooling air and a choice of the cooling technology and rational design cooling capacity (heat load) of the thermotransformer concerning actual climatic conditions in different regions of Libya.

2. RESULTS OF INVESTIGATION

A GT intake air temperature drop Δt_{B} and respective fuel saving due to GTU intake cooling air depend not only on the actual ambient temperatures t_{HB} but also on the temperatures of cooled air t_{B2} that depends on the type of thermotransformer: in ABTT the air can be cooled to the temperature of t_{B2} = 15…20 ºC and in ETT – to t_{B2} = 10 ºC and lower.

((The method of an estimation of the efficiency of GT intake cooling air [9, 10] allows choosing a depth of cooling, i.e. temperature of cooled air t_{B2} and, hence, a type of the thermotransformer: ALBTT – for t_{B2} = 10 ºC, WATT or ETT – for t_{B2} = 7…10ºC for site climatic conditions.

For GTU with the same impact of intake air temperature depression Δt on the fuel efficiency, i.e. the same decrease in specific fuel consumption Δb_e for 1 °C depression of intake air temperature:

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$\Delta b_{e1°C} = \Delta b_e / \Delta t$, it is quite convenient to use as parameter the specific fuel consumption saving – for 1 kW of GT electric power output: $B_{T.y1} = B_T / N_e$, kg/kW, where B_T – the total fuel consumption saving for GT with electric power output N_e, kW, for any time interval τ; for the estimation of annual specific fuel consumption saving as $B_{T.y1} = \Sigma[(\Delta t\ \tau)]\cdot(\Delta b_e / \Delta t)$, where τ – a time interval, within which the temperature depression Δt could be assumed as constant: τ = 1 h [9, 10].

Dependence of GT specific electric power output for 1 kW, an annual fuel economy of $B_{T.y1} = B_T / N_e$, the Kg/Kw, gained as $B_{T.y1} = \Sigma[(\Delta t_B\ \tau)]\cdot(\Delta b_e / \Delta t)$, is resulted on fig. 1.
Thus, it recognized that at a decrease in temperature of the air on an entry on 1 °C a specific fuel rate decreases for magnitude $\Delta b_{e1°C} = \Delta b_e / \Delta t$ =·0,35 g/(KWт·ч).
Values of the annual specific fuel saving $B_{f.1kW}$, relating to 1 kW of GT power output, due to GT intake cooling air from changing ambient air temperature t_{amb} to various temperatures against the temperature of GT intake air cooled t_{a2}: t_{a2} = 10 °C in ETT and to t_{a2} = 15 °C in ALBTT,

depending on the specific refrigeration capacity of q_0, relating to a single consumption of air G_a = 1 kg/s, for climatic conditions of Tripoli (tropical climate) and Hon (arid tropical climate) in 2009 are given in Figure 5.

To estimate the impact of cooling technologies consider the annual specific fuel consumption savings $B_{T.y1}$ (related to 1 kW of GT electric power output) due to GT intake cooling air from actual changing ambient temperature t_B to various cooled air temperature t_{B2} by thermotransformers of different types have been calculated for ambient conditions at the location Tripoli during 2009. The results of this analysis are presented in Fig.1.

With this, a specific fuel consumption reduction of 0.35 g/(kW·h) for every 1°C drop in gas turbine intake air temperature has been considered [1, 2].

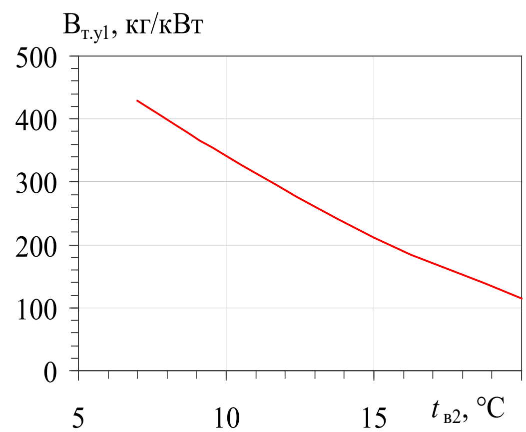

Fig. 1. Annual specific fuel consumption saving $B_{T.y1}$ (related to 1 kW of GT electric power output) Due to GT intake cooling air from actual ambient temperature t_B to various cooled air temperature t_{B2} by thermotransformers of different types: t_{a2} = 7-10 °C in RETT and ALBTT; t_{a2} = 15-20 °C in ALBTT (Tripoli, 2009).

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Knowing the annual specific fuel consumption saving $B_{T.y1}$ (related to 1 kW of GT electric power output) due to GT intake cooling air, the total annua (Tripoli) ion saving B_T for GT of any electric power output N_e may be calculated easily as B_T $B_{T.y1} N_e$. The results of the impact of cooling technologies considered on the total annual fuel consumption saving B_T for GT of electric power output N_e = 10 MW as an example are presented in Fig.2.

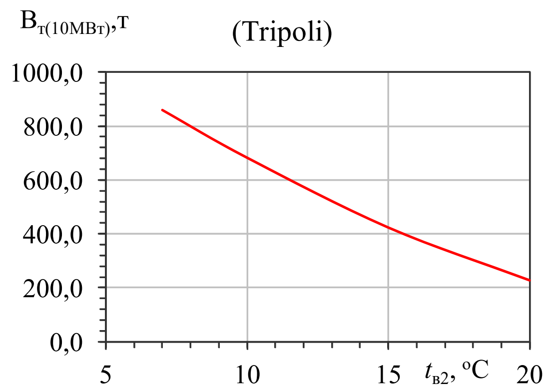

Fig. 2. Total annual fuel consumption saving Bт.y1
Due to GT intake cooling air from actual ambient temperature tв to various cooled air temperature tв2 by thermotransformers of different types: ta2 = 7-10 °C in RETT and ALBTT; ta2 = 15-20 °C in ALBTT (Tripoli, 2009)

The results of the analysis of the efficiency of the cooling technologies considered on the total annual fuel consumption saving are suitable to be presented in relative evaluation with GT intake cooling air to the temperature t_{a2} = 15 °C by ALBTT as the base variant (Fig.3)

Cooling of air to t_{B2} = 7…10 ºC in ETT or WATT in comparison with cooling to t_{B2} = 15 ºC in ALBTT for environmental conditions of Tripoli it is possible to judge efficiency of deeper on matching annual fuel economy in a relative aspect of B_T / B_{T15} on fig. 3.

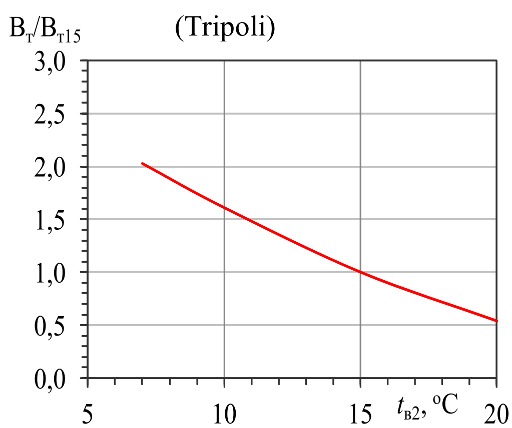

Fig. 3. Relative total annual fuel consumption saving $B_{T.y1}$ due to GTU intake air cooling from actual ambient temperature t_B to various cooled air temperature t_{B2} by thermotransformers of different types compared to intake cooling air by ALBTT to the temperature t_{a2} = 15 °C: B_T – t_{a2} = 7-20 °C; B_{T15} – t_{a2} = 15 °C in ALBTT.

Values of an annual fuel economy as a result of cooling air on entry GT to different temperatures t_{B2} in a relative aspect of B_T /B_{T15} (Tripoli, 2009): B_T – to different temperatures t_{B2}; B_{T15} – to temperature t_{B2} = 15 °C in ALBTT

Deeper cooling of air on entry GTU to temperatures t_{B2} = 10 and 7 °C in ETT or WATT provides 1,5 … 2,0 times the big annual fuel economy in comparison with cooling of air to temperature t_{B2} = 15 °C in ALBTT.

In Fig. 4 values of an annual fuel economy of B_T of one GTU by standard horsepower 10 MWT are given at different final temperatures t_{B2} chilled air on an entry for 6 regions of Libya in which in the core are had gas turbine AC: 1-Tripoli; 2-Bengasi; 3 Shahat (east region); 4-Hon (central); 5 Dzhalo (southern); 6 Nalut (the western region).

Thus, it accepted that at cooling air on entry GTU on 10 ºC the specific fuel rate is divided out to magnitude Δb_e = 3,5 g/(KWT·h) [2-4].

The effect from application of different ways of cooling of air on an entry concrete GTU in different thermotransformers (accordingly, temperatures t_{B2} chilled air) essentially depends on region environmental conditions, exceeding, for example, for the central and southern regions (curves 4 and 5) practically twice its magnitude for the east region (a curve 3).

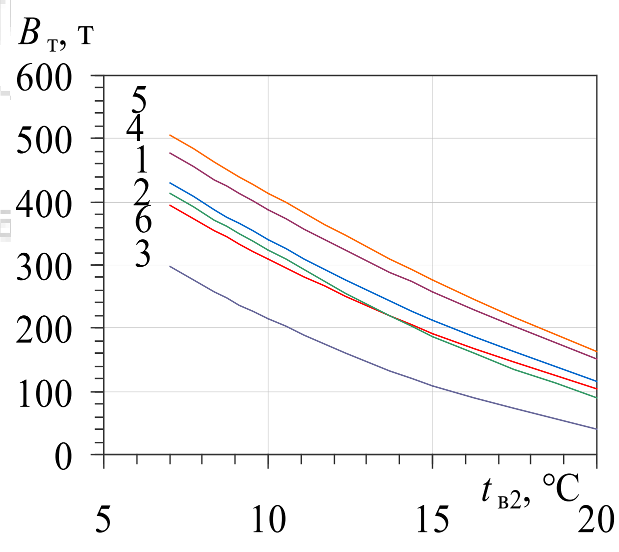

Fig. 4. Values of an annual fuel economy of B_T of one GTU in standard horsepower 10 MWT at different final temperatures t_{B2} chilled air for regions of Libya in which are had gas turbine AC, for 2009: 1 - Tripoli; 2 - Bengasi; 3 - Shahat (east); 4 - Hon (center); 5 - Dzhalo (south); 6 - Nalut (West)

At an estimation total for electrooscillating branch of the country of effect from application of this or that way of cooling of air on entry GTU (different thermotransformers) besides agency of decrease in temperature of air on an entry on fuel efficiency concrete GTU it is necessary to consider electric powers of power stations (AC), concentrated in each of 6 regions (at total power of all AC 5000 MWт): Tripoli (32 % total power AC, or 1600 MWт), Bengasi (15 %, 750 MWт), the western region (Nalut, Zavia, Zentan: 20 %, 1000 MWт), central (Hon, Sirt, Misrat: 18 %, 900 MWт), east (Shahat, Tubrak, the Saloon: 6 %, 300 MWт), Southern (Dzhalo, Saba, the Wardrobe trunk, Morzek: 9 %, 450 MWт) [1].

Values of an annual fuel economy of $B_т^p$ at the expense of cooling air on entry GT for the specified 6 regions taking into account electric power of all AC, had in regions, at different final temperatures $t_{в2}$ chilled air (different ways of cooling) are resulted on fig. 5.

Apparently, at cooling air in ALBTT ($t_{в2}$ = 12…15 ºC) values of an annual fuel economy at the expense of cooling air on entry GTU for all GTU ЭС and environmental conditions, for example, Tripoli (a curve 1), makes 30000 … 48000 т. In contrast, in WATT or ETT ($t_{в2}$ = 7…10ºC) – П = 55000…68000 т, i.e. approximately in 1,8 … 1,4 times are more that testifies to essential dependence of a fuel economy on depth of cooling of air on entry GTU and, hence, thermotransformer type.

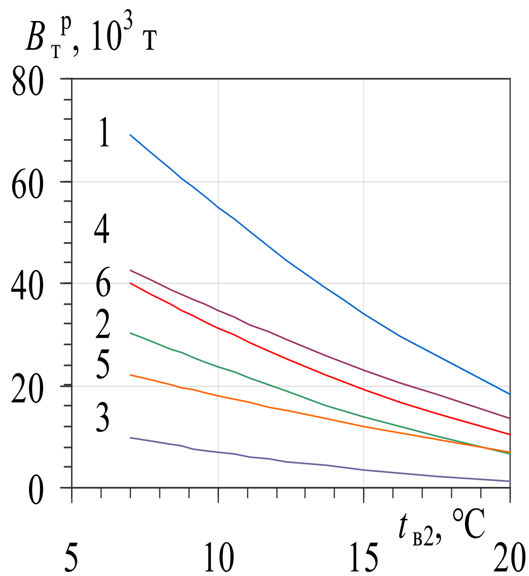

Fig. 5. Values of an annual fuel economy of $B_т^p$ at the expense of cooling air on an entry of all GTU power stations for 6 regions at final temperatures $t_{в2}$ chilled air (different ways of cooling) for 2009: 1 - Tripoli (32 %, 1600 MWт); 2 - Bengasi (15 %, 750 MWт); 3 - Shahat (the east, 6 %, 300 MWт); 4 - Hon (the center, 18 %, 900 MWт); 5 - Dzhalo (the south, 9 %, 450 MWт); 6 - Nalut (the West, 20 %, 1000 MWт).

Proceeding from the power GTU of all power stations in each of 6 regions the annual fuel economy of $B_т^p$ at the expense of cooling of air from current temperature of outdoor air $t_{нв}$ to $t_{в2}$ = 10 ºC (WATT or ETT), $t_{в2}$ = 15 ºC (ALBTT) and moistening of air to $t_м$ on entry GTU for 2009 (fig. 6) are counted.

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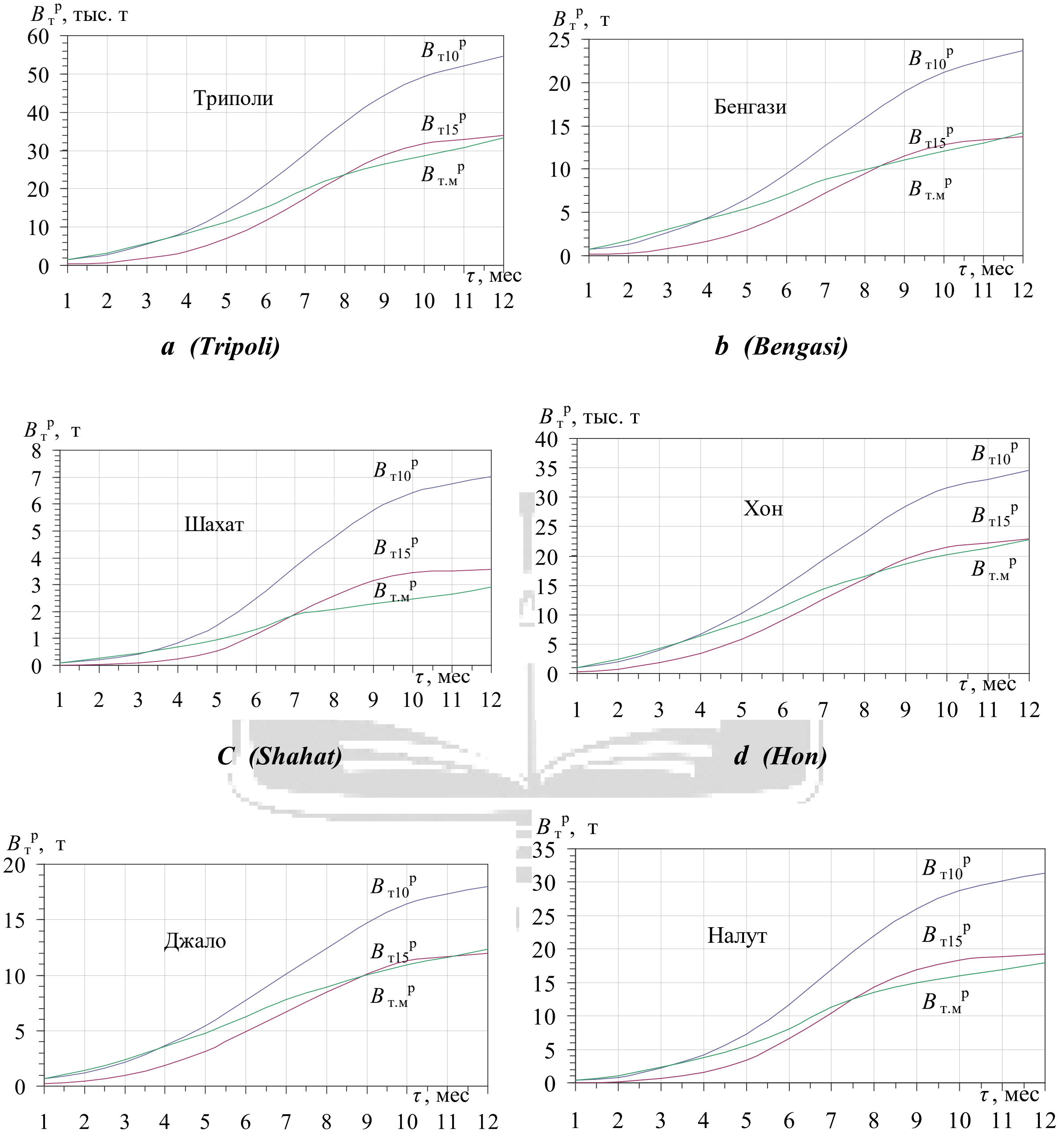

a (Tripoli) ***b (Bengasi)***

C (Shahat) ***d (Hon)***

e (Jhalo) ***f (Nalut)***

Fig. 6. An annual fuel economy of $B_т^р$ at the expense of cooling of air from the current temperature of outdoor air $t_{нв}$ to $t_{в2}$ = 10 ºC (WATT or ETT), $t_{в2}$ = 15 ºC (ALBTT), and moistening of air to $t_м$ on an entry of all GTU power stations of 6 regions for 2009: $B_{т10}^р$ – at $t_{в2}$ = 10 ºC; $B_{т15}^р$ – at $t_{в2}$ = 15 ºC; $B_{тм}^р$ – at $t_{в2}$ = $t_м$; *a* – Tripoli (32 %, 1600 MWт); b – Bengasi (15 %, 750 MWт); *in* c – the east (Shahat, 6 %, 300 MWт); *d* – the center (Hon, 18 %, 900 MWт); *e* – the south (Jhalo, 9 %, 450 MWт); *f* – the West (Nalut, 20 %, 1000 MWт).

The annual fuel economy of $B_т$ at the expense of cooling air on entry GT in all regions is rather considerable, and its difference speaks environmental conditions of regions (accordingly and depth of cooling of air), and also the total powers of power stations.

At the expense of cooling air on entry GTU total power 1600 MWт (Tripoli) in WATT or ETT it is possible to save 55000 т fuel (rock gas) for a year. Using the saved fuel, it is possible to produce in addition $230 \cdot 10^6$ KWт·h the electric power (at a specific fuel rate b_e on manufacture 1 KWт·h the electric power 240 g / (KWт·h)), on available powers GTU. Otherwise for the reception of this additional 230•106 KWт•h (at traditional maintenance GT without cooling air on an entry) it would be necessary for electric power to put into operation gas-turbine power station power 26 MWт, i.e. 1,6 % of total electric power GT installed in Tripoli.

It is necessary to note that values of effect for a way of cooling of air on entry GTU to a saturation condition (φ = 100 %) with reduction of temperature of the air to its value on the wet thermometer $t_м$ are a little overestimated by its moistening (approximately on 10 %) as the relative humidity raises practically to φ ≈ 90 %, instead of 100 % (to avoid moisture fall in the sucking diffusor of compressor GTU), besides, at calculations were not inducted restriction on the minimum temperature $t_м$ which in rather cool months $t_м$ can be hauled down more low $t_{в2}$ = 15 °C and even 10 °C. During such cool periods, the requirement for cooling air on entry GTU can be absent in general. Therefore actually a difference in effect from cooling air on entry GTU in ALBTT ($t_{в2}$ = 15 °C) and its moistening is more considerable.

Transition GT of all power stations to maintenance with cooling air on an entry provides a rather considerable annual fuel economy of $B_т$ = 170 thousand т. On the saved fuel it is possible to produce in addition 700·KWт·h the electric power (at a specific fuel rate b_e on manufacture 1 KWт·h the electric power 240 g / (KWт·h)), on available powers GT. At traditional work, GT without cooling air on an entry for reception additional 700·KWт·h the electric power would need a putting into service of the gas-turbine power station by power 80 MWт.

Values of the annual specific fuel saving Bf.1kW , relating to 1 kW of GT power output, due to GT intake cooling air from temperature of ambient air tamb to ta2 = 10 °C in REC and to ta2 = 15 °C in ABC, depending on the specific refrigeration capacity of q0 , relating to a single consumption of air Ga = 1 kg/s, for climatic conditions of Tripoli (tropical climate) and Hon (arid tropical climate) in 2009. With this a specific fuel consumption increment of 0.35 g/(kW·h) for every 1°C drop in gas turbine intake air temperature was assumed [1, 2].

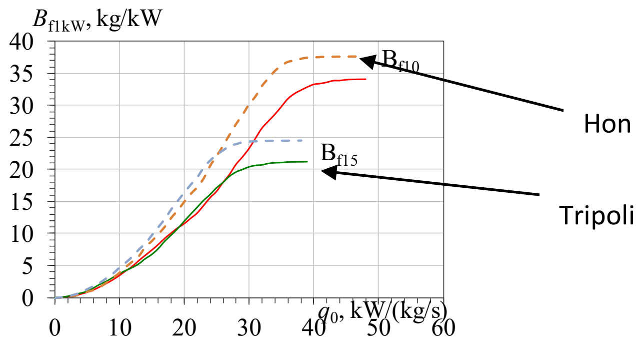

Fig. 7. Values of the annual specific fuel saving $B_{f.1kW}$, relating to 1 kW of GT power output, depending on the specific refrigeration capacity of q_0 , relating to a single consumption of air G_a = 1 kg/s, for climatic conditions of Tripoli (tropical climate) and Hon (arid tropical climate) in 2009: B_{f10} – from t_{amb} to t_{a2} = 10 °C (in REC); B_{f15} – from t_{amb} to t_{a2} = 15 °C (in ABC); —— – Tripoli; - - - – Hon

Apparently, for climatic conditions of Tripoli when cooling GT intake air to the temperature ta2 = 10 °C the rational specific refrigeration capacity of REC q0 = 38 kW/(kg/s) provides the value of annual specific fuel saving Bf10 = 33 kg/kW at high rates of its increment. The further increase in specific refrigeration capacity above q0 = 38 kW/(kg/s) does not lead to any noticeable increase in fuel saving Bf.10 . Thus, proceeding from the refrigeration capacity q0 = 38 kW/(kg/s) the full designed refrigeration capacity of REC can be adopted for climatic conditions of Tripoli: Q0 = q0 · Ga, kW. A little less value of rational specific refrigeration capacity q0 = 36 kW/(kg/s) can be adopted for climatic conditions of Hon, that provides value of annual specific annual specific fuel saving Bf.10 = 37 kg/kW.

3. CONCLUSIONS

In an assay value of efficiency of different ways of cooling of air on entry GT thermotransformers of the different types using the warmth of completed gases in absorption lithium-bromide (ALBTT) chiller as the thermotransformer to temperature t_{B2}=15ºC in ejector and absorption aqua-ammonia thermotransformers (ETT and ALBTT) to temperature t_{B2}=10ºC and lower-taking into account maintenance environmental conditions it is proved expediency of deep cooling of air on entry GTU.

It is shown that deeper cooling of air on entry GT to temperature t_{B2}=10 and 7°C in ETT or WATT provides 1,3… 1,5 times the big annual fuel economy in comparison with cooling of air to temperature t_{B2}=15°C in ALBTT. The estimation of the effect from cooling air on entry GTU in the form of an annual fuel economy for regions of Libya in which the manufacture of electric energy by gas-turbine power stations is concentrated results.

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