Statistical Method to Define Rational Heat Loads on Railway Air Conditioning System for Changeable Climatic Conditions

Andrii Radchenko, Ph.D, associate professor,
Mykola Radchenko, Dr.-Ing., professor,
Eugeniy Trushliakov, Ph.D, professor,
Serhiy Kantor, Ph.D, senior researcher,
Veniamin Tkachenko, post graduated student,
Conditioning and Refrigeration Department,
Admiral Makarov National University of Shipbuilding,
Mykolayiv, Ukraine

Abstract **– A statistical method of defining rational heat loads on railway air conditioning system with taking into account the current changeable heat loads corresponding to current climatic conditions on the route lines has been proposed. According to this method the rational designed heat load on refrigeration machine, matching current changeable climatic conditions on the route lines and providing efficient operation of refrigeration machine of air conditioning system with maximum (close maximum) refrigeration capacity production (refrigeration output) for definite period of operation (monthly, seasonal or annular period) is defined through statistical treatment of data sets of hourly refrigeration capacities corresponding to the current climatic conditions on the route lines by their summation during the operation period for various installed (designed) refrigeration capacities of machine.**

The method is based on the hypothesis of different rates of refrigeration capacity production increment for the period of operation with increasing the installed refrigeration capacity, that is revealed in slowing down the rate of refrigeration capacity production increment at over increased installed refrigeration capacity. Proceeding from this hypothesis the rational value of heat load on railway air conditioning system is chosen close to the value that corresponds to the maximum refrigeration capacity production for the period of operation. Such rational value of designed heat load on railway air conditioning system provides reduction of refrigeration machine capacity and its cost by 15…20 % as compared with traditional its designing for the maximum heat load. The operation of refrigeration machine in partial modes for enlarged installed refrigeration capacity chosen traditionally – for the maximum heat load needs application of expensive inventor compressors to control motor speed matching current changeable heat loads.

Keywords- Air conditioning system, rail way, route line, heat load, refrigeration machine, refrigeration capacity, current climatic conditions

I. INTRODUCTION

The performance efficiency of rail way air conditioning systems (Fig. 1) and their refrigeration machines depends on a duration of their operation period and modes of refrigeration machine operation: at nominal or partial heat loads with corresponding refrigeration capacity. The longer duration of air conditioning system operation all the year round, there is a larger refrigeration capacity production (refrigeration output generated).

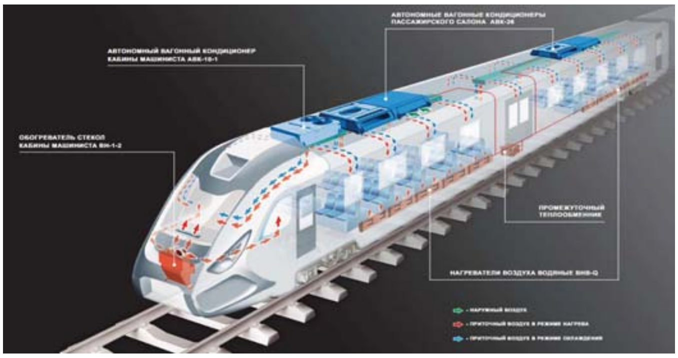

Figure 1. Rail way air conditioning systems

So as the operation efficiency of rail way air conditioning systems and their refrigeration machines depends on a duration of their operation on the route line it can be estimated by a refrigeration capacity production (refrigeration output) for the operation period considered.

In general case the refrigeration capacity production (refrigeration output) for the operation period depends on the cooling air potential in site climatic conditions and can be estimated by method based on cooling degree-hour potential [1-3] developed further for rational designing of cooling systems and heat exchangers [4-8].

As designed heat loads on air conditioning systems and their refrigeration machines selected closer to the current heat loads, corresponding to changeable climatic conditions on the route line, there is a higher refrigeration capacity production for the operation period considered. Otherwise there will be unjustified increased cost of air conditioning equipment caused by operation at partial loads for enlarged refrigeration machine with increased designed (installed) refrigeration capacity chosen traditionally – for the maximum heat load.

Goal of the work – developing the statistical method of defining rational heat loads on railway air conditioning system matching the changeable climatic conditions.

II. Research Results

To prove a method to define the rational designed heat load, matching current changeable climatic conditions, the values of specific refrigeration capacity q_0 to cover heat loads for cooling ambient air from changeable current ambient temperatures t_{amb} to the temperature t_{a2} = 15 °C on the railway rout lines "Kiev-Kherson" (K-Kh) and "Kherson-Kiev" (Kh-K) within July 2017 have been calculated.

Current values of decrease in the temperature of ambient air $\Delta t_a = t_{amb} - t_{a2}$ due to its cooling from the current ambient temperatures t_{amb} to the temperature t_{a2} = 15 °C within July 2017 are presented in Fig. 2 and corresponding values of specific refrigeration capacity q_0 (at air mass flow G_a = 1 kg/s), i.e. specific heat loads, are shown in Fig. 3.

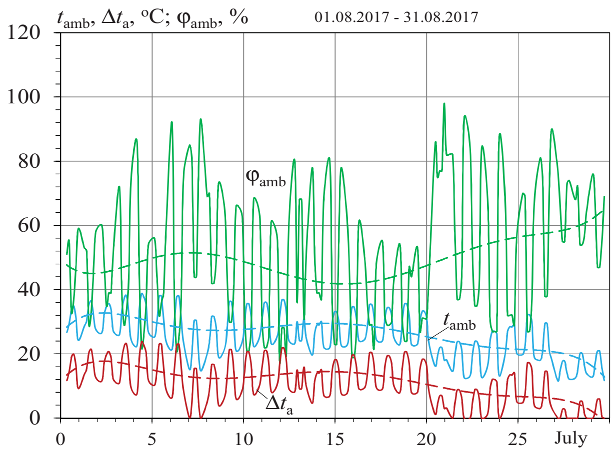

Figure 2. Current values of ambient air temperature t_{amb} and relative humidity φ_{amb} and temperature decrease Δt_a due to cooling ambient air from current ambient temperatures t_{amb} to the temperature t_{a2} = 15 °C within July 2017

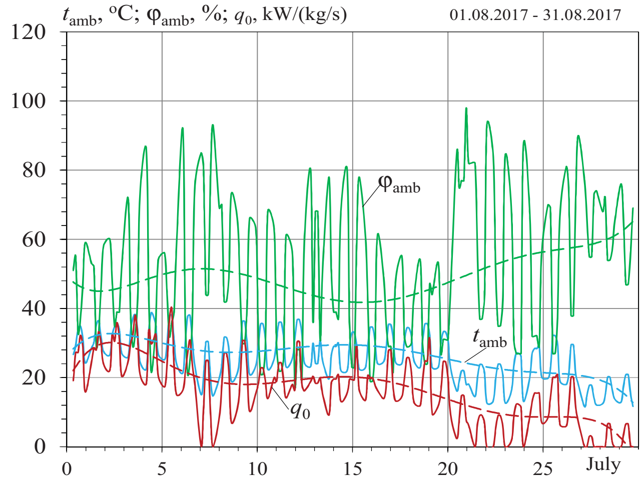

Figure 3. Current values of ambient air temperature t_{amb} and relative humidity φ_{amb} and specific refrigeration capacity q_0 (at air mass flow G_a = 1 kg/s) for cooling ambient air from t_{amb} to the temperature t_{a2} = 15 °C within July 2017

As can be seen, with cooling the ambient air from the current temperature t_{amb} to the temperature t_{a2} = 15 °C the fluctuations in the current heat load q_0 on the air cooler of the air conditioning system, i. e. in the current refrigeration capacity of refrigeration machine, are very significant. This is caused by daily changes in the temperature t_{amb} and relative humidity φ_{amb} of ambient air with decreasing the temperature t_{amb} at night down to 15 °C with corresponding drops of the heat load q_0 on the air cooler to zero (Fig. 4).

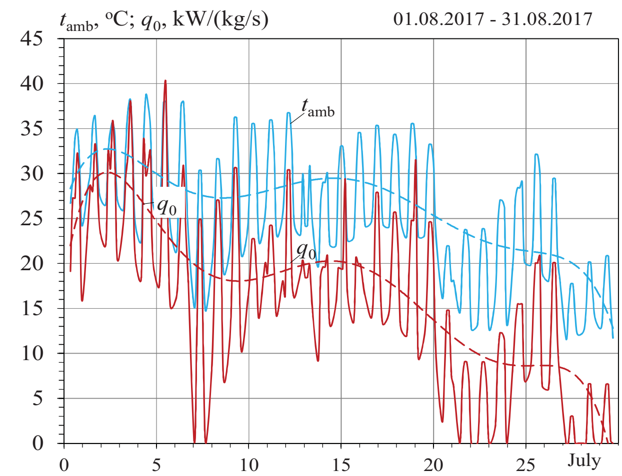

Figure 4. Current values of ambient air temperature t_{amb} and relative humidity φ_{amb} and specific refrigeration capacity q_0 (at air mass flow rate G_a = 1 kg/s) for cooling ambient air from t_{amb} to the temperature t_{a2} = 15 °C within July 2017

Such significant changes in the current heat loads q_0 on the air cooler of the air conditioning system, i. e. in the current cooling capacity of the compressor of refrigeration machine q_0, point out that if the designed maximum current heat load is chosen, this will result in a significant amount of an excessive refrigeration output in the temperate hours during a day.

Corresponding regulation of the refrigeration capacity of the refrigeration machine in a wide range of heat loads is accompanied by a decrease in its effective and electrical efficiency, and by an increase in the specific work of compression and electric energy consumption per 1 kW of refrigeration capacity or needs application of expensive inventor compressors to control motor speed maching current heat loads.

Current values of ambient air temperature t_{amb}, relative humidity φ_{amb} and absolute humidity d_{amb} within 1-6[th] of July 2017 are presented in Fig.5.

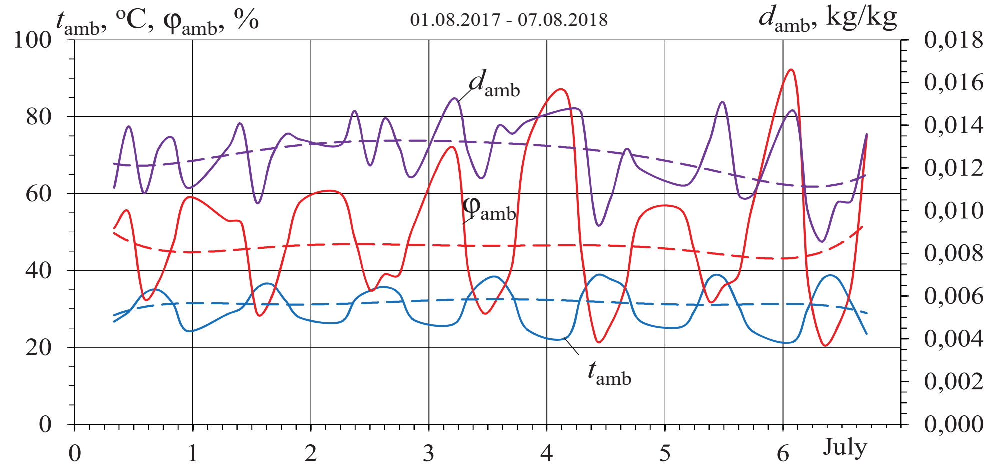

Figure 5. Current values of ambient air temperature t_{amb}, relative humidity φ_{amb} and absolute humidity d_{amb} within 1-6[th] of July 2017

The current values of temperature t_{amb} and relative humidity φ_{amb} of ambient air and temperature decrease Δt_a due to cooling ambient air from current ambient temperatures t_{amb} to the temperature t_{a2} = 15 °C and corresponding current specific refrigeration capacity (specific heat load) q_0 (at air mass flow G_a = 1 kg/s) for cooling ambient air to the temperature t_{a2} = 15 °C within each route (direct Kiev-Kherson (K-Kh) and return Kherson-Kiev (Kh-K) routes per day) for 1.08-3.08. 2017 are presented in Fig. 6.

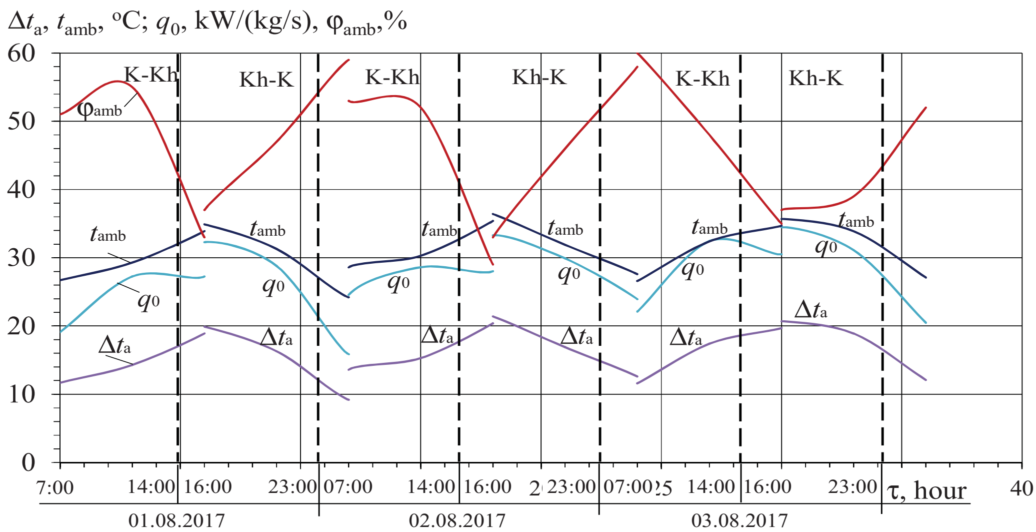

Figure 6. Current values of temperature t_{amb} and relative humidity φ_{amb} of ambient air, temperature decrease Δt_a due to cooling ambient air from current ambient temperatures t_{amb} to the temperature t_{a2} = 15 °C and corresponding current specific refrigeration capacity (specific heat load) q_0 (at air mass flow G_a = 1 kg/s) for cooling ambient air to the temperature t_{a2} = 15 °C within each route (direct Kiev-Kherson (K-Kh) and return Kherson-Kiev (Kh-K) routes per day) for 1.08-3.08. 2017

As Fig.6 shows the current values of specific refrigeration capacity (specific heat load) q_0 and of temperature decrease Δt_a due to cooling ambient air to the temperature t_{a2} = 15 °C do not coincide because of variation in relative humidity φ_{amb} of ambient air and corresponding latent heat.

The results of summarized values of specific refrigeration capacity $\sum(q_0 \cdot\tau)_{r1}$ (at air mass flow G_a = 1 kg/s) to cover heat loads for air conditioning within each route (both of direct Kiev-Kherson (K-Kh) and return Kherson-Kiev (Kh-K) routes per day) with cooling ambient air from current temperature t_{amb} to the temperature t_{a2} = 15 °C and summarized value of specific refrigeration capacity $\sum(q_0 \cdot\tau)$ for 1.08-3.08. 2017 through summarizing the values of specific refrigeration capacity $\sum(q_0 \cdot\tau)_{r1}$ for each route are presented in Fig.7.

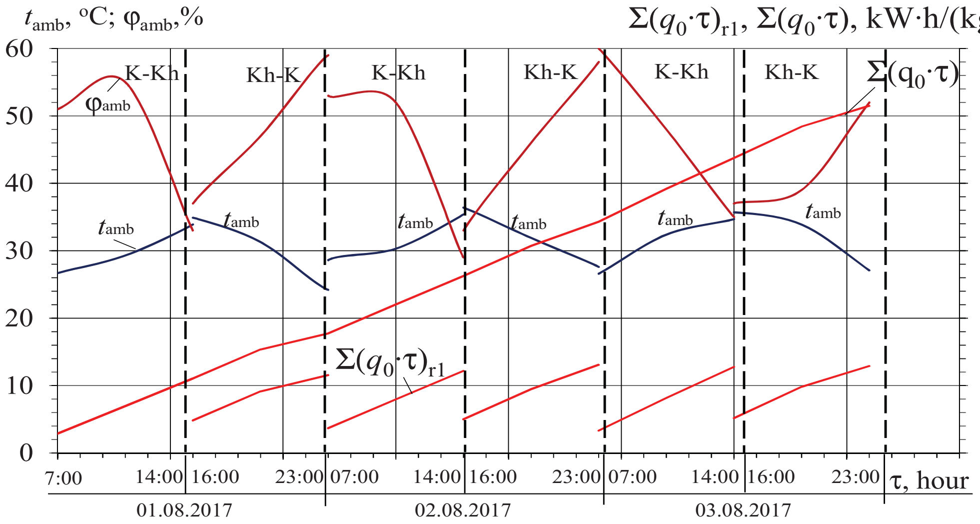

Figure 7. Current values of temperature t_{amb} and relative humidity φ_{amb} of ambient air and summarized values of specific refrigeration capacity $\sum(q_0 \cdot\tau)_{r1}$ (at air mass flow G_a = 1 kg/s) to cover heat loads for air conditioning within each route (direct Kiev-Kherson (K-Kh) and return Kherson-Kiev (Kh-K) routes per day) with cooling ambient air from current temperature t_{amb} to the temperature t_{a2} = 15 °C and summarized value of specific refrigeration capacity $\sum(q_0 \cdot\tau)$ for 1.08-3.08. 2017

As one can see, the summarized values of specific refrigeration capacity $\sum(q_0 \cdot\tau)_{r1}$ generated by refrigeration machine and correspondingly consumed for air conditioning in direct (K-Kh) and return (Kh-K) routes per day are nearly the same that is confirmed by monotonous rate of their increments $\sum(q_0 \cdot\tau)$ for 1.08-3.08. 2017.

The results of treatment of monthly (July) refrigeration output in relative values $\sum(q_0 \cdot\tau)$ (at air mass flow G_a = 1 kg/s) against designed specific refrigeration capacity $q_0 = Q_0 / G_a$ of installed refrigeration machine for cooling ambient air to the temperature t_{a2} = 15 °C and climatic conditions on the route lines Cherson-Kiev and Kiev-Cherson for July, 2017 year, are presented in Fig.8.

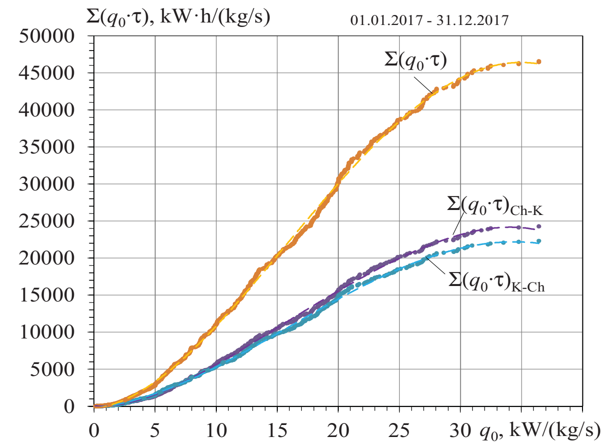

Figure 8. The results of statistical treatment of data on monthly refrigeration output in relative values $\sum(q_0 \cdot\tau)$ (at air mass flow G_a = 1 kg/s) to cover heat loads for air conditioning with cooling ambient air from current temperature t_{amb} to the temperature t_{a2} = 15 °C against designed specific refrigeration capacity $q_0 = Q_0 / G_a$ of installed refrigeration machine: $\sum(q_0 \cdot\tau)$ – summarized for all railway routs; $\sum(q_0 \cdot\tau)_{K\text{-}Kh}$ – summarized for all direct railway routs Kiev-Kherson; $\sum(q_0 \cdot\tau)_{Kh\text{-}K}$ – summarized for all return railway routs Kiev-Kherson; July 2017

As Fig. 8 shows, the monthly (July) specific refrigeration output $\sum(q_0 \cdot \tau)$ (with $G_a = 1$ kg/s) for cooling ambient air to the temperature $t_{a2} = 15$ ºC at specific refrigeration capacity $q_0 = 35$ kW/(kg/s) is evaluated as $\sum(q_0 \cdot \tau) = 46$ MW·h/(kg/s) and achieved with monotonous rate of their increments $(q_0 \cdot \tau)$ with increasing the specific refrigeration capacity q_0 from 0 to 35 kW/(kg/s) for all the routes.

Because of negligible rate of their increments $\sum(q_0 \cdot \tau)$ the further increase in specific refrigerating capacity q_0 from 35 to 45 kW/(kg/s) does not result in appreciable increment in the monthly refrigeration output $\sum(q_0 \cdot \tau)$. At the same time the further increase in designed refrigeration capacity q_0 of installed refrigeration machine causes considerable increase in its cost by 15…20 %. Thus, the specific refrigeration capacity $q_0 = 35$ kW/(kg/s) is accepted as rational to calculate a total designed refrigeration capacity Q_0 of installed refrigeration machine according to the total air mass flow G_a, kg/s: $Q_0 = G_a \cdot q_0$, kW.

III. Conclusions

A statistical method of optimum designing of railway conditioning systems to improve their operation efficiency with taking into account the current changeable heat loads corresponding to changeable climatic conditions on the route lines has been proposed. According to this method the optimum designed heat load, matching current changeable climatic conditions on the route lines and providing efficient operation of air conditioning system with maximum refrigeration capacity production for any duration of operation has been defined as a result of statistical treatment of data sets of hourly refrigeration outputs for the operation period.

The different rates of refrigeration capacity production increment to cover the current heat loads for ambient air conditioning with increasing the installed refrigeration capacity of refrigeration machine, caused by the changes in heat loads according to current climatic conditions on the route lines during operation period: negligible rate of arising their increments at over increased installed refrigeration capacity, have been revealed.

Proceeding from the hypothesis of different rates of refrigeration capacity production increment for the period of operation with increasing the installed refrigeration capacity, consisting in slowing down the rate of refrigeration capacity production increment at over increased installed refrigeration capacity, the method to choose a rational heat load on the rail way air conditioning system as a bit lower the maximum value of refrigeration capacity production within operation period has ben proposed. Such rational value of designed heat load on railway air conditioning system provides reduction of refrigeration machine cost by 15…20 % as compared with traditional its designing for the maximum heat load.

References

[1] Chaker M., Meher-Homji C.B. Inlet fogging of gas turbine engines: climatic analysis of gas turbine evaporative cooling potential of international locations. *Proceedings of ASME TURBO EXPO 2002*, Paper GT-2002-30559.

[2] Bhargava R., Meher-Homji C.B. Parametric analysis of existing gas turbines with inlet evaporative and overspray fogging. *Proceedings of ASME TURBO EXPO 2002*, Paper GT-2002-30560, 2002, 15 p.

[3] Bhargava R. Parametric analysis of combined cycles equipped with inlet fogging. *Proceedings of ASME TURBO EXPO 2003*, Paper GT-2003-38187, 12 p.

[4] Radchenko N., Kantor S. The analysis of efficiency of gas turbine inlet air chilling by waste heat recovery chillers for varying climatic conditions. *Proceedings of the 15 International Symposium on Heat Transfer and Renewable Sources of Energy: HTRSE–2014*, Szczecin, Poland, 2014, pp. 349–354.

[5] Radchenko A. Method of thermo-hour potential of gas turbine inlet air chilling and designing of rational chillers for varying climatic conditions of performance. *Proceedings of the 15 International Symposium on Heat Transfer and Renewable Sources of Energy: HTRSE–2014*, Szczecin, Poland, 2014, pp. 325–331.

[6] Radchenko A., Radchenko R. Method of estimation of potential of water extraction during gas turbine inlet air chilling. *Proceedings of the 15 International Symposium on Heat Transfer and Renewable Sources of Energy: HTRSE–2014*, Szczecin, Poland, 2014, pp. 333–340.

[7] Radchenko N. A concept of the design and operation of heat exchangers with change of phase. Archives of Thermodynamics: Polish Academy of Sciences, Vol.25, No.**4** (2004), pp. 3−19.

[8] Bohdal T., Sikora M., Widomska K., Radchenko A. M. Investigation of flow structures during HFE-7100 refrigerant condensation. *Archives of thermodynamics*: Polish Academy of Sciences, Vol. 36, No. 4 (2015). pp. 25–34.