

# Modeling of dynamics of vapor compression cooling system

**D L Karelin, A V Boldyrev, S V Boldyrev and A M Belousov**

Naberezhnye Chelny Institute, Kazan Federal University, Naberezhnye Chelny,  
Republic of Tatarstan, Russian Federation

[karelindl@mail.ru](mailto:karelindl@mail.ru)

**Abstract.** A mathematical model of cooling system with a vapor-liquid compression unit is presented. The modeling of dynamics of the parameters of the vapor compression system during the system start-up in the cooling mode was carried out. It is noted that with the accepted assumptions the evaporation and condensation temperatures stabilize fast enough: in the evaporator - in 0.5 s, in the condenser - in 2 s.

## 1. Introduction

The cooling system is one of the main elements responsible for stabilizing the thermal state of power units. As a result of intensive development of industries producing heat and electric engines for mobile machines in the direction of increasing specific power and environmental safety, the issue of increasing the efficiency of their cooling remains actual. Works of many authors [1-6] focus this issue offering various options for intensifying the process of heat exchange, in particular, by increasing the temperatures of the coolant. But this method is applicable not for all systems.

There are papers [7, 8] which authors propose to increase the efficiency of cooling systems by increasing heat transfer due to phase transitions of coolants in heat exchangers. In particular, the works [9, 10] propose a cooling method using vapor compression cooling systems (VCCS), combining the advantages of the temperature increasing and the phase transition of the coolant. Modeling of VCS parameters dynamics can be used to predict the duration of heating and cooling of power units, heat exchangers and equipment, as well as other specific time intervals for data collection which is important in the design of control units.

## 2. Materials and methods

In this paper, authors propose a mathematical model of VCCS (Figure 1), which includes models of compressor, heat exchangers (condenser and evaporator), expansion valve, and allows to calculate the transient characteristics of condensation and evaporation (boiling) temperatures.

The basic equations of the mathematical model of VCCS which were used to study the work of the cycle are presented below.



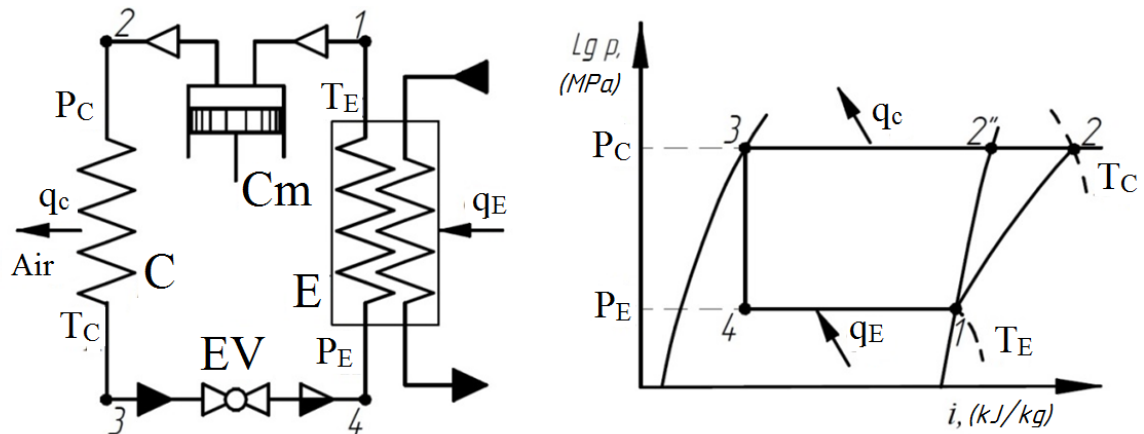


Fig. 1 Circulation of the working agent and the thermal cycle of the vapor compression cooling system (Cm – compressor, C – condenser, E – evaporator, EV – expansion valve)

### 1. Compressor

Specific work of adiabatic compression was determined by the equation:

$$l_a = P_1 \cdot v_1 \cdot \frac{k}{k-1} \cdot \left[ \left( \frac{P_2}{P_1} \right)^{\frac{k-1}{k}} - 1 \right]. \quad (1)$$

Specific indicator work of compressor

$$l_i = \frac{l_a}{\eta_a}, \quad (2)$$

here  $\eta_a$  – the adiabatic efficiency for the rotary vane compressor was assumed to be 0.82 [11].

### 2. Condenser

Heat transfer coefficient of the working agent during condensation in round tubes [11]:

$$\alpha_c = 1,26 \cdot \frac{\lambda'_c \cdot \gamma'^{0,1}_c}{(r_c \cdot v_c)^{0,5} \cdot \gamma''^{0,1}_c \cdot \sigma_c^{0,3}} \cdot q^{0,5} \cdot L^{0,35} \cdot (d_{c\_inner})^{-0,25}. \quad (3)$$

Heat transfer coefficient of air in the condenser which is a tubular heat exchanger with a staggered arrangement of finned tubes [12]:

$$\alpha_{c\_air} = 0,23 \cdot \frac{\lambda_{c\_air}}{b} \cdot \left( \frac{v_{f\_c\_air} \cdot b}{v_{c\_air}} \right)^{0,65} \cdot \left( \frac{b}{d_{c\_out}} \right)^{0,54} \cdot \left( \frac{h}{b} \right)^{0,14} \cdot \epsilon_c \cdot \epsilon_z. \quad (4)$$

Differential energy equation of condenser (two-phase region):

$$G_c \cdot C_{p_c} \left( \frac{dT_c}{dt} \right) = G_c \cdot (i''_2 - i_3) - F_c \cdot \frac{1}{\frac{1}{\alpha_{c\_air}} + \frac{\delta_{c\_tube}}{\lambda_{c\_tube}} + \frac{1}{\alpha_c}} \cdot \frac{(T_c - T_{air}') - (T_c - T_{air}'')}{\ln \left( \frac{(T_c - T_{air}')}{(T_c - T_{air}'')} \right)}. \quad (5)$$

### 3. Evaporator

Heat transfer coefficient during boiling of working agent in round tubes [13]:

$$\alpha_e = 0,65 \cdot 10^5 \cdot \frac{\lambda'_e}{d_{e\_inner}} \cdot \left( \frac{v''_e \cdot d_{e\_inner}}{v'_e} \right)^{0,73} \cdot \left( \frac{v'_e \cdot d_{e\_inner}}{v'_e} \right)^{-0,73} \cdot \left( \frac{v'_e}{a'_e} \right)^{0,3} \cdot \left( \frac{L_e}{d_{e\_inner}} \right)^{-1,69}. \quad (6)$$

Heat transfer coefficient of antifreeze in a multi-pass shell-and-tube heat exchanger-evaporator was determined from the similarity equation for the flow around a bundle of tubes with a staggered arrangement [11]

$$\alpha_{e.af} = 0,41 \cdot \frac{\lambda'_{e.af}}{d_{e.out}} \cdot \left( \frac{v_{e.af} \cdot d_{e.out}}{v_{e.af}} \right)^{0,6} \cdot \left( \frac{v_{e.af}}{a_{e.af}} \right)^{0,33} \quad (7)$$

Differential equation of energy equilibrium for the evaporator (two-phase region):

$$G_c \cdot C_{p_e} \left( \frac{dT_e}{dt} \right) = F_e \cdot \frac{1}{\frac{1}{\alpha_{e.af}} + \frac{\delta_{e.tube}}{\lambda_{e.tube}} + \frac{1}{\alpha_e}} \cdot \frac{(T'_{af} - T_e) - (T''_{af} - T_e)}{\ln \left( \frac{(T'_{af} - T_e)}{(T''_{af} - T_e)} \right)} - G_c \cdot (i_1 - i_4) \quad (8)$$

Formulating of differential equations required following assumptions: iso-enthalpy of throttling process in the expansion valve; constancy of antifreeze and air temperatures; constant mass flow of coolants; equality of the temperatures of the inner surface of the walls of the evaporator tubes and the condenser at the boundary of the vapor skin to the temperatures  $T_e$ ,  $T_c$  of the processes on the diagram, respectively (Fig. 1), use of the heat transfer equation (6) for the slug-annular, annular flow regime.

### 3. Results and Discussion

As a result of the calculations carried out by equations (2) - (8), the transient characteristics of temperatures of the working agent during evaporation and condensation at the start-up of the system in cooling mode and ambient temperature of 25°C were obtained (Fig. 2).

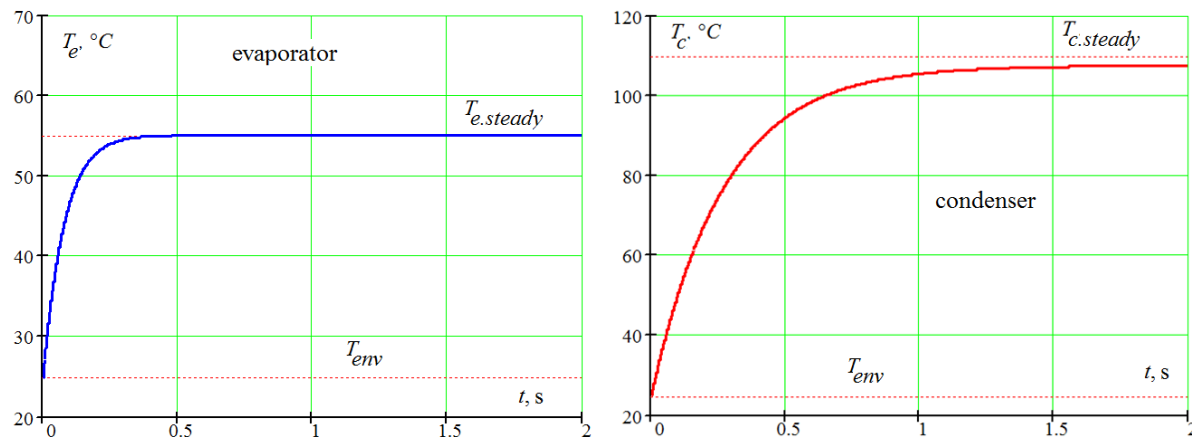


Fig. 2 The transient characteristics of temperatures of the working agent during evaporation and condensation at the start-up of the system in cooling mode

It was noted that, due to the assumptions in the mathematical model, the temperatures stabilize pretty fast (Fig. 2) due to the small values of the masses of the working agent  $m_e$  and  $m_c$  contained in evaporator and condenser, calculated by the standard method. And besides the evaporation temperature reaches a steady value within 0.5 s, and the condensation temperature within 2 s, that may be caused by significant difference in the heat capacities of air and antifreeze.

### 4. Conclusion

Further development of the mathematical model assumes taking into consideration: changes of temperature of antifreeze and air and mass flow of coolant; the formation of a vapor skin on the inner

surfaces of tubes; the cost of heat for heating the heat exchangers themselves, the mathematical model of the compressor drive, and adjustment of the expansion valve.

## References

- [1] Livencev F L 1964 High-temperature cooling of internal combustion piston-engine (Moscow: Mashinostroenie) p 204
- [2] Patrahalcev N N and Savastenko A A 2004 *Boosting of internal combustion engines* (Moscow: Legion-Avtodata) p 176
- [3] Krivov V G, Sinatov S A, Kim F G and Ustinov N A 1986 Heatsink into the space behind the cooling jacket of the forced diesel engine during its high-temperature cooling *Engine construction* No 11 pp 5–11
- [4] Kravchenko S A 1993 Diesel power plant of the mainline diesel locomotive on the basis of high-forced diesel locomotive engine with a heat recovery system and high-temperature cooling (St. Petersburg: CNIDI) p 24
- [5] Mkrtumyan E A 1938 Cooling of diesel engine at elevated temperatures of cooling water *Proceedings of Red flag Moscow MMI named after N.E.Bauman* Vol 38-39/4 p 72
- [6] Altynova N E 1984 Intensification of heat transfer in the cooling system of powerful electric converter devices (Novocherkassk: NPI) p 197
- [7] Sklifus Ya K 2015 Reducing the energy consumption of the diesel engine cooling system by changing the functional scheme and the heat transfer method (Rostov-na-Donu: RGUPS) p 159
- [8] Utilenko A I 2009 Principles of design of highly efficient cooling systems for electronic devices (Ryazan) p 419
- [9] Karelin D L, Gureev V M and Mulyukin V L 2015 Simulation of a cooling system with a vapor-liquid compression unit *Bulletin of KSTU named after A.N. Tupolev* (Kazan: editorial board of KNRTU-KAI) No 5 pp 5–10
- [10] Karelin D L 2017 Method for calculating the parameters of the thermodynamic cycle of a vapor compression cooling system *Proceedings of Academenergo* (Kazan) No 3 pp 23–31
- [11] Rozenfeld L M and Tkachev A G 1960 *Refrigerating machines and devices* (Moscow: GITL) p 666
- [12] Voronin G I and Dubrevskij E V 1973 *Effective heat exchangers* (Moscow: Mashinostroenie) p 96
- [13] Avchuhov V V and Payuste B Ya 1986 *Tasks for heat and mass transfer processes* (Moscow: Energoatomizdat) p 144