Increasing the Operation Efficiency of Railway Air Conditioning System on the Base of Its Simulation Along the Route Line

Mykola Radchenko(✉), Roman Radchenko, Veniamin Tkachenko, Serhiy Kantor, and Evgeniy Smolyanoy

Admiral Makarov National University of Shipbuilding, Heroes of Ukraine Avenue 9, Mykolayiv, Ukraine
nirad50@gmail.com

Abstract. The operation of air coolers of railway air conditioning (AC) systems is characterized by considerable variations in current heat loads according to actual climatic conditions on the route lines. This causes increased changes of refrigerant flows. Over filling the air cooler coils by liquid refrigerant recirculation enables excluding a decrease in heat flux within variations in current heat loads and provides increasing the heat efficiency of air coolers compared with conventional air coolers with complete refrigerant evaporation and superheated vapor at the exit. Thus a larger deviation of current heat load on railway route lines are permited without falling air cooler heat efficiency. The method to determine the rational design heat load on air coolers of railway AC systems, providing closed to maximum refrigeration output generation over considered time period, was developed.

Keywords: Railway air conditioner · Changeable heat load · Liquid refrigerant recirculation

1 Introduction

The performance of railway AC systems is characterized by considerable variations in current heat loads on their air coolers according to actual climatic conditions on the route line. So, the problem is to determine the rational design heat load on air coolers of railway conditioners, providing closed to maximum refrigeration output generation over considered time period.

The system of over filling the air cooler coils by liquid refrigerant recirculation enables a large deviation of current heat loads from their rational design value without considerable falling air cooler heat efficiency. The system of refrigerant circulation in air coolers by injector that enables excluding the final dry-out stage of refrigerant evaporation with extremely low intensity of heat transfer and as result provides increasing the heat efficiency of air coolers (overall heat flux) by 20–30% compared with conventional air coolers with complete refrigerant evaporation and superheated vapor at the exit might be proposed [1]. The injector uses a potential energy of high pressure liquid refrigerant,

M. Nechyporuk et al. (Eds.): *Integrated Computer Technologies in Mechanical Engineering*, AISC 1113, pp. 461–467, 2020.
https://doi.org/10.1007/978-3-030-37618-5_39

leaving a condenser, which is conventionally lost while it throttling to evaporation pressure in expansion valve.

2 Literature Review

A lot of researches deal with improving the performance of AC systems by intensification of heat transfer processes in heat exchangers [1–3], application of differ refrigerant circulation schemes [4–7], waste heat recovery technics [8–11], modern methods of modelling, experimental, monitoring and statistical methods [12–14].

As modern trend in AC systems the application of Variable Refrigerant Flow (VRF) system is considered to modulate heat load by varying refrigerant feed to air coolers [15–17]. The VRF system maintains the zone comfort by supplying adequate amount of refrigerant to air coils to meet cooling duties. The performance evaluations showed that the VRF system reduced energy consumption by 40% to 60% compared to that of central AC systems [18]. But the problem of inefficient operation of air coolers in VRF system caused by dry-out of inner walls at the final stage of inside tube refrigerant evaporation followed by dropping the intensity of heat transfer remains unsolved.

As alternative approach of the heat load modulation in AC systems the concept of incomplete refrigerant evaporation [1, 19] with overfilling air coils that leads to excluding a dry-out of inner surface of air coils is developed through liquid refrigerant recirculation by injector (jet pump).

Considerable changes in the current heat loads q_0 on the air cooler need choosing its rational design value, providing maximum refrigeration output generation over considered time period [20–22].

The basic approaches to determine a design heat load on air coolers of AC system with taking into account the currentchangeable climatic conditions were developed in [24–26] and quite acceptable small deviations of current heat loads from adesign heat load value was shown to prove the results [25] as well as expedience of over filling the air coolers by liquidrefrigerant recirculation [1] that enables large current cooling load fluctuations on railway route lines without considerablefalling air cooler heat efficiency as in present investigation.

The aim of the study is to develop the method to determine the rational design heat load on the air coolers of railway AC systems, providing closed to maximum refrigeration capacity generation under changeable actual heat loads during railway routs.

3 Research Methodology

The operation of railway AC systems is characterized by considerable changes in the current heat loads Q_0 on the route lines and in corresponding specific heat loads i.e. specific cooling capacity – related to the unit of air mass flow: $q_0 = Q_0/G_a$, were G_a – ambient air mass flow in air cooler, kg/s. The specific cooling capacity is calculated as $q_0 = \xi \cdot c_a \cdot (t_{amb} - t_{a2})$, kJ/kg, were ξ – coefficient of water vapor condensation heat, determined as ratio of the overall heat, removed from the air being cooled, including the latent heat of water vapor condensed from the wet ambient air, to the sensible heat removed; t_{amb} – ambient air temperature, t_{a2} – air temperature at the air cooler outlet, c_a – specific heat of ambient humid air.

The current heat loads are calculated according to varying actual ambient air parameters on the route lines with using the Meteomanz program [23] or others.

So as the efficiency of AC systems and their refrigeration machine performance depends on their cooling loading (current cooling capacities) q_0 and a duration τ of their operation, the summarised refrigeration capacity $\sum(q_0 \cdot \tau)$ generated during railway routes over the most hot month, might be considered as a primary criterion for the choice of a rational design cooling load of AC system. For this the current refrigeration capacities, generated by the refrigeration machine in response to the cooling duties for cooling ambient air to the target leaving air temperature, have been summarized over the summer month to determine the rational design cooling load of AC system.

4 Results of Investigation

The current values of temperature t_{amb} and relative humidity φ_{amb} of ambient air and temperature decrease Δt_{a} within 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 on the air cooler) q_0, kW/(kg/s), or kJ/kg (at air mass flow G_{a} = 1 kg/s), during direct route Kherson-Lviv (Kh-Lv) and return route Lviv-Kherson (Lv-Kh) per day for 1.08–3.08. 2018 are presented in Figs. 1 and 2.

As Fig. 1 shows the behavior of the curves corresponding to current values of specific refrigeration capacity q_0 and temperature decrease Δt_{a} within cooling ambient air to the temperature t_{a2} = 15 °C does not coincide because of variation in relative humidity φ_{amb} of ambient air and corresponding latent heat.

The results of summarizing the specific refrigeration capacity values $\sum(q_0 \cdot \tau)_{\text{r1}}$ (at air mass flow G_{a} = 1 kg/s) for cooling ambient air to the temperature t_{a2} = 15 °C during direct Kherson-Lviv (Kh-Lv) and return Lviv-Kherson (Lv-Kh) routes and their summarized value $\sum(q_0 \cdot \tau)$ for 1.08–3.08. 2018 through summarizing their values $\sum(q_0 \cdot \tau)_{\text{r1}}$ for each route are presented in Fig. 2.

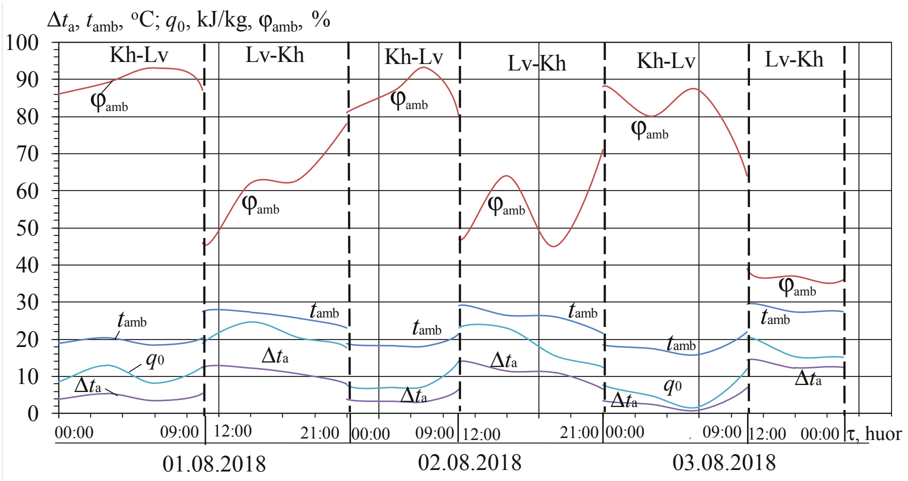

Fig. 1. Current values of temperature t_{amb} and relative humidity φ_{amb} of ambient air, temperature decrease Δt_a due to cooling ambient air to t_{a2} = 15 °C and corresponding current specific refrigeration capacity q_0 during direct routes Kherson-Lviv (Kh-Lv) and return routes Lviv-Kherson (Lv-Kh) for 1.08–3.08. 2018

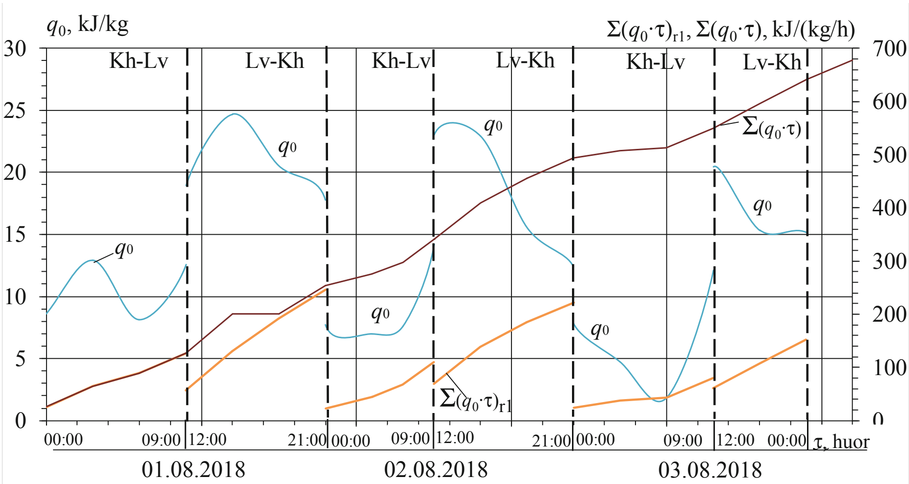

Fig. 2. Current values of specific refrigeration capacity q_0 and summarized values of specific refrigeration capacity $\sum(q_0 \cdot \tau)_{r1}$ for cooling ambient air to the temperature t_{a2} = 15 °C within each route (direct Kherson-Lviv (Kh-Lv) and return Lviv-Kherson (Lv-Kh) routes) and their summarized value $\sum(q_0 \cdot \tau)$ for 1.08–3.08. 2018

As Fig. 2 shows, the summarized values of specific refrigeration capacity $\sum(q_0 \cdot \tau)_{r1}$ for air conditioning in direct (Kh-Lv) and return (Lv-Kh) routes are nearly the same that is confirmed by monotonous rate of their increments $\sum(q_0 \cdot \tau)$ for 1.08–3.08. 2018.

Considerable changes in the current heat loads q_0 on the air cooler need choosing its rational design value, providing maximum refrigeration capacity generation over considered time period. The monthly refrigeration output in relative values $\sum(q_0 \cdot \tau)$ (at air mass flow G_a = 1 kg/s) against design specific refrigeration capacity $q_0 = Q_0/G_a$ of refrigeration machine for cooling ambient air to the temperature t_{a2} = 15 °C and climatic conditions on the route lines Kherson-Lviv and Lviv-Kherson for August, 2018 year, are presented in Fig. 3.

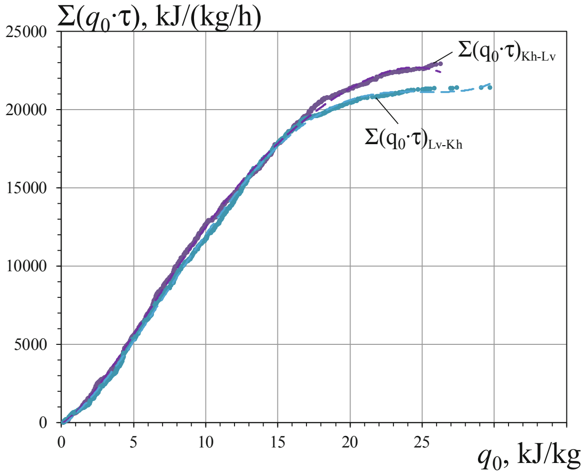

Fig. 3. The monthly refrigeration output in relative values $\sum(q_0 \cdot \tau)$ for ambient air cooling to the temperature t_{a2} = 15 °C against designed specific refrigeration capacity $q_0 = Q_0/G_a$: $\sum(q_0 \cdot \tau)_{\text{Kh-Lv}}$ – summarized for all direct railway routes Kherson-Lviv; $\sum(q_0 \cdot \tau)_{\text{Lv-Kh}}$ – summarized for all return railway routes Lviv-Kherson, August 2018

As Fig. 3 shows, the monthly (August) specific refrigeration output $\sum(q_0 \cdot \tau)$ for cooling ambient air to the temperature t_{a2} = 15 °C at specific refrigeration capacity q_0 = 30 kJ/kg, or kW/(kg/s), is evaluated as $\sum(q_0 \cdot \tau) \approx$ 23 MJ/(kg/h) for all direct railway routes Kherson-Lviv as well as $\sum(q_0 \cdot \tau) \approx$ 22 MJ/(kg/h) for all return railway routes Lviv-Kherson in August and achieved with monotonous rate of their monthly increments $\sum(q_0 \cdot \tau)$ with increasing the specific refrigeration capacity q_0 up to 30 kJ/kg.

Because of negligible rate of the monthly increments $\sum(q_0 \cdot \tau)$ the further increase in specific refrigeration capacity q_0 from 30 to 35 kJ/kg does not result in appreciable increment in the monthly refrigeration output $\sum(q_0 \cdot \tau)$ for July, but causes oversizing refrigeration machine, that leads to increasing its cost. Thus, the specific refrigeration capacity q_0 = 30 kJ/kg, or kW/(kg/s), is accepted as rational one to calculate a total designed refrigeration capacity Q_0 of refrigeration machine according to the total air mass flow G_a, kg/s: $Q_0 = G_a \cdot q_0$, kW.

5 Conclusions

The method to determine the rational design heat load on air coolers of railway AC systems, matching current changeable climatic conditions and providing closed to maximum refrigeration output generation over any considered time period of performance, was developed.

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