IOP Conf. Series: Materials Science and Engineering **134** (2016) 012015 doi:10.1088/1757-899X/134/1/012015

Optimization of energy saving decisions for the large compressor stations of machine-building firms based on the technical and economic indicators

G R Ḱhamidullina

Kazan (Volga region) Federal University
18, ul. Kremlyovskaya, 420008, Kazan, Russia

Abstract
We offer the method of energy-efficiency measures improvement based on optimization of its technical and economic indicators. As an object of research is considered the high-capacity compressor station of the machine-building enterprise.

1.Introduction

Compressor stations of large machine-building enterprises are at the same time the source of energy resource (compressed air) for the production needs and the large consumers of the electric power or other high-quality fuel and energy resources [1, 2]. This causes the continuous search of energy saving decisions at the compressor stations. Energy saving works usually are the mainly concerned with the increase of a share of useful using of the warmth which is taken to the atmosphere by the system of reverse water supply [3, 4]. It could be the utilization of warmth of the water which is taken away from air heat exchangers, from the cooling system of compressors and also the warmth taken in the cooling system of technical oils. The last way is considered in this research.

Now there is the next approach in the practice of researches, development and deployment of energy saving technical solutions: firstly we make an analysis of power efficiency of modernization variants then for the preferable variant we make the technical and economic calculations basing on famous techniques.

Unfortunately such approach could lead to the miscalculations in decision-making and stating of the projects which will not reach the optimum technical and economic indicators. It is expedient to make the search of optimum variant of structure and operating modes of the advanced technical object on the basis of technical and economic optimization with the consideration of real types of the applied equipment and features of its using [5, 6]. Наиболее показательным примером здесь является методология технико-The most attractive example here is the methodology of the technical and economic analysis of combined heat and power plants which founder is the academician L.A. Melentyev [5] distributed in the synthesis of large sources of heat and power supply. This methodology is used here as a basis for the creation of decisions for the research object (compressor station).

Content from this work may be used under the terms of the Creative Commons Attribution 3.0 licence. Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI.
Published under licence by IOP Publishing Ltd

2.Research object

The research object is submitted on the fig. 1 where we could see the initial scheme of the compressor station (CS) of machine-building enterprise with the oil-flooded screws [3].

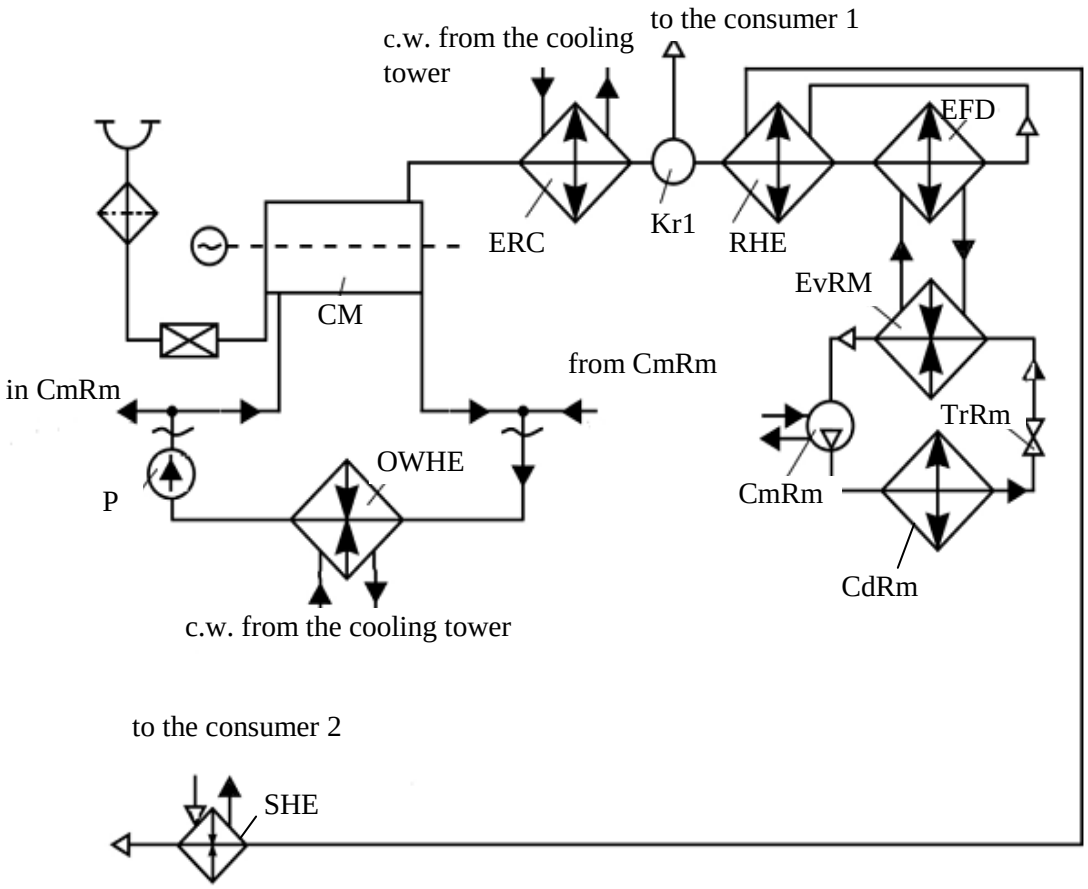


Fig.1. Initial scheme CS of machine-building firm

The scheme includes an air compression site, system of air drainage for ensuring the moist parameters of compressed air demanded in industrial technology, and a site of heating up of the compressed air for the providing the demanded air temperature given to the consumer.

In the CM compressor air compresses up to the pressure demanded to industrial production, and then comes to the system of air drainage. Air drainage is carried out in few steps. The first step – the trailer refrigerator at the exit from the ERC compressor, the second – the RHE regenerative air-air heat exchanger, the third - the EFD heat exchanger-freeze-out device (low-temperature condenser) connected to the RM refrigerating machine.

The cooled and drained air passes through RHE and goes to the heating system. In the initial scheme heating of air up to the demanded on technology temperature of 200°C is carried out in the SHE steam-and-water heat exchanger.

The other symbols accepted in the fig. 1: P - the pump; Kr1 – knot of resetting of compressed air adding; EvRM – the RM evaporator; CdRm – the RM condenser, CmRm – the RM compressor; TrRm – a throttle of RM, OWHE – oil-and-water heat exchanger, c.w. – chilled water.

On the fig. 2 we could see the modified scheme CS [4] where the energy saving solution directed on utilization of warmth of compressor oil in heat pumping installation (HP) with the subsequent using

of the warmth transformed on higher level for preliminary heating of the air directed then through the heater to the consumer.

In fig. 2 are accepted the next symbols: EvHP – the HP evaporator; KmHP – the HP compressor; TrHP – HP throttle; CdHP – the HP condenser. Other designations are similar to fig. 1.

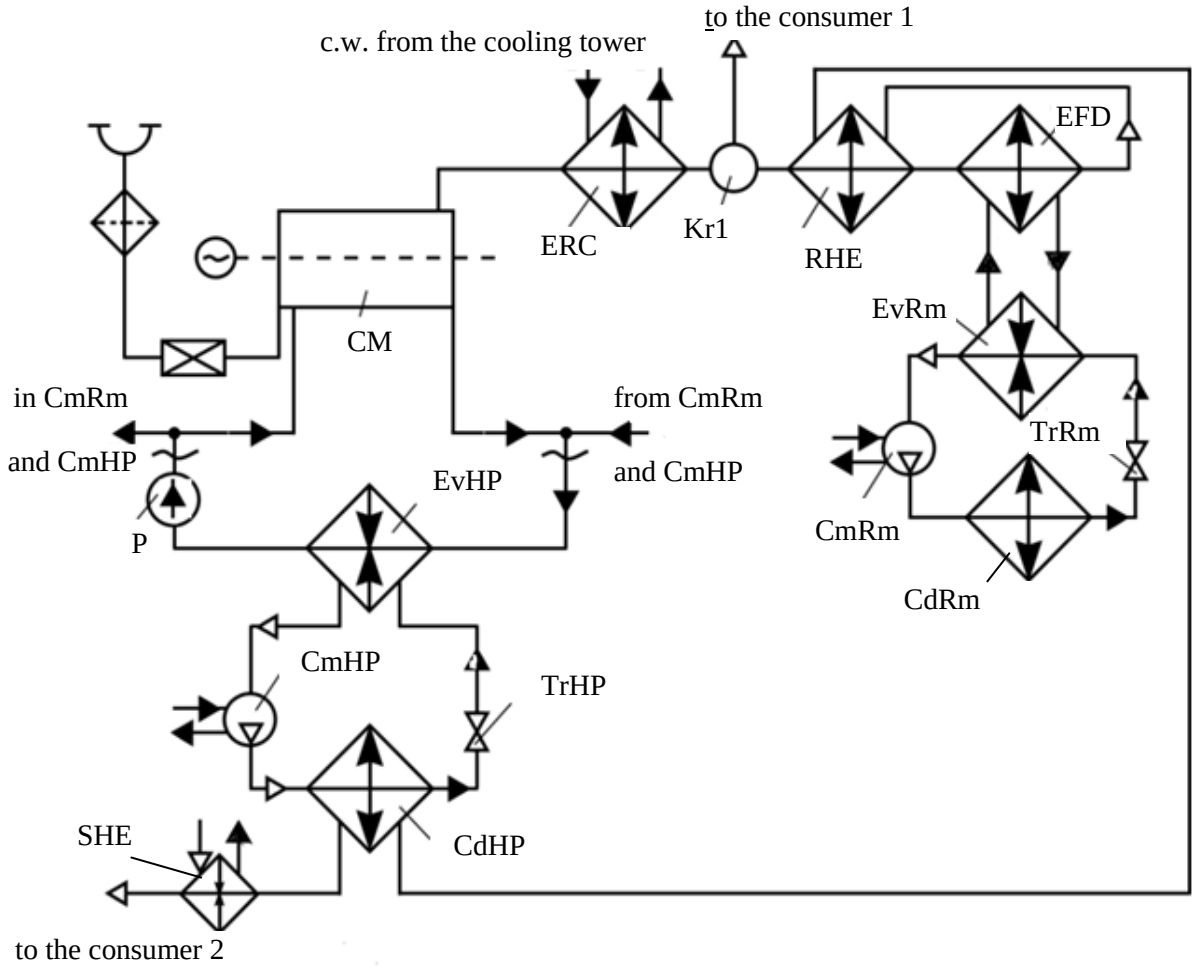


Fig.2. Modified scheme of CS

3.Research methods

The optimum level of intermediate heating in the modified scheme (fig.2.) of air depends on two factors: the positive, connected with direct economy of warmth water vapor, and negative, connected by that in HP additional expenses of the electric power are made for ensuring level of thermotransformation.

Using the analogy with [5, 7, 8] the task of search the most favourable technical or economic parameters combination is formulated as follows:

1. First we are looking for the maximum (minimum) value of efficiency criterion described in the function form:

$$\Phi = \Phi(Z, X)_{\sigma}, \tag{1}$$

with the presence of the nonlinear limiting conditions look like

$$\varphi_i(Z, X)_{\sigma} = 0;\ i = \overline{1,n}, \tag{2}$$

and the inequalities like

$$(f_p)_{\min} \le f(Z, X)_{\sigma} \le (f_p)_{\max};\quad p = \overline{1,a} \tag{3}$$

and also with the restrictions on parameters like

$$\left.\begin{array}{l} Z_{\min} \le Z \le Z_{\max};\quad Z \in \sigma_m; \\ X \in L_t. \end{array}\right\} \tag{4}$$

Z here is the set of continuously changing parameters (see the p. 3 in the list);

X is the set of discretely changing parameters (see the p. 2 in the list);

σ - set of the characteristics of the considered external factors;

$\varphi = \{\varphi_1, \varphi_2, ..., \varphi_n\}$ - the system of the balance equations for all knots (parts) of system;

$f = \{f_1, f_2, ..., f_a\}$ - the set of technical characteristics on plant knots on which are making the limiting conditions;

the "min" and "max" indexes specify the minimum and maximum values;

σ_m is the dimension of considered space;

L_t is the some final set of discrete elements of *t* dimension.

With the using of identification of consecutive linkages chains between the balance equations setting the values of model parameters there is an opportunity to present the full system of the n-equations in the form of strict sequence of subsystems [5]. Thus it is enough to limit the defining input and output parameters of subsystems (a vector of independent parameters $\overline{X}$) using the conditions like (4), for the reaching of all dependent internal parameters of a subsystem (a vector of Y dimensions of *n*) automatically meet this condition.

Therefore

$$Z = (\overline{X}, Y); \tag{5}$$

provided (that)

$$(\overline{X}_j)_{\min} \le \overline{X}_j \le (\overline{X}_j);\ j = \overline{1,s};\ s = m\text{-}n. \tag{6}$$

One additional feature of the considered systems is that there could be technically the restrictions on nonlinear characteristics on which the criterion function Φ doesn't depend obviously.

As a result the general sequence of task solution is as follows:

1) We define the parameters X and $\overline{X}$, providing the maximum (or minimum) value of efficiency criterion;

2) Then we define the vector Y, proceeding from the received value $X and\ \overline{X}$, as a result of calculation of n-system of equations.

In general terms the equation for definition looks like

$$Y = Y(X, \overline{X}) \tag{7}$$

3) Functions Φ and f are also defined on each step as the functions of independent parameters X and $\overline{X}$.

With the using of the arguments above the objective is reduced to a problem of finding the function extreme (a minimum or a maximum depending on chosen criterion of technical and economic efficiency).

$$\Phi\left(X,\overline{X}\right) \text{ with } \left(X,\overline{X}\right)\in R, \tag{8}$$

where R is the area of admissible values set by conditions

$$\left(f_p\right)_{\min} \le f_p\left(X,\overline{X}\right) \le \left(f_p\right)_{\max},\ p=\overline{1,a}; \tag{9}$$

$$\overline{X}_{\min} \le \overline{X} \le \overline{X}_{\max},\ \overline{X}\in\boldsymbol{\sigma}_s; \tag{10}$$

$$X \in L_t \tag{11}$$

Thus it is supposed that with the fixed values X, functions $\Phi\left(\overline{X}\right)$ and $f_p\left(\overline{X}\right)$ are differentiated.

On the analogy with [5] the solution of a task breaks into two stages coordinating the object parameters with the iterative procedures:

Stage 1. Finding the set of the most favourable parameters $\overline{X}$, i.e. the parameters which in the definition range are changing continuously.

Stage 2. The determination of set of the most favourable parameters X, i.e. the parameters which are changing discretely.

4.Results and conclusions

The imposed restrictions look as follows:

1) The potential of the thermal energy developed in HP which is released from HP is limited by the conditions (from conditions of technical feasibility of the decision):

temperature $t''_{c.w.} \le t^{HP}_{Cd} \le 125$ °C,

where the $t''_{c.w.}$ is the temperature of the cooled compressed air on leaving the drainage system, °C.

For this parameter is used the designation $\overline{X}_{1i}$, where $i=\overline{1,n}$ is the number of variant of the current settlement combination of these parameters; n – total number of the considered variants.

The second parameter is the temperature level of compressed air at the exit from RHE, $t'_{\text{c.w.}}$ arriving then to the drainage system. For this parameter in the model description is used the designation $\overline{X}_{2i}$.

With the parameters $\overline{X}_{1i}$, $\overline{X}_{2i}$ is depend the following chain of the parameters defining technical and economic indicators of the decision:

X_{3i} is the thermal equivalent of the specific consumed electric power of HP, kW;

X_{4i} is an expense of the working agent in HP, kg/s;

X_{5i} is an expense of the heating steam in the SHE heat exchanger, kg/s

X_{6i} is an expense of the refrigerating agent (element) in RM, kg/s

X_{7i} - the thermal equivalent of the specific consumed electric power of HP, kW;

X_{8i} is an expense of the cooling water in the RM condenser, kg/s

X_{9i} - the temperature of the warmed-up compressed air at the exit from RHE, °C.

As the criterion function was considered the annual economy of the given costs on KS defined by a ratio, roubles/year:

$$\Phi_{ec} = \sum_{i=1}^{n} E_i C_i - \sum_{j=1}^{m} E_j C_j - (K_{mod.CS} - K_{CS})[(\mathrm{E}_i + f) + Z_{add}], \qquad (12)$$

where $\mathrm{E}\left(X, \overline{X}\right)$ is the amount of energy resource; C – energy resource cost; K – level of capital investments; E_i - the accepted coefficient of investment assignments; f – share of annual costs for depreciation, repair of the equipment, salary of workers and other expenses; Z_{add} are the additional unaccounted annual expenses in the modified CS scheme; the $i = (\overline{1,n})$ - index corresponds to types of the saved energy resources; index $j = \left(\overline{1,m}\right)$ – corresponds to types of the spent too much energy resources.

The saved resources in the modified system of CS are:

- thermal energy of steam, t/year;
- reverse water, t/year;
- the electric power spent in system of reverse water supply for pumps and fans of coolers.

The too much spent energy resource in the system is the electric power which is in addition spent for HP drive gear.

The economy or the excessive consumption of energy resources were determined by the balance equations depending on the combination of the above-stated parameters $\overline{X}_{1i}$, $\overline{X}_{2i}$ and $X_{4i} \div X_{9i}$ set in the calculations.

Optimum value of the Φ_{ec} function is seeking for from the condition:

$$\frac{d\Phi_{ec}}{d\alpha} = 0, \qquad (13)$$

where $\alpha = [0, 1]$ is a share of the forced-out thermal loading of a steam preheater due to use of the warmth which is taken away in the HP condenser.

The carried-out optimizing technical and economic calculations of the example task showed 20% deviation of the optimum regime parameters in the modified CS which are calculated on thermodynamic indicators towards the reduction of a share of the forced-out α steam [4].

The deviation is concerned with the possibility of accounting the additional factors in the offered method of the technical and economic concerned with the real opportunities of power regulation of HP depending on the thermotransformation mode.

Nevertheless the undiscounted payback period [6] is a little more than one year which confirmed the high efficiency of the proposed energy saving actions.

References

[1] Israfilov Z K and Kashapov N F 1991 *Journal of Engineering Physics* **60** pp. 364–8

[2] Galyautdinov R T, Kasparov N F and Luchkin G S 2002 *Inzhenerno-Fizicheskii Zhurnal* **75** pp. 170–3

[3] Kumirov B A 2006 *Systems of firm supply with the compressed air* (Kazan: Kazan state energy university)

[4] Konakhina I A and Voropayev A N 2009 *Synthesis of power effective system of compressor station with the thermosiphon cooling system of technical oil* (Vologda: Vologda State Technical University) pp. 193-6

[5] Konakhina I A and Nazmeyev Yu G 2002 *Heat-Power Systems and Power balances of Industrial Facilities* (M.: Publishers of Moscow Power Engineering Institute) p. 407

[6] Tabunshchikov Yu A 2005 *Guide on the estimation of economic efficiency investment into the energy saving measures* (M.: AVOK-PRESS) p.120

[7] Fayrushin I, Kashapov N and Dautov I 2014 *J. Phys.: Conf. Ser.* **567** 012009

[8] Dautov G, Dautov I, Fayrushin I and Kashapov N 2013 *J. Phys.: Conf. Series* **479** 012014