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Performances of a Turbocompressor Heat Pump as Common Characteristics of the Elements of the Energy System

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PERFORMANCES OF A TURBOCOMPRESSOR HEAT PUMP AS COMMON CHARACTERISTICS OF THE ELEMENTS OF THE ENERGY SYSTEM

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1. BASIC ASPECTS OF THE ANALYSIS

This paper deals with problems connected with modelling and utilization of characteristics of large turbocompressor heat pumps which use water as a carrier of heat from the heat source to the heat consumer, and F12 as a refrigerant.

The heat pump is analysed as a sub-system of an energy system in which it is integrated with the heat source and the heat consumer. The heat pump consists of: one-stage sentifugal compressor, flooded shell and tube evaporator, shell and tube condenser, and regulating float valve, alternatively thermo-regulating valve as shown in Fig.1. An integrated element of the heat pump with the heat source is the evaporator, and with the heat consumer is the condenser.

The characteristics of the energy system and turbocompressor as representative of the heat pump from the following specific aspects are analysed:

- to determine a procedure for modelling characteristics of the heat pump and the energy system as a whole;
- to find an optimal combination of the heat pump elements in its design;
- to make a rational choice of the heat pump at a known range of capacity;
- to determine criteria for optimal guide for exploatation of an installed head pump;
- to define initial data for the design of heat pump elements;
- to examine the influence of the turbocompressor choice upon the heat pump capacity at given values of the evaporator and the condenser.

The general analysis is illustrated by diagrams for one heat pump with the following nominal basic values: heat capacfty Q_c = 3,5 MW, evaporation temperature t_0=20°C and condensation temperature t_k = 72°C.

2. CHARACTERISTICS OF THE HEAT PUMP ELEMENTS

The heat capacity and the temperature rise that should be realized with the heat pump are given as the heat consumer needs, but they are conditioned by the usable heat flux and the temperature level of the heat source.

The large heat pumps are designed individually with previously defined capacity range which imposes the need for rational construction and optimal adjustment with their essential elements.

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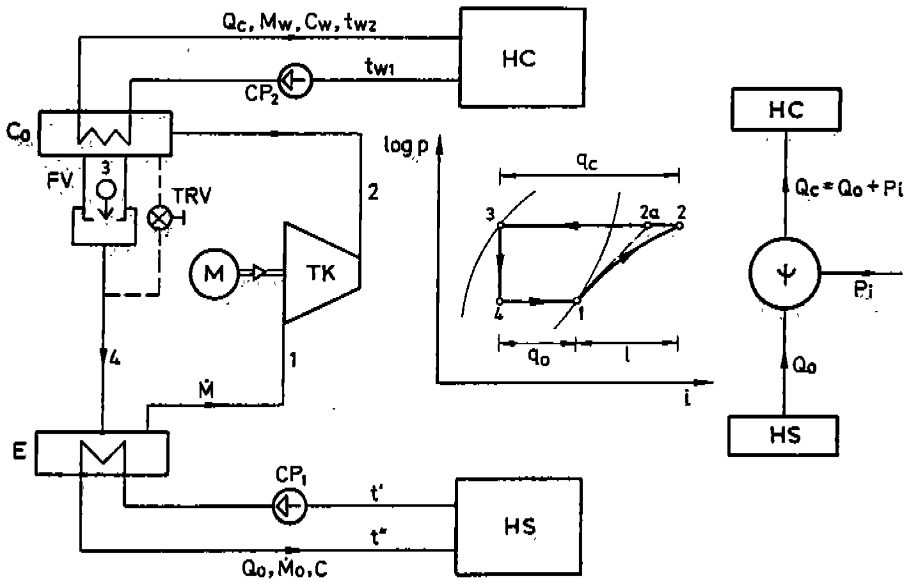

E - evaporator
TK - turbocompressor
M - motor
Co - condenser
FV - float valve
TRV - thermoregulating valve
HS - heat source
HC - heat consum
$CP_{1,2}$ - pump
ψ - COP

$\dot{V}$ - flow rate
Q_c - condenser capacity
Π - pressure ratio
t_o - evaporating temperature
t_k - condensing temperature
$\Delta t_k = t_k - t_o$ - temperature lift

Fig.1. Model of the heat pump with simbolic scheme and logp-i diagram

The turbocompressor is an element of the heat pump which is not directly connected with other sub-systems. That is why it has a very important effect on the operation of the heat pump and the whole energy sistem.

Work characteristics may be represented /2/ and expressed by the following relation:

$$f_1(\dot{V}_1, \Pi, Ma, Re, k, \Omega_i) = 0 \qquad (1)$$

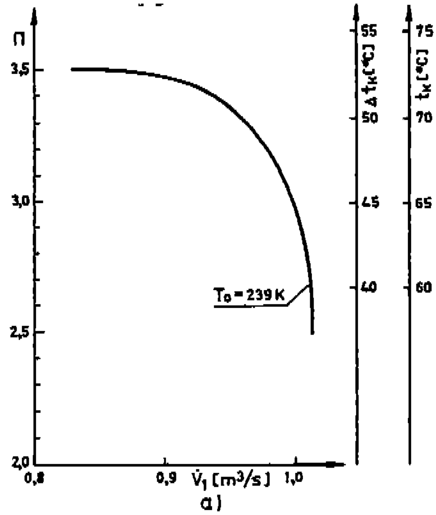

Fig.2a. Internal turbocompressor characteristics

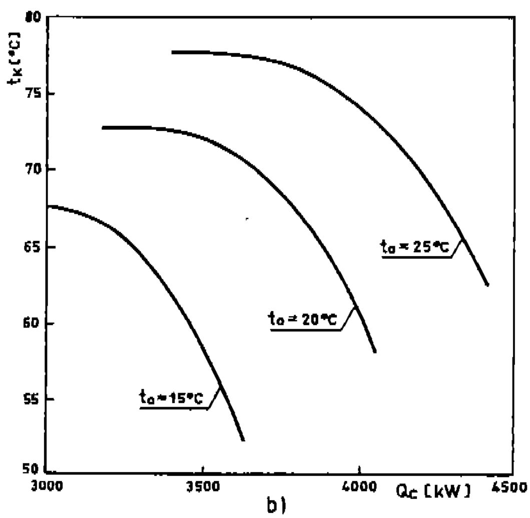

Fig.2b. External turbocompressor characteristic

The equation (1) defines the functional dependences among: the volume flow at the inlet ($\dot{V}_1$), pressure ratio (Π), Mach number (M_a), Reynold's number (Re), physical characteristic of the refrigerant (k), and characteristcs of the construction and shapes of the turbocompressor flow space (Ω_i).

The analysed example, Fig.2, presents a graphic interpretation of the equation (1) transformed into the following analytical forms of internal (Fig.2a) and external (Fig.2b) characteristics of the turbocompressor: $f_2(\dot{V}_1, \Pi, t_o, t_k) = 0$ and $f_3(Q_c, t_o, t_k) = 0$.

Energy systems and their capacity can be grouped in two general types, depending on the heat consumer demands and the heat source phenomena.

The first case is when the heat source temperature, i.e. t_0 is constant, and the needed heat by the heat consumer Q_c and its temperature level, i.e. t_k are changed at time τ according to some law expressed with $f(Q_c,T_k,\tau) = 0$, in a given capacity range.

Fig.3 shows the turbocompressor characteristics f_3 for t_0=const. and its transferred characteristics with regulating system as the consumer characteristic f_4.

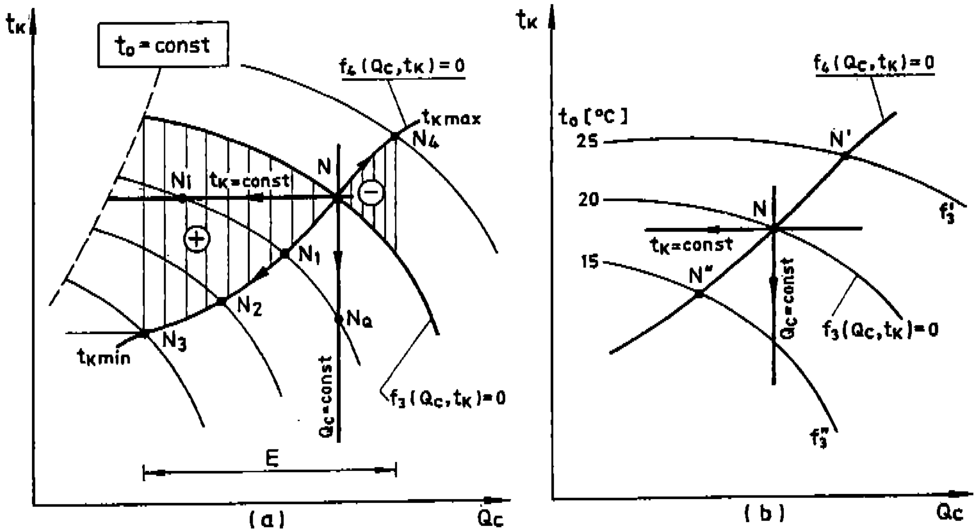

Fig.3. Diagram of the work adjustment of the heat pump to the heat consumer needs

In this case only at the point of the nominal condition $N(Q_N,t_{kN})$ there is an equation of the generated heat in the heat pump and its temperature level with those values needed by the heat consumer. For the conditions on the left from the point N the heat pump generates the heat at the higher temperature lavel than necessary (+), and on the right of the point N at the lower (-) one. This problem may be overcome by introducing the compressor regulating system, with which the compressor characteristic will be transformed in the whole capacity range, so that it will constantly change the working conditions at the balanced points Ni, as can be seen in Fig.3a.

For the special case, also interesting for the practice, we may consider consumer characteristics Q_c=const. and t_k=const., at which the heat pump could be adjusted with the compressor regulating system (points N_a,N_i).

The second general case happens when the temperatures of the heat carrier from the heat source t', i.e. t_0 are changed. For this case the basic characteristics of the turbocompressor are changed, as can be seen in Fig.3b, with nominal points N, N', N". Continuous adjustment of the heat pump with the consumer characteristic, in this type, is possible by means of the turbocompressor regulating system.

The evaporator characteristic as an integrated element of the subsystems, heat pump - heat source, may be analytically defined by two conditions - (a) balance of the taken heat from the heat source and the given heat to the refrigerant in the evaporator and (b) the criterion for the heat exchange in the evaporator, that is:

$$Q_o = M_o c(t'-t") = \dot{M} q_o \tag{2}$$

$$Q_o = k_o F_o \frac{t' - t"}{\ln \frac{t'-t_o}{t" - t_o}} = k_o F_o (t_m - t_o) \tag{3}$$

The results from the equations (2) and (3) give the evaporator characteristic:

$$Q_o = \dot{M}_o c(t'-t_o)(1-e^{-\frac{k_o F_o}{\dot{M}_o c}}) = f_o(t',t_o) \tag{4}$$

The analysis of the equation (4) is made essier with the use of a computer /2/.

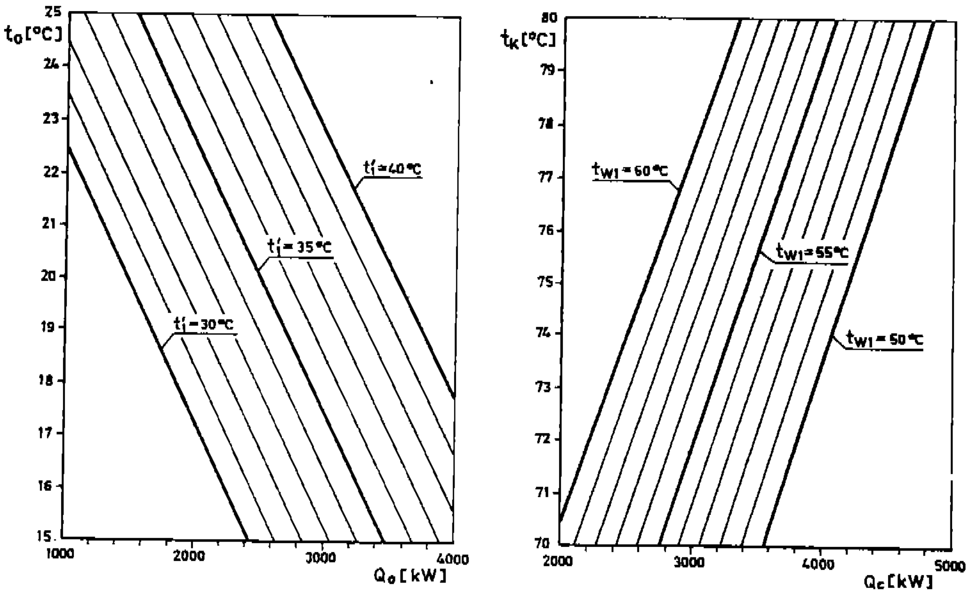

Fig.4. Characteristics of the evaporator (a) and the condenser (b)

For chosen or estimated evaporator and determined temperature condition, according to the equation (3), approximate evaporator characteristic is the family of lines, Fig.4a, whose inclination is defined by the equation:

$$tg\phi_o = \frac{Q_o}{t_m - t_o} = k_oF_o \tag{5}$$

In designing or choosing the condenser it is taken that its heat capacity, estimated at its discharge, is equal to that one of the condenser. The condenser capacity as integrated element of the heat pump, with the heat consumer may be defined by the following expressions:

$$Q_c = \dot{M}_w c_w (t_{w2} - t_{w1}) = \dot{M} q_c \tag{6}$$

$$Q_c = kF \frac{t_{w2} - t_{w1}}{\ln \frac{t_c - t_{w1}}{t_2 - t_{w2}}} = kF(t_c - t_{wm}) \tag{7}$$

The results from the equations (6) and (7) give the the condenser characteristic:

$$Q_c = \dot{M}_w c_w (t_e - t_{w1})(1 - e^{-\frac{kF}{M_w c_w}}) \tag{8}$$

For defined or chosen condenser and determined work condition, according to the equation (7), approxiamately, condenser characteristic is family of lines with inclination:

$$tg\phi_c = \frac{Q_c}{t_c - t_m} = kF \tag{9}$$

3. CHARACTERISTICS OF THE ENERGY SISTEM

The work adjustment of the compressor with the evaporator may be seen through the system of equations (1 - 8), that is, through the cirve of adjusted work conditions, Fig.5.

Even if we choose a type and size of the regulating valve which will satisfy all work conditions, we could exclude its influence during the modelling the characteristics of the energy system. Work points for different work conditions of the energy system can be determined at the intersections of the condenser characteristic with that one from the compressor - evaporator sub-system, Fig.6. This enables simultaneous observation of all characteristic values: $t_o, t_k, t', t_{w1}, Q_c$.

4. INFLUENCE OF THE COMPRESSOR SIZE ON THE OPERATION OF THE ENERGY SYSTEM

If we choose a compressor with larger flow rate than normally needed (in the example for 25%) in the course of shaping the system characteristic and finding its work points, we come to the conclusion that with the same evaporator and condenser in both cases we get an increase of heat capacity Q_c and condensing temperature t_k. However, the degree of that increase is noticeably smaller than the designed one, which can be seen from the data given in table 1.

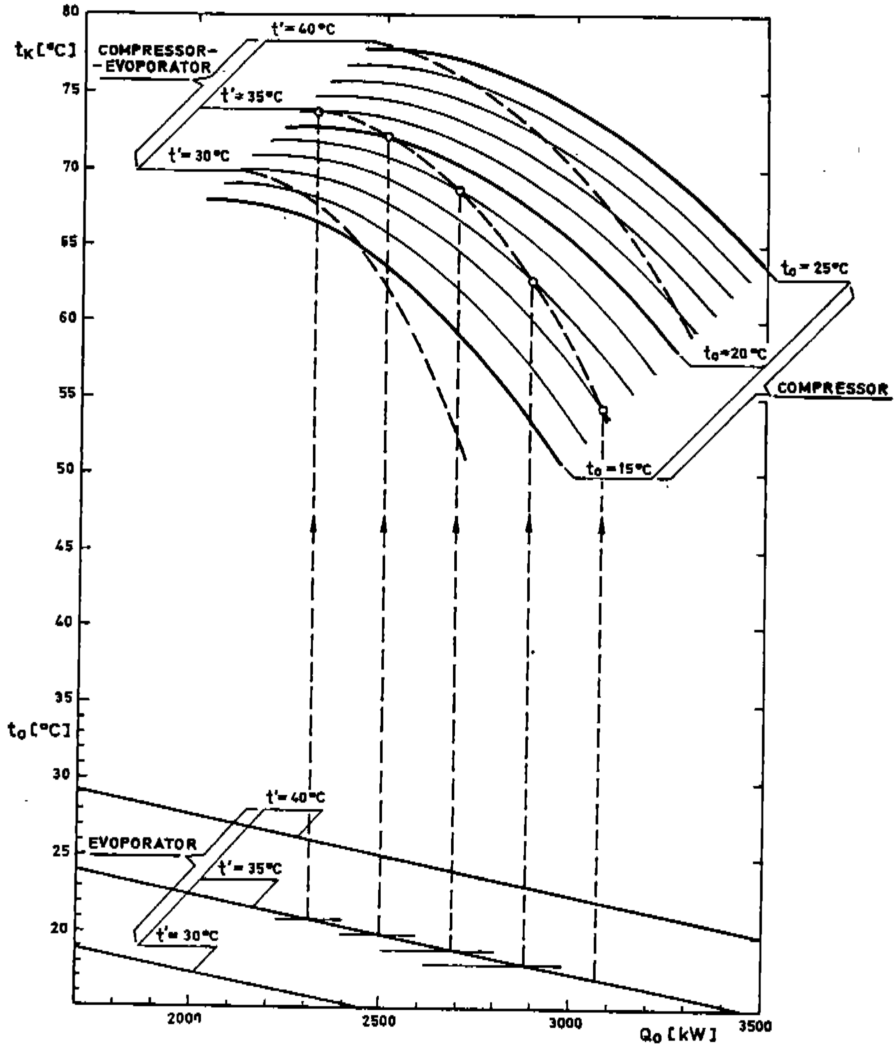

Fig.5. Characteristic of the subsystem compressor-evaporator

Table 1. Influence of the compressor size on the characteristics of the energy system

ITEM		Nominal flow rate of the compressor $\dot{V}_1$ (m^3/s)			
		$\dot{V}_{1I}$ = 0,93		$\dot{V}_{1II}$=1,25 V_{1I} = 1,16	
		t_k (°C)			
		72	65	72	65
Capacity of the heat pump Q_c (MW)		3,5	3,9	4,25	4,63
Temperatures (°C)	t_o	20	20	20	20
	t'	35	36,5	30,8	40,5
	t_{wl}	53	42	46,5	34

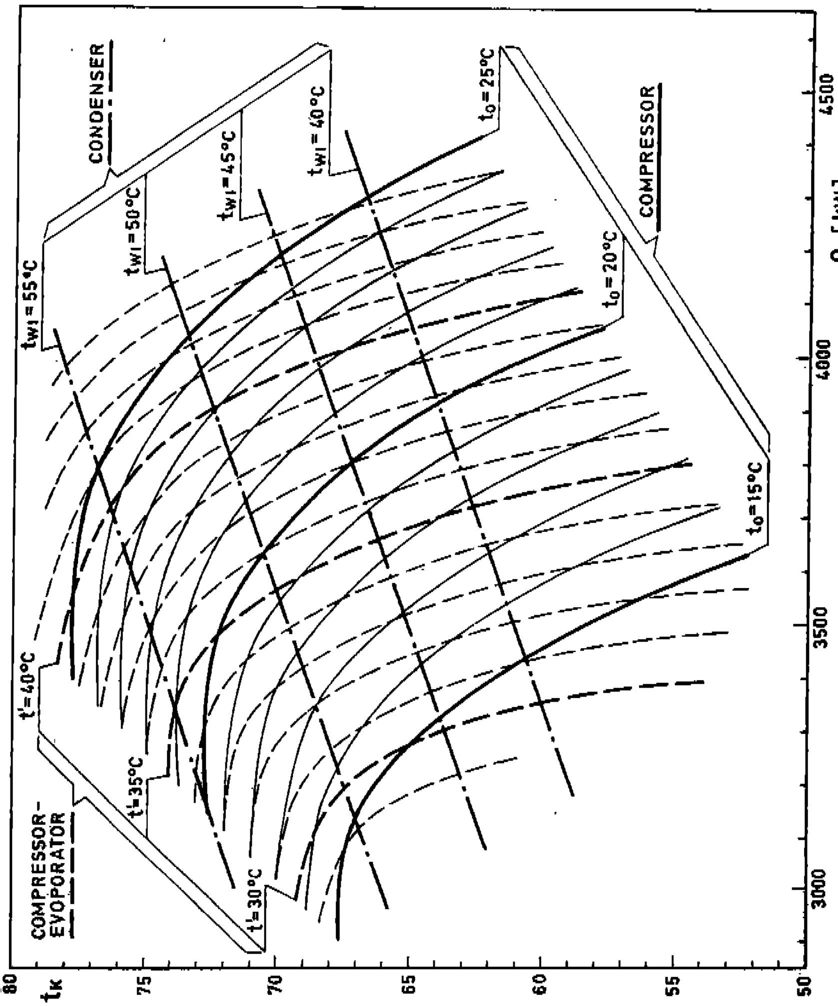

Fig.6. Work points of the energy system

5. CONCLUSIONS

We have analysed the characteristics of the large turbocompressor heat pumps and their adjustment with the heat source and the heat consumer. Analytical and graphic forms of the characteristics with the procedure for their adjustment are given.

Because of the shaping of the characteristics of the energy system it is necessary to copy the gas-dynamic, internal characteristic of the turbocompressor in the system $Q_c - t_o - t_k$. It is shown that with the regulating systems of the turbocompressor and the energy system it is possible to conduct work conditions in which the consumer demands are adjusted to the characteristics of the heat pump and heat consumer.

Two methods for finding common characteristics of the subsystems and work points of the energy system in general are presented. The influence of the size of the turbocompressor upon the work of the energy system is examined.

The results of the analysis may be used in the design of the heat pump and in its choice, that is, in the estimation of its elements, and also in its exploitation, because of the optimal guidance of its work conditions.

6. REFERENCES

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PERFORMANCES OF A TURBOCOMPRESSOR HEAT PUMP AS COMMON CHARACTERISTICS OF THE ELEMENTS OF THE ENERGY SYSTEM

S U M M A R Y

The turbocompressor heat pump is defined as a refrigerating system composed of the following essential elements: turbocompressor, evaporator, condenser and control valve. The authors demonstrate the characteristics of the elements of the heat pump in analytical and graphic form. The interaction of the elements is considered and the common characteristics of the heat pump as an energy system are defined. Special attention is given to the characteristic heat capacity as a function of the condensation and evaporation temperatures. A selection of heat pumps and their optimal exploatation are recommended.

PERFORMANCES DE LA POMPE À CHALEUR DE TURBOCOMPRESSEUR INTEGRÉE DANS UN SYSTEME ÉNERETIQUE

RÉSUMÉ: La pompe à chaleur du turbocompresseur est définié en tant qu' un systéme de refroidissement composé de turbocompresseur, évaporatuer, condensateur et soupape régulatrice. On a exposé les caractéristiques des éléments de la pompe à chaleur sous une forme analytique et graphique. On a envisagé les dépendances entre la pompe à chaleur à source thermique et le consomateur de la chaleur avec lequel elle constitue le systéme énergétique. On suggére des recommandations à l'aide des diagrammes ci-inclus pour un choix optimal et l'exploitation de la pompe à chaleur de turbocompresseur.