The Method of assessment and selection optimal technological decision (by the example of the choice of cast iron smelting technology)

[1]A.S. Puryaev, [2]E.A. Rybkina, [3] L.G. Zakirova

[1]Department of Logistics and Marketing, Kazan (Volga region) Federal University, Russia
[2]Department «Management of enterprises», Kazan State Power Engineering University, Russia
[3]CJSC «AGROFORCE GROUP», Russia
Tel: +79172688319. E-mail: aidarp@mail.ru

Abstract. The essence and relevance of the optimization of the technological process in the foundry industry is uncovered in the article. Possible types of processes of iron smelting are presented. Particular parameters of optimization of technological processes of iron smelting are developed. The mathematical apparatus for the assessment and selection of the optimal variant of the technological process of smelting is offered. Estimation procedure and selection of the best option smelting technology from the totality of existing alternatives is developed. [A.S. Puryaev, E.A. Rybkina, L.G. Zakirova. **The Method of assessment and selection optimal technological decision (by the example of the choice of cast iron smelting technology).** *Life Sci J* 2014;11(9):544-549]. (ISSN:1097-8135). http://www.lifesciencesite.com. 90

Key words: optimization of technological process; cast iron smelting; desirability function; methods of optimization.

1.Introduction

Encountered real tasks in the technology of foundry production engineering are very varied. They can be conventionally divided into extremum problems (extremum seeking, optimal variant) and task descriptions or interpolation (the research of general regularities of the phenomena occurring in the system). Often these tasks are solved together. The optimization task is a private, but very widespread practice task. What is meant by optimization? Optimize is to give something optimal (most favorable) properties, index; select the best of possible variants [1].

Optimization of technological process – giving it the optimal technological process (most favorable) properties, indexes, or determining the best technological process of the possible options for the set criteria. From the definition shows, that the optimization process must be seen as a process consisting of two independent parts. The first part is the optimization of the process itself, that is, in determining the most favorable properties, indicators selected technological process. And the second – in the selection of the optimal variant of the process of possible alternatives to the established criteria. The problem of determination of the most favorable variant of technological processes of smelting of alloys and founding from them casts, connected with a host of set of criteria production. These include: conservation (minimizing environmental of harmful substances discharge); occupational health and safety (automated manufacturing level); saving of material, labor resources, energy (resource conservation); lower cost price; the quality of the manufactured alloy, casts; compliance with product standards; production flexibility and regularity of processes, amount of investment; indicators of efficiency of investments, etc. The task of a choice of one or another technology of production, including and smelting cast iron foundry production, is a multi-objective, which allows you to get a compromise version of melting cast iron, conditions the constraint on a whole range of private parameters optimization.

Table 1: Duplex processes of melting cast iron.

#	Shorthand of duplex and triplex-processes	Title of duplex and triplex-processes
1	C–CFF	Cupola – Combustion Fixed Furnace
2	C–CRF	Cupola – Combustion Revolve Furnace
3	C–AF	Cupola – Electric Arc Furnaces
4	C–IICFM	Cupola – Inductive Iron-smelting Crucible Furnace for Mixing
5	C–IIHFM	Cupola – Inductive Iron-smelting Hot air Furnace for Mixing
6	IICF–IICFM	Inductive Iron-smelting Crucible Furnace – Inductive Iron-smelting Crucible Furnace for Mixing
7	IICF–IIHFM	Inductive Iron-smelting Crucible Furnace – Inductive Iron-smelting Hot air Furnace for Mixing
8	IICF–EAF	Inductive Iron-smelting Crucible Furnace – Electric Arc Furnaces
9	EAF–IICFM	Electric Arc Furnaces – Inductive Iron-smelting Crucible Furnace for Mixing
10	EAF–IIHFM	Electric Arc Furnaces – Inductive Iron-smelting Hot air Furnace for Mixing
11	EAF–EAF	Electric Arc Furnaces – Electric Arc Furnaces
12	SF–AFM	Smelting Furnace – Automatic Filling machines

Smelting of cast iron in foundry production, or the so called secondary melting of cast iron, is carried out mainly in the following melting aggregates:

cupola, inductive furnaces, electric arc furnaces. Accordingly, processes is differ: cupola (C), induction (IF) and arc smelting (EAF) cast iron.

In large-series and mass production of casts widespread is duplex- and triplex-processes for melting cast iron.

In practice, foundry production, there are the following types of duplex processes presented in table 1 [2].

Triplex-processes, existing in foundry production, are obtained by combining duplex processes with AFM, starting with point 3 to point 11 of table 1, i.e. it turns out 9 triplex processes. Despite this, the technology of melting cast iron is concerned with the work of melting furnaces seven types: C, CFF, CRF, IICF, EAF, IIHFM and AFM.

2. Materials, methods and results

Working of private parameters optimization of the technological process of melting cast iron. One of the elements of optimization of the technological process of melting is to optimize the cupola mixture. The composition of the metal cupola mixture is largely determines the quality and cost price of iron castings.

A large quantity of components of the cupola mixture and a relatively wide range of possible use of each of them makes the task of selection of the composition of the furnace ambiguous, although each of the possible options can provide the specified chemical composition and mechanical properties of cast iron. In that case, as a factor, ways of influence on optimized object (produced cast iron) acts composition of furnace. And optimization parameters are composition, mechanical properties and the cost of cast iron, the last of which is mainly determined by the value of the cupola mixture.

In practice, foundry production optimization problem melting addressed to specific melting aggregates. So for cast iron melting in the cupola there equations to calculate the total content of C, Si and Mn in the iron depending on the conditions of melting, which are the metal temperature, the composition of these elements in the cupola mixture [3]. Gorfinkel V.M. and Chernobrovkin V.P. for specific performance optimization cupola furnace and the temperature of melted cast iron offered mathematical-statistical model of a cupola process in which the factors are taken: effective height; the cross sections of a core set line of tuyere in percentage to the area of the cross section for cupola; the height of the hearth; pressure and consumption of blowing; coke consumption and the size of its pieces; weight of metal furnace charge; height idle furnace charge [4].

For Induction melting Kolesnikov G.A. is recommends optimization methods, which consists in the use of the generalized mathematical model of the process of adoption of chemical elements. Similarly, as with the cupola melting, optimization parameters are the contents of C, Si, Mn, P in liquid iron, while the independent variables (factors) in except to the content of these elements in the furnace taken: superheat temperature alloy in a furnace; delay in the furnace of the reached overheating; number modifier ferrosilicium 75. The derived system of equations used in solving various variants of tasks of optimization of the process of smelting iron. For example, when solving the problem of maximum absorption of carbon alloy of carburizer, when valid for the grade of cast iron content of Si, Mn, P, or ensuring a minimum value of the furnace materials [4].

When arc smelting of cast iron as the additional tasks of optimization, in except to the above are the optimization of the electric parameters of the regime ultra-high capacity (UHC), optimization of a slag regime arc furnaces UHC [5]. In the first case as control parameters (factors) are the phase currents in the furnace, furnace transformer voltage during all cycle of melting and for the optimization parameters are accepted productivity of the furnace, the specific consumption of electricity, index of wear of the lining, the specific consumption of electrodes, power factor, specific active power capacity, factor of utilization of the time, both individually and in the aggregate.

Optimization of a slag regime in electric arc furnaces with UHC can be carried out in accordance with the generalized criterial function, formulated by private criterion [6]. For private optimization options are accepted: the level of refining the melt by harmful components (R,S,Cr); the level of impact of slag on the furnace lining; stabilization level the Electromechanical characteristics of the system of management of the electric arc; the level of influence of slag on the form of graphite inclusions. And ways of influencing them – certain formulations of slag.

The next task of optimization of melting process is to define the method of adjustment of the chemical composition during the smelting of ferroalloys and modifiers, such as ferromanganese, ferrochrome, ferrosilicium. The criteria of optimization can be selected breaking point strength of σ_b [6].

As parameters of evaluation and selection of technological processes of melting cast iron can potentially be used technological, economic, environmental indicators, and indicators characterizing conditions, protection of working conditions and quality of performance of functions of the technological process, both individually and in the aggregate. Moreover, these indicators are based and from the point of view of system approach, as consider the effects of the other subsystems of the iron foundry production (subsystem of the molding and casting operations, thermo-finishing processing, ecology, social sphere, management, organization of production) on the technological process of melting cast iron.

So to them in the general case, include: the temperature of the metal; the release of harmful gases, noise, dust, content carbon monoxide in the waste gases; the chemical composition of the produced cast iron; the content of harmful impurities in the cast iron; heat resistance and the cost of the lining, specific cost of fuel and electricity; productivity of the process; ensure regularity of liquid alloy; the ability to melt cast iron of different kinds and marks; specific energy consumption in the regime of melting and superheating; the duration of the melting and conditioning; the possibility of replacing ingot cast iron scrap (including steel), waste production and ferroalloys; the terms of the protection of laborand safety measures; properties of castings of the melted alloy; a coal gas of elements in the alloy; the possibility of modification and alloying alloy in a melting aggregate; the speed of the melting of the charge and refinement to a given chemical composition; reliability; the duration of the repair works; removal of castings from 1 m^2 of production space; coefficient of efficiency when overheated and refinement; compliance technological process for a line of indicators type of production; possibility of desulfurization directly in smelting of cast iron, defective production through the fault of the melting, the cost price of liquid cast iron.

Selection of optimal technological process in real-life situations complicated, because it requires simultaneous account some and often of no small importance private parameters. Under a private parameters in this article mean one of the possible parameters of the technological process, requiring optimization. Solution of the problem of choosing optimal variants on some private parameter greatly simplifies the task, but increases the probability of inadequate reflection of the real situation. And this leads to significant additional expenditure, an important especially in the conditions of market economy. In the course of the conduct research we offer the following complex of private optimization settings when you select the technological process of melting cast iron (19 parameters).

This complex of private parameter of optimization can be changed, improved at change of conditions of the foundry production and the emergence of new technologies for melting iron. This complex is relevant for technological processes of melting stated in table 1.

Table 2: Complex of private parameters optimization of the technological process of melting iron [2, 7].

Iron smelting
Technical-technological
1. Pig iron grade 2. The maximum technological melt temperature, °C 3. The minimum content of sulphur after smelting, $\times 10^{-2}$ 4. Group (category) the complexity of the casting on the grounds of 1,3,5,6-10
Technological and economic
1. Type of the production process 2. The specific productivity of labor, tonne / (man×hour) 3. The maximum productivity, tonne / hour 4. The cycle of melting and holding, hour
Ecological
1. Heat radiation, watt / м^2 2. Noise, decibel (A) 3. Vibration, decibel 4. Dust, kg /tonne 5. Harmful substances, мм^3 / tonne
Social
1. The coefficient of labor protection process of working (0 - 1)
Qualitative
2. Complex index, mark 3. Complex index to other requirements of the customer, mark
Economic
1. Internal rate of return (IRR), % 2. The period of payback (PP), year 3. Investment in project (I), million rubles

Mathematical apparatus of evaluation and selection processes for melting cast iron. Selection of optimal version solution melting cast iron in the general case is an integral component in solving the main problems of economy – increase of efficiency of use of limited resources. The proposed set the private parameters optimization, consisting of six groups (presented above), inevitably leads to the possibility of the emergence of conflicting answers to the task of evaluation and selection of the technological process of melting in foundry production. I.e. the situation may arise where in some areas (e.g. economic) there is just one version of a process, and on the other (for example, social or environmental) is another. Therefore, the task of choosing optimal variants of existing alternatives, taking into account the developed complex of private parameters optimization is a compromise.

One way of finding a compromise is the method of function of desirability E.S. Harrington [8, 9, 10]. The basis for building this generic function is the conversion of natural values of particular parameters in a dimensionless scale of desirability (preferable). The purpose of the scale is an establishment of conformity between the physical and psychological parameters optimization. Under the physical refers to various parameters that characterize the functioning of a prototype system. This may include economic, technical and economic, scientific and technological, aesthetic, statistical, and other parameters.

Under psychological parameters are understood subjective evaluation of researcher of desirability (preferable). Psychological parameters are expressed in numerical system (scores, mark) on the scale of desirability. This mathematical apparatus optimization allows you to combine different physical nature and dimensions of the private parameters of optimization in one scale, capable of adequately reflect the real situation of a choice of the studied processes.

To obtain scale desirability convenient to use prepared designed tables of correspondences between the attitudes of preferences in the empirical and numerical (psychological) systems (see table 3).

Numerical system preferences, presented in table 3, and is the dimensionless scale desirability developed Harrington. The value of this scale have the interval from *0* to *1* and are denoted as *d* (desirable). Value of *i*-th of the particular parameter optimization translated in a dimensionless scale desirability indicated via D_i, is called a private desirability, where i = 1,2,3...n – number of the current parameter, n – is the number of private parameters.

Table 3: Harrington's Scale of desirability.

Empirical preference scheme (desirability)	Numerical preference scheme (the system of psychological parameters)
Very good	1,00 – 0,80
Good	0,80 – 0,63
Satisfactorily	0,63 – 0,37
Badly	0,37 – 0,20
Very badly	0,20 – 0,00

Sense $d_i = 0$ is absolutely unacceptable level of the *i*-th parameter optimization. Sense $d_i = 1$ – best value *i*-th parameter.

Desirability function corresponding to the desirability scale Harrington has the following form:

$$d = e^{-e^{-y'}}, \qquad (1)$$

where y' – encoded value of the parameter y, i.e. its value in a representative scale.

The choice of marks on a scale desirability of *0,37* and *0,63* explained ease of calculation, because *0,37 = 1/e*, and *0,63= 1-1/e*. Sense $D_i = 0,37$ usually used as the valid range [8, 9, 11, 12, 13, 14, 15]. Figure 1 shows a graph of the above-mentioned function of desirability.

This curve conversion, is not the only possibility, however, it appeared empirically as a result of observations for real solutions to researchers-experimenters [8]. The curve has useful properties of *continuity, monotony, smoothness*. Besides, in the areas of the desirability of near to *0* and *1*, it is less «sensitive» to change a parameter value, than in the middle zone (from 0,20 to 0,80) that allows you to accurately adjust the number of possible variants of the decision (with $d = 0,37$).

In practice, it is often sufficient graphical method to conversion private settings in the scale of the desirability of using the curve as nomogram [9]. But there are reasons why this may seem to be ineffective:

1. The bulk of individual parameters (more than ten) makes this procedure is time-consuming and less evident than for a smaller number of parameters (up to five).

2. Insufficient of accuracy graphical of conversion into the scale of desirability.

3. Insufficient of accuracy of the selected position on the scale of values of the particular parameter optimization.

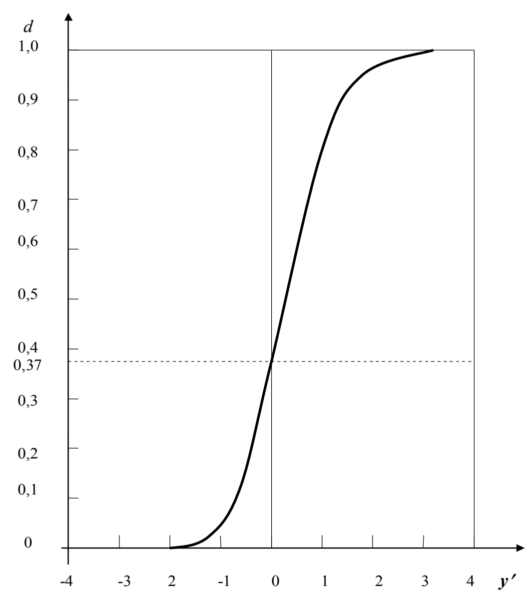

Figure 1: The graph of the E.S. Harrington's the function of desirability with unilateral constraint

So in this case it is more expedient to resort to the analytical method for determining the desirability of using the expression given in the formula (1). You must first install a mechanism to convert y_i in y_i'.

In order to use this method when selecting the optimal solution, initially, you must install (set) the bounds of permissible values for all private optimization settings. Restrictions may be unilateral (y_{min} or y_{max}) or bilateral (y_{min} and y_{max}). Mark $d_i = 0,37$ on the scale desirability corresponds to y_{min} or y_{max} unilaterally contingencies, with bilateral contingencies- and y_{min}, and y_{max}. Case of bilateral contingencies is quite rare and is more complicated, to estimate the parameters.

Introduced complex of private parameters of optimization requires unilaterally contingencies by solving the problem of selection of optimal processes of melting and casting of cast iron (see formula 1 and figure 1).

After all the private parameters (y_i), conversed in their desirability (d_i), you should begin to build a generalized parameter optimization called generalized the function of desirability D of Harrington. One of the best ways to solve the problem of choosing the optimal variant is the representation of a generalized function of desirability as a geometrical mean private of desirability (2):

$$D = \sqrt[n]{d_1 \times d_2 \times \ldots \times d_i \times \ldots d_n}, \qquad (2)$$

The generalized parameter of this type allows, first, to exclude option decisions from a aggregate, if at least one of its private option does not satisfy the strict requirement of the researcher ($d_i = 0$); secondly, it allows to use the same scale of preference (see table 3).

The Generalized function of desirability D type (2) satisfies a number of requirements to parameters optimization [8], namely:

- is a quantitative;
- is a single (expressed by one number);
- is a single valued, i.e. a given set of values of private response corresponds to one value of a generalized function;
- is universal, i.e. provide a comprehensive summary of object;
- complies with the requirement of completeness, i.e. is quite General, not specific, characterizes the object as a whole.

Technique of assessment and the choice of the technological process of melting cast iron. Author develops the methodology of the evaluation and selection process of smelting cast iron consists of the following stages [2, 7]:

1. Initially, under given constraints and (or) desirable levels of the decision-maker (DM) or the customer should determine the number of valid choices of technological process of melting cast iron in the first *five groups of private optimization options* (in addition to economic), using the method of generalized function of desirability Harrington (the method of aggregation), which is presented above. For this purpose all possible (or available at the designer) technological processes of melting must first know the values of particular parameters optimization of the above groups, to determine their private desirability (d_i), define a generalized function of desirability each technological process (D_j*). The validity of variants of the decision on the data groups of private parameters is determined by the criterion $D_j^* \geq 0,37$.

2. Next to the modernized plot melting need to determine the value of particular parameters of the economic group (*IRR, PP, I*) when using each of the N a valid choice of the technological process of melting.

3. For the final determine the optimal technological solution of N of valid processes should:

a) Define a private function of desirability (d_i) of the parameters of the economic group (*IRR, PP, I*);

b) Define the generalized function of desirability for each of the N options according to the formula:

$$D_j = \sqrt[4]{D_j^* \times d_{1j} \times d_{2j} \times d_{3j}} \qquad (3)$$

where D_j^* – the value of the generalized parameter optimization, fixed for the first five groups of parameters of the j-th variant of the decision; d_{1j}, d_{2j}, d_{3j} – value private desirability of parameters of economic groups (i.e. *IRR, PP, I*, accordingly) of the j-th variant of the decision;

c) according to the criterion $D_j \geq 0,37$ define a set of comparable results, allowable values, effective local criteria (*IRR,NPV, PP, I*) variants of technological processes of melting cast iron;

d) determine which option is best, most satisfying the given constraints on the criterion $D_j \rightarrow max$..

3. Conclusion

The proposed technique allows to choose the optimal variant of the melting process in the conditions when the limits are set on a whole range of private parameters optimization. The optimization options can be of different physical nature and of nature. Method solves the complicated task of evaluating and selecting the best alternative technological process of melting of a combination of existing alternatives. The example of use this method is presented in article [16].

Corresponding Author:
Dr. Aidar Puryaev, Department of Logistics and Marketing, Kazan (Volga region) Federal University, Mira Str., 68/19, 423810, Naberezhnye Chelny, Russian Federation.
Tel: +79172688319.
E-mail: aidarp@mail.ru

References

1. Ozhegov, S.N. and N.Yu. Shvedova, 1989. Dictionary of Russian language: 70000 words. Moscow: "Russkij jazyk", pp: 924.
2. Puryaev, A.S., 2004. System of the selection of technological processes of melting and casting iron. Naberezhnye Chelny: Kama State Polytechnic Institute, pp: 191.
3. Girshovich, N.G., 1978. Handbook of cast iron smelting. Moscow: "Mashinostroenie", pp: 758.
4. Vozdvyzhensky, V.M., V.A. Grachev and V.V. Spassky, 1984. Foundry alloys and technologies of their melting in the engineering industry: Educational manual for engineering universities in the specialty "Machines and technology of foundry industry". Moscow: "Mashinostroenie", pp: 432.
5. Kuznetsov, B.L., 1990. Intensification of melting high quality cast iron for castings in the electric arc furnace on the basis of new methods of inner processing melts, PhD thesis, Ural Polytechnic Institute, Ekaterinburg.
6. Demin, D.A., V.F. Pelih and O.I. Ponomorenko, 1995. Optimization of the method of adjustment of the chemical composition of cast-iron with lamellar graphite. "Litejnoe proizvodstvo", 7-8: 42.
7. Puryaev, A.S., 1997. The optimum variant of melting processes information. News items. "Litejnoe proizvodstvo", 6: 32-33.
8. Adler, Y.P., E.V. Markov and J.V. Granovsky, 1976. Planning of the experiment in search for optimal conditions. Moscow: "Nauka", pp: 279.
9. Novik, F.S., 1979. Mathematical methods of planning of experiments in physical metallurgy, section: Choice of the optimization parameters and factors. Moscow: Moscow Institute of steels and alloys, pp: 96.
10. Novik, F.S. and Ya.B. Arsov, 1980. Process optimization technology metals by methods of experiments planning. Moscow, Sofia: "Mashinostroenie", "Tekhnika", pp: 304.
11. Novik, F.S., L.B. Kogan, D.P. Ivanov and Yu.G. Vinogradov, 1972. The Planning of industrial experiments in foundry. "Litejnoe proizvodstvo", 5: 5-7.
12. Shtarkman, B.P., T.M. Kartashova, I.M.Monich and I.N.Rasminsky, 1969. The use of function of desirability for a comprehensive assessment of quality of the suspension of polymethyl methacrylate. "Plastmassy", 1: 61-63.
13. Shtarkman, B.P., T.M. Kartashova, E.A.Sereda and V.L. Balakirskaja, 1969. Optimization of the formulation and mode of gelatinization plastisols. "Plastmassy", 2: 10-12.
14. Kozhevnikov, I.Yu., F.S. Novik, V.I. Ohanov and T.G. Yakovleva, 1976. Planning of experiments in studying the influence of the methods of secondary refining and purity of the charge on the quality of steel. «Zavodskaja laboratorija», 42(1): 80-82.
15. Kartashova, T.M. and B.I. Shtarkman, 1970. The generalized criterion of optimization- a function of desirability. "Informacionnye materially", 8(45): 55-63.
16. Puryaev, A.S., E.A.Rybkina and L.G.Zakirova. The example of an assessment and selection of the optimal variant of technological process of iron smelting. Life Sci J 2014; 11(11):151-156.

8/3/2014