



ON MODELING OF ECONOMIC CHARACTERISTICS OF PROCESSES IN HEAT TREATMENT

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ABSTRACT:

The object of this study is to work out a software package, which can be used in the processes of heat treatment of materials. The program will be of use in cost calculation and some financial indices of the process. The heat treatment process in VIH 6045/90PGQ-HV vacuum furnace is described and analyzed and some economic characteristics are elaborated, which makes it possible to calculate the Break even point and Payback period. The results of analysis allow developing integrated software between the economic and technical parameters, which would provide opportunities for flexible decisions in a dynamic environment.

KEY WORDS:

Heat Treating; Break Even Point; Payback Period; Integrating Software.

1. INTRODUCTION

Modeling the parameters of a given system is an effective alternative to cope with current and investment problems. There are many economic subjects that need clear and precise information concerning the operation costs in using of heat treatment equipment [1,2,3].

Salt tubs provide hopeful quality of details without having any risk of carbonization or decarbonization (excessive or missing carbon stratifying) and low deformation level. The up-to-date restricted usage of salt tubs is connected also with problems referring to the environment protection, safety technique and conditions of work. This results mainly from the highly restrictive US and EU member countries' legislation in the field of environment conservation and human resources protection. The process is characterized with low energy-consumption, high automation level and simple push-button. Using of under pressure heat-treatment of steel made the production of instruments and details produced from costly materials less necessary. The process simplifying allowed many subjects to turn to long run hiring or even purchasing of vacuum furnaces [4,5].

The process of treating of steels under pressure is similar to other ones connected with heat treatment, however it is distinguished for some characteristics that should be taken into consideration. Heat treating of steels in vacuum furnaces is preferred compared to steel processing in dissolved salts, because of: increased reliability of materials, resulting from heating performed with absent oxidization and lack of decarbonization; disguising of heated instruments, which causes increasing of elasticity and improving the plasticity of the processed material; lower deformation

level of heat-treated products as a result of regulated heating and cooling process; higher resistance to wearing out; preserving and even improving the instrument's roughness; easy and safe servicing of the vacuum furnaces. The quenching elements in steels interact with some gas components, such as carbon oxide, hydrogen, water steam and oxygen. Contents of these unwanted gases can be reduced through setting the working space under a vacuum. It turns out that the oxygen and other residual gas quantities after setting under a vacuum are too small to start running a process of oxidization. On the other hand, the lead heaters of fire-box have higher oxygen affinity as compared to the quenching steel elements.

Another peculiarity of vacuum treatment is degasifying and evaporation. Heating in vacuum leads to releasing hydrogen, which results in bettering the quality due to the increased elasticity and deformability of steels. The lower is the pressure in the vacuum furnace the higher is the danger of evaporation of some quenching elements (manganese, chrome) from the steels' surface. The object of the heat treatment process in vacuum is to remove all harmful surface reactions, which could possibly appear in the salt tube.

The low heat conductivity of highly tempered steels exerts effect on the heating rate. The needed cooling speed is determined by the instrument size and kind of material. Under equal conditions, the larger an instrument section is the slower its cooling speed is. Cooling of core lags behind in time as compared with cooling of surface. The higher speed of cooling mean leads to higher temperature difference between the core and the surface. The highest cooling speed is that of water followed by oil, different salt tubes and finally gases, of which nitrogen is mostly applied, in spite of the fact that the helium and hydrogen cooling intensity is 40 % and 70 % respectively higher than that of the nitrogen. The speed of the surface cooling depends on heat transferring carried out by the cooling gas. The stronger pressure and higher circulation rate of the cooling gas increase the cooling speed [6]. All this contributes to the interest shown towards the vacuum furnaces. Moreover, their module pattern affords an opportunity for hiring also of their subsystems.

The modeling process is complex, requiring specialized knowledge in the field of heat treatment technology. Practice shows that decision-making is dictated as by the engineering necessities, as well as by the fast changing economic environment. Modeling of financial flows in the processes of heat-treating of details would serve also as a mean for finding optimal variants in introduction and operation. A similar type model provides a possibility for working out a program, which to facilitate the future engineering activity connected with the heat-treatment processes.

The object of study is the process of heat treatment (cooling, quenching, getting finished state) of iron-carbonic alloys (steels, cast irons) carried out in vacuum furnace with each its activity being regulated including in relation to its financial parameters. Several program products are used, such as "compound algorithm" calculation system with logical functions providing opportunity to use the process on the principle "what-if", which is a precondition for testing both pessimistic and optimistic variants.

The following methods are used in the study: method of linear graph; methods from the information technologies and mathematical modeling; method of the situation analysis; methods connected with economic statistics; accounting methods for cost distribution; methods from the financial analysis for determining the break even point and payback period. Knowledge about the fundamental principles of thermodynamics and technology of processes connected with heat-treating of iron-carbonic alloys is also used in the study.

The purpose of this work is to elaborate a program model for accounting the operation costs in the different processes of heat treatment of materials.

2. ECONOMIC PARAMETERS IN THE HEAT TREATMENT PROCESS

2.1. Economic description of operations

The study and regulation of the process operations provide a possibility for choice of cost allocation and calculation methods.

Table 1. Economic parameters of the process n methods.

No	Abbreviation	Operation Costs
1	HTC	Heat Treatment Cycle
2	SO	Shift Operation
3	WD/M	Working Days/Month
4	IC	Investment Costs
5	FC	Fixed Costs
6	VC	Variable Costs
7	AD	Allowances for Depreciation
8	CI	Costs of Installments
9	RI	Rate of Interest
10	CW	Costs of Wages (Salary Costs)
11	CR	Costs of Rent
12	OC	Operation Costs
13	CE	Costs for Energy
14	CYS	Cycle
15	CGC	Costs for Gas Consumption
15	CCW	Costs of Cooling Water Consumption
17	CCM	Cost of Charging Mechanism
18	CMR	Maintenance and Repair Costs
19	M	Mont (MFC – FC for month base)
20	BEP	Break Even Point
21	PBP	Pay Back Period

Costs are allocated on the basis of operations described in table 1, which allows easy to distribute the spent sums by calculation items.

2.2. Determination of costs, finances

The costs of the process are differentiated into investment and operation ones. The allocation of investment costs will answer the question "How much should we pay for purchasing and installing the heat treatment furnace?" while that of operation costs will answer the question "What does it cost the maintenance of the particular process?" The calculation includes also the material costs of the process and makes it possible to work out a model, which to be universal for all "users" of the equipment. Another cost differentiation is that to variable costs, depending on the produced quantity and fixed ones, not depending on it.

The Break Even Point and Payback Period calculation shows at what operation level the costs will be covered and after what a period the investment will be paid back.

2.3. Calculation of the heat treatment process

A vacuum furnace for heat-treating of a type VIH 6045/90PGQ-HV, Wild Barfield - Senior Process Heating Ltd [5] is chosen for studying. To calculate the process of quenching we must have data available provisionally called input information.

Operation camera sizes (Fire-box sizes): 600 X 450 X 900 mm;

Max. temperature: 1350 C°;

Operation temperature: 700° - 1300 C°;

Maximal useful weight: 400 kg.

Duration of a treatment cycle: 4-5 hours.

Furnace capacity for an operation shift (8 hours) is 2 cycles, for two shifts – 4 cycles and for three shifts – 5 cycles.

This information does not always concern directly the economic parameters of the system but is extremely important for the operating conditions and hence for the type of the used operation conditions. In contrast to the preceding information, that in table 2 exerts a direct influence on the economic characteristics of the process.

Table 2. Input data for VIH 6045/90PGQ-HV

Row/ Column	1	2	3	4
1	Initial indicators			Dimension
2	1.Working days per a month			21
3	2.Number months per a year			12
4	3.Number shifts per a day			3
5	4.Number of machine-hours/day 1-8h. 2-16h. 3-24h.			24
6	5.Labor costs per1 hour- lv			3,5
7	6. Depreciation term		6.1.in years	3,33
8			6.1.in months	40
9	7. Annual depreciation rate			30%
10	8. Average annual interest		% Yearly	10%
11	9. Payback period		Years	5
12			Months	60
13	10. Rent per a sq. m., lv.			25
14	11. Rented premises - Length m			5,5
15	Width m			7,5
16	12. 1 kilowatt (KW) el. energy, lv..			0,17
17	13. Number of cycles/ day			5
18	14. Number of cycles/ month			105
19	15 .Gas price/m ³ - lv.			0,7
20	16 . Water price/m ³ , lv.			0,5
21	17. Necessary for a cycle – minimum 300 kg Put respectively:			300
22	18. Put for month and realized			31500
23	29. Purchasing price of 1 kg steel			5
24	20 Selling price of 1 kg processed steel			8

For calculating the process, it is sufficiently to use the data presented in table 2 as follows:

- **IC – Investment costs**

IC = purchasing price + price of installation

Investment costs are too often attended with delivery costs (transportation and storage).

- **FC – Fixed costs** (allocated on a month base)

$$FC = AD + CI + CW + CR \quad (1)$$

- **AD – depreciation costs**

AD = Annual rate of depreciation allowances x Depreciation sum = IC x 30%: 12 months yearly/ Depreciation rate is taken from (Source: Bulgarian Tax Legislation)

- **CI – Installment costs** - IC x (1 + r)ⁿ : number of installments (2)

In some cases the installments may be leasing ones, etc. In our opinion, before making decision about weather to buy the equipment with own funds or with a certain loan, the profitableness of capital is to be examined.

- **CW – Wages and Insurances Costs**

In one-shift operation regime ISO = 8 h /day x costs / hour x days / month (3)

In two-shift operation regime ISO = 8 h /day x costs / hour x days / month

In three-shift operation regime ISO = 8 h /day x costs / hour x days / month

The current practice of paying the labor is monthly allocation of salary, which can be easily changed in the described model.

- **CR - Rent costs**

$$1 \text{ m}^2 = y \text{ (ls)} \times \text{length} \times \text{width (of premises)} \quad (4)$$

Rent can be calculated as proportion of the total rent of the working site. In this case, an additional calculation is necessary to estimate the part of the rent costs belonging to the work with vacuum furnace.

- **VC – Variable costs**

$$CE+CGC+CCW+CCM+CMR \quad (5)$$

- **CE – Energy costs**

Energy consumption of a process in the vacuum furnace:

Heating of details - 140 kw / h;

Cooling through a hydraulic turbine - 60 kw / h;

Others: vacuum pump; change-over switch, etc. - 15 kw / h;

Total: - 215 kw / h;

$$\text{In } 1 \text{ SO} = 215 \times \text{price of kw/h (y)} \times \text{number of cycles/day (2)} \quad (6)$$

x number of days / month

$$\text{In } 2 \text{ SO} = 215 \times \text{price of kw/h (y)} \times \text{number of cycles/day (4)}$$

x number of days / month

$$\text{In } 3 \text{ SO} = 215 \times \text{price of kw/h (y)} \times \text{number of cycles/day (5)}$$

x number of days / month;

- **CGC- Costs for cooling gas consumption (argon)**

Argon with contents 2 vpm. - H₂O. Price of m³ argon – (y); Pressure of the cooling gas – 6 bar. Total gas consumption 20 m³ per a cycle.

$$\text{In } 1 \text{ SO} = 20\text{m}^3 \times \text{price of m}^3/\text{h (y)} \times \text{cycles number/day (2)} \quad (7)$$

x number of days / month

$$\text{In } 2 \text{ SO} = 20\text{m}^3 \times \text{price of m}^3/\text{h (y)} \times \text{cycles number/day (4)}$$

x number of days / month

$$\text{In } 3 \text{ SO} = 20\text{m}^3 \times \text{price of m}^3/\text{h (y)} \times \text{cycles number/day (5)}$$

x number of days / month;

- **CCW – Water cooling costs.**

The vacuum furnace has a cooling system, in which the water is used repeatedly. Losses amount to nearly 0.6 m³/h.

$$\text{In } 1 \text{ SO} = 0.6 \text{ m}^3 \times \text{price of m}^3/\text{h (y)} \times \text{cycles number/day (2)} \quad (8)$$

x number of days / month

$$\text{In } 2 \text{ SO} = 0.6 \text{ m}^3 \times \text{price of m}^3/\text{h (y)} \times \text{cycles number/day (4)}$$

x number of days / month

$$\text{In } 3 \text{ SO} = 0.6 \text{ m}^3 \times \text{price of m}^3/\text{h (y)} \times \text{cycles number/day (5)}$$

x number of days / month

- **CCM - Cost of Charging Mechanism**

In 1 SO = average price 1000 lv./m ;

In 2 SO and 3 SO = average price 2000 lv/m;

- **CMR – Maintenance and Repair Costs**

In 1 SO = average price 2000 lv./m ;

In 2 SO and 3 SO = average price 3000 lv/m;

- **CMR (MC) - material costs**

Price of the material (steel) - (y)

$$\text{In } 1 \text{ SO} = 300 \text{ kg} \times (y) \times \text{cycles/day (2)} \times \text{number of days / month} \quad (9)$$

$$\text{In } 2 \text{ SO} = 300 \text{ kg} \times (y) \times \text{cycles/day (4)} \times \text{number of days / month}$$

$$\text{In } 3 \text{ SO} = 300 \text{ kg} \times (y) \times \text{cycles/day (5)} \times \text{number of days / month}$$

Table 3. Cost calculation / Monthly base

Row/ Column			1	2	3	4
25	1	IC	Investment costs			600000
26	1,1		Manufacturing price of the furnace			550000
27	1,2		Installation, setting-up, testing			50000
28		TOC	Total operation costs/month			43682,05
29	2	FC	Fixed operation costs/month			33900,35
30	2,1	AD	Depreciation costs			15000
31	2,2	CI	Investment costs			16105
32	2,3	CW	Labor costs (wages + insurances)			1764
33	2,4	CR	Rent costs			1031
34	3	MVC	Variable operation costs/month			9781
Row/ Column				Per cycle Q	Costs Cycle	Costs, m
35	3,1	CE	Consumed electric energy kw / h; Total	215	30,1	3160,5
36	-		Heating, kw / h	140	19,6	2058
37	-		Cooling – water turbine kw / h	60	8,4	882
38	-		Others, kw /h	15	2,1	220,5
39	3,2	CGC	Gas consumption / cycle – m ³	20	2,55	267,75
40	3,3	CCW	Water consumption	0,6	7,2	151,2
41	3,4	CCM	Cost of Charging Mechanism			2000
42	3,5	CMR	Maintenance and Repair Costs			3000
Row/ Column				Q, kg		Material costs month
43	4,1	CM	Materials – kg / month	31500		157500
44	5		Operation costs per hour			86,67
45	5,1		Total costs / hour / material + operation /			399,17
46	6		Costs of heat treatment/kg			1,38
47	6,1		Total costs / month /material + operation /			201182,05

- (TR) Calculation of Total Revenues and
- FC - kilogram и VC - kilogram

Once all costs in the operation process being calculated, it is not difficult to calculate the incomes and costs in case of a certain quantity produced – table 3 and table 4.

Table 4. Calculated revenues / Costs per a unit of produce

Row/ Column			1	2	3	4
48		TR	Revenues	Sold Q, kg	Market price, lv.	Total revenues
49				31500	8	252000
50		TC	Costs / kg	6,38		
51		FC	Fixed costs	1,07		
52		VC	Variable costs	5,31		

- BEP - Break even point (table 5).

It is calculated through dividing the total fixed costs by the difference between the price and the variable costs per a unit of production.

$$BEP = \frac{FC}{P_1 - VC_1} \quad (9)$$

Table 5. Break Even Point

Row/ Column			1	2	3	4
53		BEP	Break Even Point	Quantity, Q		
54			Operation	12604,84		
55			Total /operation + investment/	23919,73		

- PBP – (Pay Back Period) (table 6).

The payback period of investments is calculated through dividing the total investment costs by the total net currency flows (NCF). For the concrete example, the net monetary flows are taken only for the particular investment. The costs and revenues are taken for the first year and are further directly transferred for the rest years of repayment of the investment at static levels of r.

Table 6. Pay Back Period of investments

Row/ Column	1	2	3	4
56	PBP	Period of the investment paying off	Days	Months
57			1037	35
				2.9

3. PROGRAMMING OF ECONOMIC PARAMETERS OF THE HEAT TREATMENT PROCESS

MS EXCEL 2003 is used for drawing up the program. The operation programming itself is performed in the sequence presented in Fig. 1 with following the indicated calculation model. Notwithstanding its simplicity of introduction of formulas comprising operations as addition, subtraction, multiplication and division, there exist specificities in some operations, necessitating the logical functions of the “compound algorithm” program.

Logical description of the program:

INTRODUCE IN	THE FORMULA:	
Row № 5 Column № 4	= IF(r4;c4<=1;8;IF(r4;c4<=2;16;24)	(10)
Row № 7 Column № 4	=100%/r9;c4	(11)
Row № 8 Column № 4	= r7;c4*12	(12)
Row № 12 Column № 4	= r11;c4*12	(13)
Row № 17 Column № 4	= IF(r5;c4<=8;2;IF(r5;c4<=16;4;5))	(14)
Row № 18 Column № 4	= r2;c4*r17;c4	(15)
Row № 22 Column № 4	= r18;c4*r21;c4	(16)
Row № 25 Column № 4	= SUM(r26;c4: r27;c4)	(17)
Row № 28 Column № 4	= r29;c4+r34;c4	(18)
Row № 29 Column № 4	= SUM(r30;c4: r33;c4)	(19)
Row № 30 Column № 4	= r25;c4*r9;c4/ r3;c4	(20)
Row № 31 Column № 4	= SUM(r25;c4* (((1+r10;c4)^r11;c4))/ r12;c4)	(21)
Row № 32 Column № 4	= r2;c4* r5;c4* r6; c4	(22)
Row № 33 Column № 4	= r13;c4* r14;c4*r15;c4	(23)
Row № 34 Column № 4	= r35;c4+r40;c4+ r41;c4+ r42;c4+ r43;c4	(24)
Row № 36 Column № 4	= r2;c4* r17;c4* r36;c3	(25)
Row № 36 Column № 3	= r36;c2*r16;c4	(26)
Row № 37 Column № 4	= r2;c4* r17; c4* r37;c3	(27)
Row № 37 Column № 3	= r37; c2*r16;c4	(28)
Row № 38 Column № 4	= r38;c3*r17;c4*r2;c4	(29)
Row № 38 Column № 3	= r 38;c2*r16;c4	(30)
Row № 39 Column № 4	= r2;c4*r17;c4* r39;c3	(31)
Row № 39 Column № 3	= r39;c2*r19;c4	(32)
Row № 40 Column № 4	= r2;c4*r5;c4*r20;c4*r40;c2	(33)
Row № 40 Column № 3	= r5;c4*r20;c4*r40;c2	(34)
Row № 41 Column № 4	=IF (r5;c4<=8;1000;2000)	(35)
Row № 42 Column № 4	=IF (r5;c4<=8;2000;3000)	(36)
Row № 43 Column № 4	= r43;c2*r23;c2	(37)
Row № 43 Column № 2	= r22;c4	(38)
Row № 44 Column № 4	= SUM(r28;c4/(r2;c4* r5;c4))	(39)
Row № 45 Column № 4	= SUM(r28;c4+ r43;c4)/(r2;c4* r5;c4)	(40)
Row № 46 Column № 4	= r28;c4/r43;c2	(41)
Row № 47 Column № 4	= r28;c4+r43;c4	(42)
Row № 49 Column № 2	= r43;c4	(43)
Row № 49 Column № 3	= r24;c4	(44)
Row № 49 Column № 4	= r49c2*r49;c3	(45)
Row № 50 Column № 2	= r51;c2+ r52;c2	(46)
Row № 51 Column № 2	= r29;c4/r49;c2	(47)
Row № 52 Column № 2	= (r43;c4+r34;c4)/r49;c2	(48)
Row № 54 Column № 2	= (r52;c2*r43;c2)/(r49;c3-r52;c2)	(49)
Row № 54 Column № 2	= (r52;c2*r43;c2+ r43;c4)/ (r49;c3-r52;c2)	(50)
Row № 55 Column № 4	=(r25;c4*(1/(1+r10;c4)^r11;c4))/ ((r49;c4*(1/(1+r10;c4)^r11;c4)) - (r28;c4*(1/(1+r10;c4)^ r11;c4))))	(51)
Row № 55 Column № 3	= r55;c4* r3;c4	(52)
Row № 55 Column № 2	=p55;k4* p3;k4*30	(53)

Note: r;c - row;column; rows and columns correspond to those in the tables of the model.

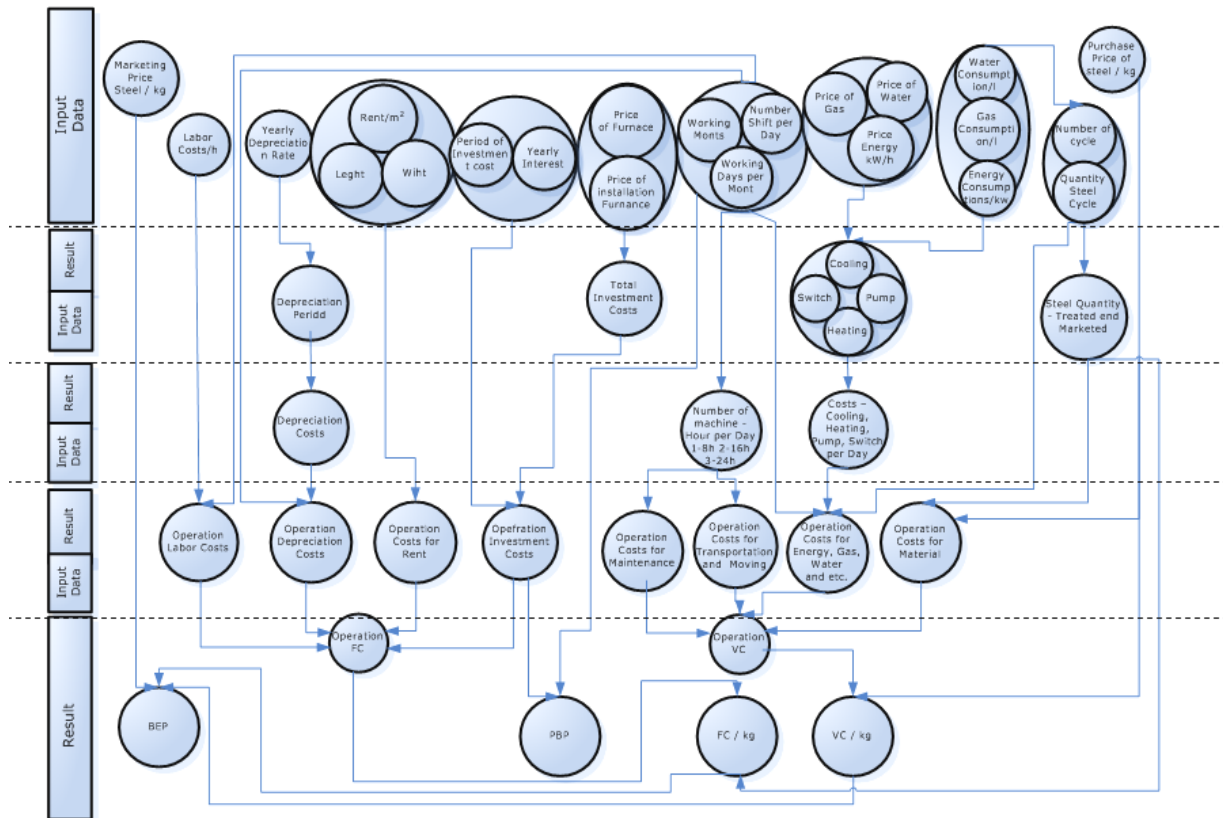


Fig.1 Data flows

4. CONCLUSIONS

4.1. For the different heat treatment processes (quenching, getting finished state) a program model is developed for estimation of all income and cost indicators.

4.2. Worked out program can be used for developing of integrated software, which can serve for estimating the economic and technical parameters of the heat treatment process.

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