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Enhancing the Operation Efficiency of Railway Air Conditioning System along the route line

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Abstact
On analyzing the operation of air coolers of railway air conditioning (AC) systems, characterized by considerable variations in current heat loads according to actual climatic conditions on the route lines, the reserves to increase its efficiency by intensification of refrigerant evaporation in air coils and enlarging the range of deviation of refrigerant flows from their optimum values without noticeable decreasing heat flux were revealed. To realize this it has been proved that over filling the air cooler coils by liquid refrigerant injector recirculation 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. Moreover a larger deviation of current heat load on railway route lines are permited without considerable falling air cooler heat efficiency due to refrigerant injector recirculation at available numbers of circulation. 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

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, and develop the system of refrigerant circulation in air coolers enabling 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 was proposed. The injector uses a potential energy of high pressure liquid refrigerant, leaving a condenser, which is conventionally lost while it throttling to evaporation pressure in expansion valve.

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, and the system of refrigerant circulation in air coolers, that allows a considerable deviation of refrigerant flow from the optimum value, corresponding the maximum heat flux, without considerable reduce of heat flux, under changeable actual heat loads during railway routs.

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 [1] 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.

The method to determine the rational design heat load on air coolers, providing closed to maximum monthly refrigeration output generation (July) was developed [2-4] and fluctuation of current heat loads in relation to the rational design heat load value was compared with available range of deviation of refrigerant mass velocities from their optimum values without noticeable decreasing the heat flux for liquid refrigerant recirculation in air coolers. The results of comparison have shown that liquid refrigerant recirculation in air coolers by injector enables large current cooling load fluctuations on railway route lines without considerable falling air cooler heat efficiency.

Results of investigation

Heat loads on railway air conditioning system on route line

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 Kiev-Kherson (K-Kh) and return route Kherson-Kiev (Kh-K) per day for 1.08-3.08. 2017 are presented

As it 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 $\sum(q_0 \cdot \tau)_{r1}$ (at air mass flow G_a = 1 kg/s) for cooling ambient air to the temperature t_{a2} = 15 °C during direct Kiev-Kherson (K-Kh) and return Kherson-Kiev (Kh-K) routes and their summarized value $\sum(q_0 \cdot \tau)$ for 1.08-3.08. 2017 through summarizing their values $\sum(q_0 \cdot \tau)_{r1}$ for each route are presented.

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

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 Cherson-Kiev and Kiev-Cherson for July, 2017 year, are presented.

As it shows, the monthly (July) specific refrigeration output $\sum(q_0 \cdot \tau)$ for cooling ambient air to the temperature t_{a2} = 15 ºC at specific refrigeration capacity q_0 = 32 kJ/kg, or kW/(kg/s), is evaluated as $\sum(q_0 \cdot \tau) \approx$ 22 MJ/(kg/h) for all direct railway routes Kiev-Kherson as well as $\sum(q_0 \cdot \tau) \approx$ 24 MJ/(kg/h) for all return railway routes Kherson-Kiev in July and achieved with monotonous rate of their monthly increments $\sum(q_0 \cdot \tau)$ with increasing the specific refrigeration capacity q_0 up to 32 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 32 to 37 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 = 32 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.

A fundamental approach in enhancing heat efficiency of air coolers

A convective evaporation of refrigerant inside tubes (channels) is characterized by sharp drop in intensity of heat transfer at the final stage of evaporation when so called burnout takes place (Fig. 4). This occurs due to tube inner wall surface drying out with transition of annular flow to disperse (mist) flow.

In compact air coolers with finned tubes the coefficient of heat transfer to refrigerant α_a at the final stage of its evaporation is much lower than to air α_{air}. This results in sharp decrease in overall heat transfer coefficient k and in the heat flux q at burnout vapor fraction about $x_{cr} \approx 0{,}9$ corresponding to drying the tube inner wall surface with the transition from annular to disperse flow.

Calculations were conducted for plate finned tubes of 10 and 12 mm inside and outside diameters, air temperature at the inlet t_{air1} = 25 °C and outlet t_{air2} = 15 °C, refrigerant boiling temperature at the exit t_{02} = 0 °C, refrigerant *R*142b.

Taking into account that a refrigerant vapor at the exit of conventional air cooler with thermoexpansion valve is to be superheated by 5-10 ºC, a share of the surface, corresponding to the final stage of refrigerant boiling and vapor superheating with extremely low intensity of heat transfer, is about 20-30 %.

A sharp decrease in the heat transfer coefficient to refrigerant α_a with the transition from annular to disperse flow takes place for most of refrigerants.

Enhancing heat efficiency of air coolers of railway conditioners in varying climatic conditions

The performance of railway conditioners is characterized by considerable changes of heat loads according to current climatic conditions on the routes.

To provide intensive heat transfer on all the length of air cooler coils it is necessary to exclude their ending post dry out sections, i.e. make the air coolers operate with incomplete boiling. The unevaporated liquid should be separated from the vapor in the liquid separator and directed again by jet pump (injector) to the air cooler for evaporation.

An injector recirculation of liquid refrigerant in air cooler can be successfully implemented in refrigeration machines of railway conditioners.

The injector uses the potential energy of refrigerant pressure drop from condensing to evaporation pressure, which is conventionally lost while throttling high pressure liquid refrigerant in thermo-expansion valve.

The highest thermal efficiency of the air cooler corresponds to the maximum value of heat flux $q_{max} = k\theta$, where θ − logarithmic temperature difference; k − overall heat transfer coefficient. The existence of maximum heat flux q_{max} is caused by the following. With increasing mass velocity of refrigerant ρw the heat transfer coefficient to refrigerant α_a and overall heat transfer coefficient k increases. But the refrigerant pressure drop ΔP and corresponding refrigerant boiling temperature drop Δt_0 increases also. Such opposite influence of the refrigerant mass velocity ρw upon k and θ causes the existence of maximum of function $q = k\theta$ at quite definite value of ρw. This value is considered as optimum mass velocity of refrigerant $(\rho w)_{opt}$.

The results of thermal efficiency comparison of conventional air cooler with complete evaporation and superheated vapor at the exit and of advanced air cooler with incomplete evaporation due to liquid refrigerant recirculation by injector are shown. The conditions at the air cooler outlet are the following: refrigerant boiling temperature at the evaporator exit t_{02} = 0 °C, there is a dry inner tube wall with a vapor superheated in 10 °C for the conventional throttle circuit and wetted wall with $x_2 < x_{cr}$ for the injector recirculation circuit; in disperse mixture the vapor is superheated in 5 °C as compared to the boiling temperature t_{02}; refrigerant R142b; incoming air velocity w = 6 m/s.

A complete evaporation of refrigerant in the conventional air cooler is characterized by a number of its circulation $n = 1/x_2 = 1.0$, where x_2 – refrigerant mass vapor fraction at the outlet.

It shows, that a recirculation of liquid refrigerant in the air cooler by injector provides an increase in heat flux q by 20…30 % compared with conventional air coolers with complete refrigerant evaporation and superheated vapor at the exit and enables a larger deviation of refrigerant mass velocities ρw from their optimum values (more than twice) without noticeable decreasing the heat flux q. This means that larger cooling load fluctuations are permited without falling air cooler heat efficiency.

On analyzing the changes of current heat loads on air cooler of railway conditioner on route line Kiev-Kherson-Kiev within the range of q_0 = 18-34 kJ/kg with taking into account of rational specific refrigeration capacity q_{0rat} = 32 kJ/kg, their deviation is within the range q_{0rat}/q_0 = 0.94-1.8, whereas the available permissible deviation of refrigerant mass velocities ρw from their optimum values due to injector liquid refrigerant circulation is $\rho w/\rho w_{opt}$ = 0.5-2.0, i.e. more larger.

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. 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 about 20% compared with conventional air coolers with complete refrigerant evaporation and superheated vapor at the exit was proposed. The injector uses a potential energy of high pressure liquid refrigerant, leaving a condenser, which is conventionally lost while it throttling to evaporation pressure in expansion valve. Recirculation of liquid refrigerant in air coolers by injector enables a large deviation of refrigerant mass velocities from their optimum values (more than twice) without noticeable decreasing the heat flux, that means that larger current cooling load fluctuations on railway route lines are permited without considerable falling air cooler heat efficiency.

So as any railway AC system includes liquid separator to collect excessive refrigerant during changeable current heat loads and to provide a safe performance of compressor, the proposed innovative refrigerant injector recirculation system does not need any considerable changes in conditioner design and addition refrigerant volume due to decreased air cooler dimensions by about 20 %.

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