УДК 621.561

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COMPREHENSIVE COMPUTATIONAL METHOD OF VAPOR-COMPRESSION TRANSFORMERS OF HEAT

The method of the joint numerical analysis of loop variables and the heat exchange equipment of a contour of vapor-compression transformers of heat, considering non-stationary operating mode and irreversible losses in devices and contour pipelines is developed. The method is realized in the form of the software package and can be used at design or a choice of the transformer of heat taking into account a coolant and the valid equipment entering its structure.

Introduction. Taking into account a wide application of vapor compression heat transformers in various industries, a new generation of technical systems should have high reliability, long working lifespan, and little specific amount of metal. Transformers of heat include a wide range of devices and, depending on the application can be classified as refrigeration units, heat pumps, and combined cooler-heater units.

In the process of designing or implementing heat transformer there is a problem of choosing an energy-efficient device as a whole or its parts, mainly, heat exchangers and a compressor. To make the right choice is rather difficult, because the efficiency is influenced by various internal and external factors, which are determined by operating conditions.

The problem can be most successfully solved by using computational analysis and design methods, which allow investigating the system with the defined specifications. The analysis showed that the proposed computational methods do not allow calculating simultaneously cycle parameters and heat exchange circuit devices, considering a non-stationary operating conditions and the loss of pressure in the circuit elements [1–7]. Thus, the development of a comprehensive method of analysis involves interrelated computational methods of cycle parameters and heat exchange circuit devices of vapor compression heat transformers, considering non-stationary operating conditions, the mode of the compressor operation, and the loss of pressure in the devices and in the circuit lines and it is of current and scientific interest.

Main part. Vapor compression heat transformer is a complex technical system, including both main and ancillary equipment (Fig. 1). The main equipment comprises evaporator, compressor, condenser, and thermostatic expansion valve.

The developed computational method consists of interconnected blocks of equipment units and heat transformer circuit. Fig. 2 presents an integrated diagram of the comprehensive computational method, which shows possible aspects of the research.

The computational model forms a completed system and allows calculating simultaneously cycle parameters and heat exchange circuit devices, as well as designing individual equipment units.

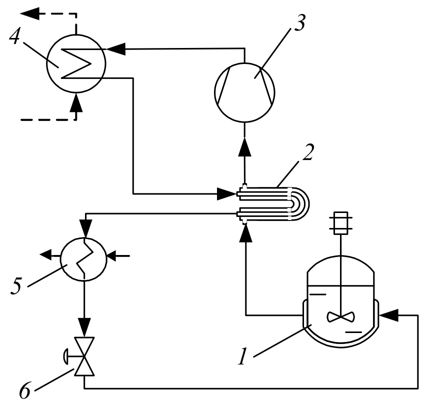

Fig. 1. Scheme of the circuit heat transformer:
1 – evaporator; *2* – regenerator; *3* – compressor;
4 – condenser; *5* – coolant;
6 – thermostatic expansion valve

Comprehension computational method includes the following items:

- definition of the cycle parameters with reversible and irreversible compression of the refrigerant in the compressor ;
- computation of operating conditions, i.e. calculating simultaneously cycle parameters and heat exchange circuit devices of the given scheme, considering stationary and non-stationary operating conditions, taking into account the actual operation of the compressor and the loss of pressure in the circuit elements;
- comprehension computational design, i.e. integrated computation of the cycle parameters involving the optimization of heat exchange circuit devices, taking into account the actual operation of the compressor and the loss of pressure in the circuit elements.
- individual design or confirmatory analysis of heat exchangers and technological heat transformer circuits associated with the source and consumer of the heat.

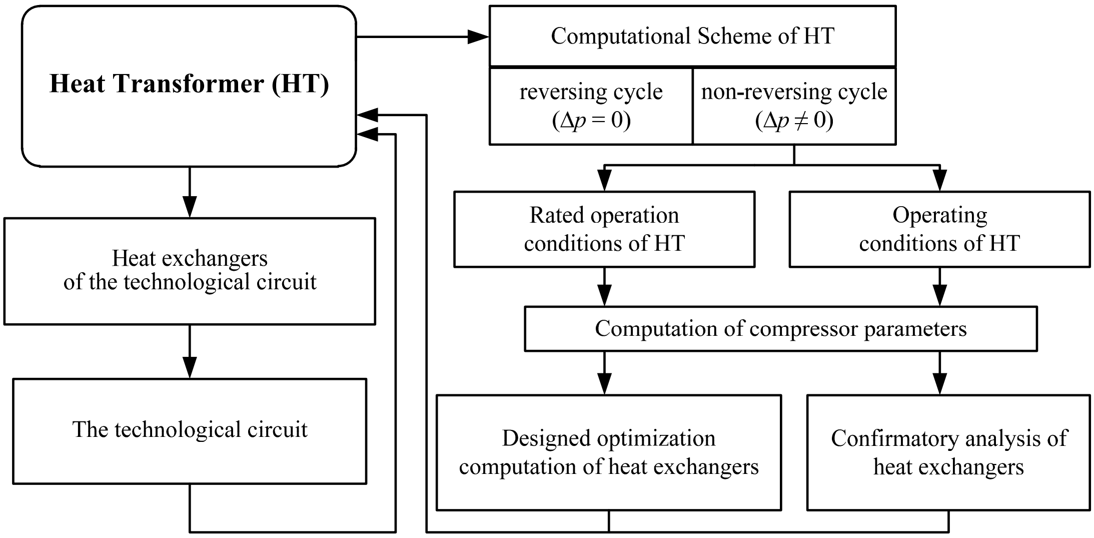

Fig. 2. Comprehension computational method scheme of heat exchange devices

The principal difference of the presented method is the possibility to analyze the operation mode of heat transformers in the non-stationary operating conditions, taking into account the loss of pressure in the circuit elements, and the possibility of a unified optimization computation of heat exchangers of various design and purpose.

Heat exchange equipment can be differently designed that required the development of a unified approach to its numerical analysis, which takes into account the non-stationary operating conditions.

The main heat exchangers (evaporator and condenser) are calculated in two sections: a phase transition and for single-phase floorage. Each of the sections is described with separate systems of equations of thermal transfer and thermal balance. In this case, the total heat exchange area

$$F = F_{\mathrm{I}} + F_{\mathrm{II}}, \qquad (1)$$

where F_{I} – boiling area (condensation), m^2; F_{II} – area of single-phase floorage of superheated steam, m^2.

When analyzing the transformer heat operation in off-design operating conditions, the limiting line between the sections changes, with $F = const$. It allows obtaining adequate results.

Non-stationary operating conditions of heat transformer are determined by the operation of the evaporator and changing external conditions. Heat transfer in the evaporator is described by the equations:

$$\frac{dQ}{d\tau} = k\Delta t F;$$

$$\frac{dQ}{d\tau} = \eta_1 G_1 \left[c_{p,1}\left(t_{1,1} - t_{1,2}\right) + h_{fg}(1 - x)\right]; \qquad (2)$$

$$\frac{dQ}{dt} = \eta_2 M_2 c_{p,2},$$

where Q – heat , J; τ – time, sec; k – coefficient of heat transfer, W/ (m^2·K); Δt – mean temperature difference, $^{\circ}$C; η – efficiency considering the losses in the heating or cooling of the environment; G – mass transfer rate, kg/sec; c_p – thermal capacity, J/(kg·K); t – temperature, $^{\circ}$C; h_{fg} – heat of the phase transition, J/kg; x – quality of wet vapor; M – mass of the cooled medium, kg. Indices: 1 – coolant; 2 – cooled heat-bearing agent in the evaporator or heated heat-bearing agent in the condenser; 1,1 – input, 1,2 – output.

Being numerically integrated, it is assumed that $d\tau$ operating condition is quasi-stationary one for sufficiently small time interval. For the investigated cases the minimum time interval $d\tau$ was determined as a result of computational experiment so that the end result was not significantly altered. At each time interval of quasi-stationary operation condenser and ancillary devices are also calculated.

The system of equations (1)–(2) is completed by the computation of the thermal transmittance factor and logarithmic mean temperature difference being adjusted for operating media floorage diagram [4]. Heat transfer coefficient for single-phase floorage and condensation is calculated according to the ratio given in [3–5], while boiling refrigerants – according to [7, 8]. When heat transform computation is designed, a completed system of equations is solved for the heat transfer area, and in conformity analysis the heat floorage is determined as a function of source parameters and heat consumer. Simultaneously, calculating the heat exchanger, it is determined the loss of pressure in the operating media floorage caused by frictional resistance and local resistance. Operational characteristics of the compressor are determined by the functional dependencies on actual volumetric efficiency, indicator and electromechanical efficiency.

Comparison of cycle parameters of the cooler-heater device, obtained by HEATTR and Refrigeration Utilities

Parameter	Operation time of the device			
	10 min		130 min	
	HEATTR	Refrigeration Utilities	HEATTR	Refrigeration Utilities
Specific cooling capacity, kJ/kg	152.0	153.7	145.2	147.8
Specific heating capacity, kJ/kg	189.20	191.02	203.39	207.38
Specific work, kJ/kg	37.82	37.28	58.21	59.54
Pressure rate	2.81	2.79	4.58	4.56
Transformation coefficient	5.08	4.12	3.49	2.48

The method also allows optimizing computation of heat exchangers. Depending on the design purpose, the weight of the device, the heat floorage or any other of the required indices becomes the optimal index. Explicit restrictions on function of the purpose determine the range of variation of design factors; implicit ones display the limit values of the loss of pressure, pumping capacity of heat-bearing agent, extension ratio for finned area of heat exchange. Minimum purpose function is iterative net method of alternate spacing.

The developed method is implemented as software package HEATTR [9, 10]. The package allows calculating the operational parameters of the heat transfers, choosing optimal solutions when designing and selecting heat transfer equipment.

The database is composed of the parameters of the compressor equipment and widely distributed refrigerants R22, R134a, R218, R290, R600a; it can be extended if necessary. Computational method is applicable in the temperature range of the refrigerant from –40 to 150 °C, respectively in the evaporator and condenser.

The accuracy of this method of analysis is confirmed by comparison with experimental data in the process of computational experiment [11].

The data obtained for the cooler-heater units using the developed software package were compared to the data obtained using the Refrigeration Utilities [12], which allows calculating the parameters of the cycle only and not considering the operation of the circuit equipment. The comparison results are given in the table. Cooler-heater operates in the non-stationary operating conditions, which are determined by the evaporator. A device is made in the form of static heat exchanger of volumetric type. 1000 liters of cooled milk at the initial temperature 35^{o}C is charged into the condenser. To intensify the process it is stirred by the agitating apparatus. The heat output from milk, with increasing potential in the condenser is used to heat water used for technological needs. In the device being investigated, the condenser is single-cut coil heat exchanger with displacer. The condensation temperature is maintained at 50 0C. Water temperature at the condenser input is 50C. When the device operates, the time of cooling milk is limited by 3 hours till 40C. Refrigerant R22 was used as precoolant.

Two quasi-stationary operating conditions, corresponding to 10 and 130 min of the device operation, listed in the table were chosen for comparison. The results of the comparison of the parameters corresponding to the appropriate time intervals are satisfactory. Maximum deviation result on cooling capacity is 1.8 %, and heating capacity – 1.9%.

Conclusion. The developed method implemented as a software package for the joint analysis of the cycle parameters, heat exchangers and piping circuit elements of vapor-compression heat transformers considering non-stationary operating conditions and irreversible losses.

This method of analysis allows designing heat transformers and predicting actually obtained parameters considering the designed equipment in rated operation conditions and off-design operating conditions.

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Received 20.02.2013