EVALUATION OF THE ADVANTAGES OF VACUUM HEAT TREATMENT

S. P. Konakov and A. I. Lyapunov


At present, the quality of products in basic engineering depends considerably on the correctly chosen heat treatment [1 – 3], which is an obligatory part of any machine-building production. Let us consider the ecological and economical aspects of two heat-treatment technologies, i.e., a traditional technology in salt baths and an advanced [1] technology in vacuum furnaces, and evaluate the economical efficiency of each of them.

In order to evaluate the economical efficiency, we will compare a VDNF vacuum furnace produced by the Eltherma plant (Poland) [1] and a salt tank of native production [1] with the same capacities.

The expenses will be calculated by the formula

\[ Z_{\text{tot}} = Z_{\text{cap}} + Z_{\text{main}} + Z_{\text{env.prot}}, \]

where \( Z_{\text{tot}} \) are the total expenses, \( Z_{\text{cap}} \) are the expenses for the main and auxiliary equipment, transportation, and mounting, \( Z_{\text{main}} \) are the expenses for the materials used (salts, alkalis, acids, electric power, gases, repair, wages, and salaries), \( Z_{\text{env.prot}} \) is the cost of measures for environmental protection, namely, the cost of cleaning the equipment, maintenance of the cleaning equipment, cost of reducing emissions, waste and utilization, compensation for damage due to harmful working conditions.

Here is an example of a calculation in rubles for 1991 prices.

The capital expenses for heat treatment in a salt tank include:

- the cost of the furnace \( C_f = 35 \) thousand rubles;
- the cost of the auxiliary equipment for neutralization, passivation, mechanized transportation of the parts, water-feeding pumps, storage facilities for salts, acids, and alkalis 100 – 150 m² in area, etc., i.e., \( C_{\text{aux.eq}} = 23 \) thousand rubles;
- the cost of the mounting \( C_m = 7 \) thousand rubles.

Hence,

\[ Z_{\text{cap}} = C_f + C_{\text{aux.eq}} + C_m = 65 \text{ thousand rubles}. \]

The capital expenses for heat treatment in a vacuum furnace consist of the cost of the furnace \( C_f = 150 \) thousand rubles and the cost of the mounting \( C_m = 10 \) thousand rubles.

The cost of the auxiliary equipment is included in the cost of the VDNF furnace delivered by the Eltherma plant directly to the user’s heat-treatment shop.

The maintenance cost \( Z_{\text{main}} \) for a salt tank is composed of the cost of the salts [4], the alkalis, the acids, the hot and cold water, the electric power, the rent of the storage facilities, and the wages of the personnel (two people).

The consumption of \( \text{BaCl}_2 \) is about 6 tons/year for a two-shift operation, the consumption of acids is 2.5 – 3.0 tons/year, the consumption of \( \text{Na}_2\text{CO}_3 \) is 3.5 – 4.0 tons/year, that of \( \text{HgCl}_2 \) is 1.0 – 1.5 tons/year, that of hot water is 17,280 tons/year, and that of cold water is 34,560 tons/year:

\[ Z_{\text{main}} = C_m + Z_w + Z_r, \]

where \( C_m \) is the cost of the material and \( Z_w \) and \( Z_r \) are the expenses for wages and repair.

Substituting the cost of the salts, acids and alkalis, electric power, water, and wages into this formula, we obtained the sum of the maintenance expenses equal to 14,700 – 15,300 rubles/year with allowance for the delivery of the original materials and the cost of the transportation.

The maintenance costs in heat treatment in a vacuum furnace consist of the cost of the gases if they are required, the cost of the electric power, and the salary of one operator, which amounts to 3500 – 4000 rubles/year.

The expenses for environmental protection and compensation to workers for harmful conditions at the working place in heat treatment in salt tanks can be determined by the formula [5]

\[ Z_{\text{tot}} = Z_{\text{clean.eq}} + Z_{\text{main.clean.eq}} + P_{\text{emiss.}} + Z_{\text{dam}}, \]

where \( Z_{\text{clean.eq}} \) are the expenses for ventilation, mist-elimination, water turnover, and storage of solid waste, which amount to 11 thousand rubles; \( Z_{\text{main.clean.eq}} \) are the expenses for replacing the filters in moist eliminators and fans, and maintenance and repair of the water-turnover system and other cleaning equipment, which amount to 5 – 6 thousand rubles; \( P_{\text{emiss.}} \) is the cost of reducing emissions, which is determined by the cost of the emissions into the atmosphere and water basins and the disposal of the solid waste; \( Z_{\text{dam}} \) in-
includes the compensation for and cost of prevention of occupational diseases equal to 1.5 – 2.0 thousand rubles/year.

The payment for contamination of the environment by atmospheric emissions is calculated by the formula [6]

\[
P_{\text{atm}} = \sum_{i=1}^{n} N_{r.n_i} K_i M_{p_i} + 5N_{r.n_i} K_i (M_{l_i} - M_{p_i}) + 25N_{r.n_i} K_i (M_{i} - M_{l_i}),
\]

where \(i\) is the type of contaminating substance, \(N_{r.n_i}\) is the reference normal payment for the emission of one ton of the \(i\)th contaminating substance within the permissible range, \(K_i\) is the coefficient describing the ecological situation in the given region, and \(M_{p_i}, M_{l_i}, M_i\) are the emissions of contaminating substances into the atmosphere within the maximum permissible concentration, within the limit, and the total emissions (in tons), respectively.

The values of the coefficients \(K_i\) are assumed to be 1.1 in the East Siberian Region and 2.0 in the Central Black Earth Region.

The cost of emissions into the water basin is determined by the formula

\[
P_{w} = \sum_{i=1}^{n} N_{r,n_i} K_i^w M_{p_i} + 5N_{r,n_i} K_i^w (M_{l_i}^w - M_{p_i}^w) + 25N_{r,n_i} K_i^w (M_{i}^w - M_{l_i}^w),
\]

where \(i\) is the type of contaminating substance, \(N_{r,n_i}\) is the reference normal payment for the emissions in an amount not exceeding the permissible range, rubles, \(K_i^w\) is the coefficient of the ecological significance of the water basin, and \(M_{p_i}^w, M_{l_i}^w, M_i^w\) are the emissions of contaminating substances into the water basin within the permissible concentration, within the limit, and the total emissions, respectively.

The coefficients allowing for the ecological factors range from 1.08 to 2.9.

The cost of disposal of the waste is expressed by the formula

\[
P_{\text{waste}} = \sum_{i=1}^{n} C_i M_{p_i} + 5C_i (M_i - M_{p_i}),
\]

where \(i\) is the type of waste, \(C_i\) is the rate cost for disposal of one ton of the \(i\)th waste, \(M_{p_i}\) is the actual disposal of the \(i\)th waste within the permissible range, and \(M_i\) is the total amount of the given waste.

In heat treatment conducted in salt tanks, the toxic vapors emitted into the atmosphere bear HgCl₂, cyanides, acids, and harmful substances of types I, II, and III. Shops equipped with gas-cleaning and neutralizing equipment emit into the atmosphere 10 – 20% of all the vapors and gases emitted from the salt tanks during the heat-treatment process. About 10 kg of BaCl₂, 2 kg of HgF₂, 1 kg of KCN and CaCl₂, 10 liters of 20% HCl, and 10 kg of NaCO₃ are evaporated in one shift.

Enterprises possessing a water turnover system throw 20% of the used water into the sewage system, which amounts to 3456 tons/year of hot water and 6912 tons/year of cold water. Calculations show that the total amount of waste water containing harmful and toxic substances is 10,368 tons/year. In enterprises possessing no closed water turnover system, the amount of such water is 5 times higher.

The solid waste is stored and then transported to burial places. For example, in Germany BaCl salts are stored in worked-out mines. The toxic waste of barium salts is also treated by sulfuric acid compounds such as Fe₂SO₄, Na₂SO₄, and H₂SO₄, which yields water-soluble BaSO₄ [4].

Knowing the amount of waste emitted into the atmosphere and into the waste-water system and substituting the figures into the formula for the cost of atmospheric and water-basin emissions and utilization of the solid waste, we can calculate the total payment for all the harmful emissions.

The calculation includes the following payments: for the emission of the contaminating substances into the atmosphere within the permissible range and within the limit (temporarily agreed upon outburst) (3.3 rubles/arb.ton); for the emissions into the water basin within the permissible range and within the limit (443.5 rubles/arb.ton); for nontoxic waste (115 rubles/arb.ton); for toxic waste of class I (for example, HgCl₂, BaCl₂, KCN) (14,000 rubles/arb.ton); for toxic waste of class II (6000 rubles/arb.ton); for toxic waste of class III (4000 rubles/arb.ton); for toxic waste of class IV (9000 rubles/arb.ton).

The total payment in two-shift operation of a salt tank at an enterprise where the waste does not exceed the permissible ranges can attain 7900 – 9500 thousand rubles a year, depending on the region. The enterprises having actual emissions exceeding the permissible ranges have to pay 5 times more for exceeding the permissible ranges and 25 times more for exceeding the limit. Then the total payment for the emissions can be 3 – 5 times more, namely, 27 – 35 thousand rubles.

Substituting all the terms into the formula of total expenses, we obtain the amount of heat-treatment expenses in salt tanks and in vacuum furnaces (Tables 1 and 2).

These figures do not reflect the full ecological and economical damage due to the emissions and utilization of the solid heat-treatment waste in salt tanks. The damage caused by contamination of the environment manifests itself in various aspects, namely, moral, aesthetic, prestige, natural, social, economic, and legal.

From the moral standpoint it is responsible for the state of people's health, their mood, negative emotions, illnesses, and the death of vegetation. In the aesthetic aspect, it is felt...