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FUNDAMENTAL CHARACTERISTICS OF RELIABILITY IN TECHNOLOGICAL PROCESSES IN FERROUS METAL INDUSTRY

Abstract. Problems of reliability in the areas of metal industry are of the most immediate interest. The efficiency of using the different technological schemes is closely connected with ensuring the required accuracy, productivity and operational economy which are mostly defined by the degree of their reliability. The decisive influence on the perfection of technological processes has the level of scientific support, because on the stage of scientific researches the potential of innovations, which is materialized through design and construction work into production, is laid. The purpose of this work – to develop mathematical and computational models for assessment the reliability of fundamental characteristics in technological processes in the areas of non-ferrous and ferrous metal industry with the aim of achieving the required quality of output. The suggested strategy of quantitative and qualitative assessment of reliability on the basis of fundamental conservation laws on maximum entropy will provide the prevention of errors on the stage of scientific elaboration in order to avert the appearance of defect or remove it without bringing it into a final stage of production, which is extremely important in the countries with market-oriented system of controlling the technology level and quality. The application of ruggedness analysis technology in technological output and processes offered in this work will lead to improved production method and considerable reduction in expenditure on production of this output, improvement in quality and competitive capability. The novelty of the thesis consists in that for the forts time to the analysis of the technology of chemical-and-metallurgical processes and schemes there will be applied objective and fundamental information criteria expressed in universal units, i.e. bits. Methods of computer modeling have been developed for calculation of fundamental characteristics of production in a way of refinement the cast iron technological schemes reliability. Methods of computer modeling have been developed for calculation of fundamental characteristics of in production in a way of direct receiving iron technological schemes reliability.

Key words: modeling, ruggedness, technological processes, qualitative and quantitative assessment, entropy, information, hierarchical systems, technological products.

Introduction. Quantitative estimations of sense and value of the information can be made for the information analysis of quality of technological products and processes of their reception only after the preliminary agreement about what precisely in each concrete case has value and sense for the considered phenomena [1-8]. Methods of calculation the information suggested by Shannon allow to reveal a ratio of quantity of the predicted information and quantities of the unexpected information which cannot be predicted beforehand, and thus to enable to define a qualitative and quantitative estimation of the certain technological circuit. As a probability of detection of the main element of technological system it is possible to accept its maintenance in a product, expressed in shares of unit. For example, let's examine the maintenance of a considered chemical element in products of technological repartition. Also for probability of detection it is possible to take the maintenance of suitable fraction (remnants, briquettes) in a corresponding product. The same concerns the process of extraction of an element in this or that product, as in this case a parameter of extraction is equal to a probability of transition of the given element from one condition of system into another. These both parameters - the maintenance and extraction - can be equally used for an estimation of quality of a product or technological repartitions.

The formula allows to estimate the complex indeterminancy of a group of technological operations undergoing analyses, as well as technological schemes as a whole, which will result in determining predictability and technological reliability of these operations [5, 9, 10]. The work suggests a formula for estimating complex indeterminancy of a group of technological operations undergoing analyses before and after their improvement, as well as technological schemes as a whole in the information units.

Methods. Technical and technological modernization of industry is closely connected with the development of new and improvement of known technologies, reduction of the energy expenses on production of the product, increasing of production efficiency. The world industry, having concentrated in itself enormous a great number of enterprise on mining of ore, melting and conversion of black and non-ferrous metals, chemical and machine-building complexes, plants of precise mechanical engineering, appliance-engineering and radio electronics must receive the further development. To study the regularities of the processes of enrichment, extraction, reception, refining of metals, as well as processes, connected with the change in contents, structure and characteristic of alloys and materials in metallurgy physic-chemical and mathematical methods of the research are used. The Improvement of the technological processes with considering of the raw materials complex in structure is impossible on the only base of traditional methods of the opening the causal relationships in processes of the general technological scheme with analysis of their material and heat balances. The additional analysis of these processes is necessary on base of information entropy by Shannon; the reason for it is to integrate disembodied hitherto factors on extraction of valuable components and their contents in final products on redistribution and on technological scheme as a whole with the following use of this method for analysis and comparative estimation at chemist-metallurgical production. In this connection using as a base the information entropy by Shannon we designed a method of integrating disembodied hitherto factors on extraction of valuable components and their contents in final products on redistribution and on technological scheme as a whole with the following using of this method for analysis and comparative estimation of chemist-metallurgical production. As original data we used reference materials on contents and extraction of elements, published in brief guide to metallurgy of the non-ferrous metals by the authors Gudima N. B., Shein I. P. [11] and the most recent reference book under editing by M.E. Dritza [12] on the characteristics of elements in two volumes, where all the latest data from foreign reference book, monograph and scientific articles are taken into account. With the aim to conduct the comparative analysis of the competitive schemes or improving operations taken apart on united generalized criterion of complex completeness, as well as uncertainty, we shall consider usage of the formula by Shannon for determination of the information balance of the production processes by means of factors of the extraction and contents of ferric. For entropy-information analysis of any object the formula by Shannon for expression of the uncertainty of the system is broadly used [13]:

$$H = -\sum_{i=1}^{N} p_i \log_2 p_i \tag{1}$$

where pi - is a probability of the finding of any uniform system element in their multitude N; $\sum_{i=1}^{N} p_i = 1$, $p_i \geq 0,\ i = 1,2,...,N$.

As a characteristic of probability of finding the main system element it is possible to take its contents expressed in fractions of the unit. For instance, this is the contents of extracted chemical element ferric in corresponding products. The same is true for the process of the extraction of the element into one or another product, since in this case factor of the extraction is identical to probability of the transition of the given element from one state of the system into another. Both these factors - contents and extraction - can be used at equal degree for estimation of the uncertainty in product quality or technological operation. Then for the single controlled system element we use common mathematical calculations for expression of the information uncertainty as follows.

If p - is a probability of finding of the controlled element in product or transition at extraction, then uncertainty or unexpectedness of each of these events is a reciprocal from its determined identification that is 1/p. In our variant of the estimation of uncertainty in the behavior of the only one system element this uncertainty is expressed by following formula:

$$H = \log_2 \frac{1}{p} = -\log_2 p = -\frac{\ln p}{\ln 2} \tag{2}$$

Before the publication of K. Shannon's theory R.Hartly has suggested to define quantity of the information under the formula:

$$H_{n(\max)} = \log N_n = \log N_0^{k^n} = k^n \log N_0, \tag{3}$$

where $N_n = N_0^{k^n}$, n - number of levels, k - length of a code of elements at each level of hierarchical system.

Let N_n - number of elements of n-level. I_0 - capacity of the information of a zero level of technological system. Then the capacity of the information of n-level counting upon one element is expressed by the formula:

$$I_n = k^n I_0 .$$

Results. In the technological circuit considered by us $k = 2$ there is a sample of set of elements - an element and not an element (in our case of ferric and all other elements in aggregate) then the equation (3) will become:

$$H_{n(\max)} = 2^n \log N_0 = 2^n \log_2 2 = 2^n .$$

Essentially important advantage of an information estimation of quality of products or technological operations is that a suggested parameter H_n, as well as any entropy-information sizes, can be added. The given property of additive is immanently inherent to entropy and information and is a basis for expression of the law of preservation of their sum. Hence, technological uncertainty of various operations within the limits of the unified circuit can be expressed by a system parameter of uncertainty:

$$H_{\sum n(\max)} = \sum_{i=0}^{n} H_i = \sum_{i=0}^{n} 2^i \text{, Bit/el.}$$

Information capacity of hierarchical system and n- level are defined by equality:

$$I_{\sum_n} = \sum_{i=0}^{n} \frac{H_{i(\max)}}{(i+1)!} = \log N \sum_{i=0}^{n} \frac{\prod_{m=0}^{i} k_m}{(i+1)!},$$

$$I_n = \frac{H_{n(\max)}}{(n+1)!} = \frac{\prod_{m=0}^{n} k_m \log N}{(n+1)!}, \tag{4}$$

where $H_{n(\max)}$ - greatest possible entropy of a system.

The system determined component $I_{\sum_n}(d)$ and the determined component of the information $I_n(d)$ is defined by equality:

$$I_{\sum_n}(d) = \sum_{i=0}^{n} 2^i \left[1 - \frac{1}{(i+1)!}\right] \text{ Bit/el.,}$$

$$I_n(d) = 2^n \left[1 - \frac{1}{(n+1)!}\right] \text{ Bit/el.}$$

Having defined degrees of determination and ineradicable stochasticity at each level of technological system under formulas [3]:

$$d_n = \frac{I_n(d)}{H_{n(\max)}}, \qquad h_n = \frac{I_n(h)}{H_{n(\max)}} = 1 - d,$$

let's analyze the received results of the carried out calculations which are submitted in table 1.

Table 1 – Settlement information-entropy characteristics of technological repartitions in hierarchical system for k = 2, N_0 = 2

n	$I_n(d)$	$H_{n(\max)}$	d_n	$I_{\sum_n}(d)$	$H_{\sum_{n(\max)}}$	$d_{\sum}$
	$2^n\left[1-\frac{1}{(n+1)!}\right]$	2^n	$\left[1-\frac{1}{(n+1)!}\right]$	$\sum_{i=0}^{n}2^i\left[1-\frac{1}{(i+1)!}\right]$	$\sum_{i=0}^{n}2^i$	$\frac{\sum_{i=0}^{n}2^i\left[1-\frac{1}{(i+1)!}\right]}{\sum_{i=0}^{n}2^i}$
0	0	1,0	0	0	1,0	0
1	1,0000	2,0	0,5000	1,0000	3,0	0,3333
2	3,3333	4,0	0,8333	4,3333	7,0	0,6190
3	7,6667	8,0	0,9583	12,0000	15,0	0,8000
4	15,8667	16,0	0,9917	27,8667	31,0	0,8989
5	31,9556	32,0	0,9986	59,8222	63,0	0,9496
6	63,9873	64,0	0,9998	123,8095	127,0	0,9749
7	127,9968	128,0	1,0	251,8063	255,0	0,9875
8	255,9993	256,0	1,0	507,8056	511,0	0,9937
9	511,9999	512,0	1,0	1019,8055	1023,0	0,9969
10	1024,0000	1024,0	1,0	2043,8055	2047,0	0,9984
11	2048,0000	2048,0	1,0	4091,8055	4095,0	0,9992
12	4096,0000	4096,0	1,0	8187,8055	8191,0	0,9996
13	8192,0000	8192,0	1,0	16379,8055	16383,0	0,9998
14	16384,0000	16384,0	1,0	32763,8055	32767,0	0,9999
15	32768,0000	32768,0	1,0	65531,8055	65535,0	1,0

Let's define the quality of technological redistribution and distributed products on the grounds of comparing analysis of the competitive schemes on united generalized criterion of complex uncertainty and completeness of the technological scheme of steel production by domain process and direct reception ferric. Since the extraction of any component is pro rata to its contents in source material and back pro rata to its contents in product then in the first approximation extraction of ferric from terrestrial cortex in ore resources is possible to estimate on correlation:

$$\beta_0 \cong \frac{\alpha_{з.к.}}{\alpha_{р.м.}} \cdot 100\% \tag{5}$$

where β_0 - a factor of the extraction at zero level of technological scheme, $\alpha_{з.к.}$ - a factor of the contents in terrestrial cortex, $\alpha_{р.м.}$ - a factor of the contents in ore resources.

Since for ferric

$$H_k = \sum_{i=0}^{n} H_i \tag{6}$$

on the grounds of information formula by Shannon (2) we shall conduct entropy-information analysis of each technological redistribution for calculating the complex uncertainty and completeness of the technological scheme as a whole on example of steel production. Having received characteristic of complex uncertainty of the technological scheme it is possible by means of turned formula

$$p_k = \exp(-H_k \ln 2) = 2^{-H_k} \text{ the parts of the unit (p.u.).} \tag{7}$$

find corresponding to it characteristics of complex certainty of the technological scheme [14] steel production.

The Results of comparative calculations on redistributions and on technological scheme of steel production by domain process as a whole are presented in table 2, by direct reception of ferric in table 3.

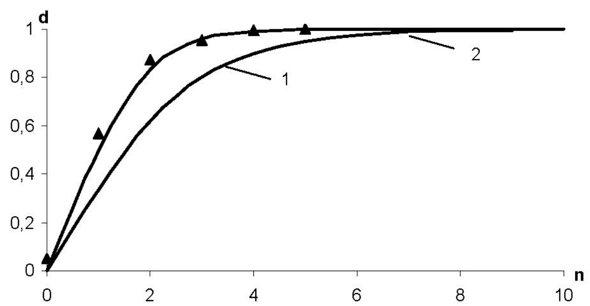
Table 2 – Information estimation on extraction and contents of technological redistribution at steel production by domain process

Technological redistributions	Factors of the contents		Factors of extraction		$H_{\alpha\beta}$	$p_{\alpha\beta}$
	α	H_α bit	β	H_β bit		
Mining	0,5000	1,0000	0,1020	3,2934	4,2934	0,0510
Enrichment	0,6550	0,6104	0,8700	0,2009	0,8113	0,5696
Domain melting	0,8830	0,1795	0,9910	0,0130	0,1925	0,8751
The Smelting	0,9550	0,0664	0,9980	0,0029	0,0693	0,9531
Re-melting	0,9950	0,0072	0,9990	0,0014	0,0086	0,9940
Refining	0,9999	0,0001	0,9999	0,0001	0,0002	0,9998
H_k bi t	–	1,8636	–	3,5117	5,3753	–
p_k p.u	0,2748	–	0,0877	–	–	$2{,}4087 \cdot 10^{-2}$

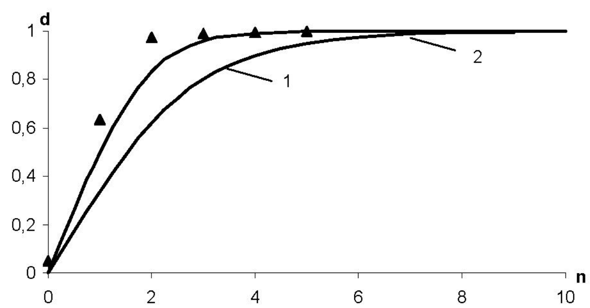
Table 3 – Information estimation on extraction and contents of technological redistribution of steel production by direct reception of ferric

Technological redistributions	Factors of the contents		Factors of extraction		$H_{\alpha\beta}$	$p_{\alpha\beta}$
	α	H_α bit	β	H_β bit		
Mining	0,5000	1,0000	0,1020	3,2934	4,2934	0,0510
Enrichment	0,7140	0,4860	0,8920	0,1649	0,6509	0,6368
Plating	0,9800	0,0291	0,9950	0,0072	0,0363	0,9751
The Smelting	0,9910	0,0130	0,9980	0,0029	0,0159	0,9890
Re-melting	0,9950	0,0072	0,9990	0,0014	0,0086	0,9940
Refining	0,9999	0,0001	0,9999	0,0001	0,0002	0,9998
H_k bi t	–	1,5354	–	3,4699	5,0053	–
p_k p.u	0,3449	–	0,0902	–	–	$3{,}1131 \cdot 10^{-2}$

The Comparing of calculating data on new model (2), (7) with practical data (the tables 2, 3) let's illustrate graphically in coordinates in accordance with (figure).



a)



b)

Dependency of the information estimation of the factors on extraction and contents from level of the technological scheme of steel production:
a) Domain process; b) direct reception of ferric
n - number of level, d - determination,
1 - System determination, 2 - level determination, points - practical data

At comparison of reference data on extraction and contents of the target component of technological organization of steel production by domain process (the table 2) with new model (2), (7) we revealed adequate correlation (R = 0,847942, t_R = 6,035314 > 2) for system determination, much higher for level determination (R = 0,991408, t_R = 115,8812 > 2). At comparison of reference data on extraction and contents of the target component of technological organization of steel production by direct reception of ferric (the table 3) with new model (2), (7) we revealed identical correlation (R = 0,733544, t_R = = 3,176112 > 2) for system determination and (R = 0,96213, t_R = 25,89641 > 2) for level determination.

Discussion. Calculations offered by us for information analysis of steel quality and metallurgical redistribution of the conversion of ferric already in the first approximation correlate with dynamics of raise of deterministic constituting in abstract hierarchical system. Thereby, intercoupling is set between technological factors on extraction and contents of ferric with probability of its transition and finding on every level and on technological scheme as a whole at steel production by domain process and by direct reception of ferric on the grounds of analysis of entropy-information characteristics.

With the aim to improve steel-melting production specialists from many leading metallurgical companies of the world continue to investigate ecological safe and cheaper technology of steel melting. Last years in the world steel branch they have been actively searching for profitable technology, capable to substitute the traditional process of steel production by means of domain stoves and oxygen convertor. But, as we predict the domain process of steel production will prevail on any other process of steel reception.

Such is information estimation of certainty at realization of the technological schemes which can be used for comparison of their state before and after the improvement alongside with base characteristics of the complex uncertainty.

Conclusion. Use of the measure of certainty and uncertainty of the information allows to analyze the general mechanisms of entropy-information laws of the technological repartitions being a fundamental basis of all spontaneously proceeding processes of accumulation of the information which result in self-organizing technological processes, namely, to hierarchical systems. For multilevel hierarchical system of technological repartition it is important to describe the subordinate level as interaction of the interconnected subsystems, each of which possesses the information properties. Therefore at reception of an information estimation main attention is inverted on into-level and intra-level interactions. The considered approach, in our opinion, fully complies with the basic requirements of the system entropy-information analysis as while modeling hierarchical system of technological processes it provides integrity of its consideration due to the general-theoretical and methodical concepts allowing to keep in sight the system as a whole entirely for the solution of a task at all levels of hierarchical system.

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ФУНДАМЕНТАЛЬНЫЕ ХАРАКТЕРИСТИКИ НАДЕЖНОСТИ ТЕХНОЛОГИЧЕСКИХ ПРОЦЕССОВ В ЧЕРНОЙ МЕТАЛЛУРГИИ

Аннотация. Проблемы обеспечения надежности в области металлургии являются чрезвычайно актуальными. Эффективность использования различных технологических схем связана с обеспечением требуемой точности, производительности и экономичности, которые в значительной степени определяются уровнем их надежности. Решающее влияние на совершенство технологических процессов оказывает уровень научного обеспечения, так как именно на этапе научных исследований закладывается потенциал нововведений, который через проектно-конструкторские работы материализуется в производство. Цель проводимых нами исследований – разработать математические и компьютерные модели для расчета фундаментальных характеристик надежности технологических процессов в области цветной и черной металлургии с целью достижения требуемого качества продукции. Предлагаемый алгоритм качественной и количественной оценки надежности на основе фундаментального закона сохранения максимума энтропии позволит предотвращение ошибок именно на стадии научных проработок, чтобы предотвратить возникновение дефекта или устранить его, не доводя до окончательной стадии производства изделия, что особенно важно в странах с рыночной экономикой системы управления техническим уровнем и качеством. Применение предложенной нами технологии анализа надежности технологической продукции и процессов приведет к рационализации процессов и значительному снижению затрат на изготовление данной продукции, повышению ее качества и конкурентоспособности. Научная новизна работы состоит в том, что впервые к анализу технологии химико-металлургических процессов и схем производства цветных и черных металлов применены объективные и фундаментальные информационные критерии, выраженные в универсальных единицах информации – битах. Перспектива исследования распространяется на любые металлургические и химические производства. Разработаны методы компьютерного моделирования для расчета фундаментальных характеристик надежности технологической схемы производства стали путем рафинирования чугуна. Разработаны методы компьютерного моделирования для расчета фундаментальных характеристик надежности технологической схемы производства стали прямым получением железа.

Ключевые слова: моделирование, надежность, технологические процессы, качественная и количественная оценка, энтропия, информация, иерархические системы, технологический продукт.

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ҚАРА МЕТАЛЛУРГИЯ САЛАСЫНДА ТЕХНОЛОГИЯЛЫҚ ПРОЦЕСТЕР СЕНІМДІЛІГІНІҢ ФУНДАМЕНТАЛЬДЫ СИПАТТАМАЛАРЫ

Аннотация. Металлургия саласындағы сенімділікті қамтамасыз ету проблемалары өте маңызды болып табылады. Әр түрлі технологиялық сұлбаларды пайдалану тиімділігі талап етілетін дәлдікті, өнімділікті және үнемділікті қамтамасыз етумен байланысты, сұлбалар едәуір дәрежеде олардың сенімділігі деңгейімен анықталады. Технологиялық процестердің жетілгендігіне ғылыми қамтамасыз ету деңгейі шешуші әсер етеді, себебі атап айтқанда ғылыми зерттеулер кезеңінде енгізілген жаңалықтар әлеуеті салынады, ол жобалық-конструкторлық жұмыстар арқылы өндіріске іске асырылады. Жұмыстың мақсаты – өнімнің талап етілетін сапасына қол жеткізу мақсатында түсті және қара металлургия саласындағы технологиялық процестер сенімділігінің маңызды сипаттамаларын есептеу үшін математикалық және компьютерлік модельдерді әзірлеу. Энтропия максимумын сақтаудың фундаментальды заңы негізінде сенімділікті сапалық және сандық бағалаудың ұсынылатын алгоритмі, ақаудың пайда болуын болдырмау үшін және оны бұйымды өндірудің соңғы сатысына дейін жеткізбей жою үшін, атап айтқанда ғылыми зерттеулер сатысында қателерді болдырмауға мүмкіндік береді, бұл әсіресе техникалық деңгей мен сапаны басқару жүйесінің нарықтық экономикасы бар елдерде маңызды. Ұсынылған технологиялық өнім мен процестердің сенімділігін талдауды қолдану процестерді рационалдауға және берілген өнімді жасауға жұмсалатын шығындарды едәуір азайтуға, оның сапасы мен бәсекеге қабілеттілігін арттыруға әкеледі. Тақырыптың жаңашылдығы – химия-металлургиялық процестер мен сұлбалар технологиясын талдауға әмбебап ақпарат бірліктері – биттермен өрнектелген, объективті және маңызды ақпараттық критерийлер алғаш рет қолданылатын болады.

Түйін сөздер: модельдеу, сенімділік, технологиялық процестер, сапалық және сандық бағалау, энтропия, ақпарат, технологиялық өнімдер.

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