MATHEMATICS METHODS AND INFORMATION SYSTEMS IN CHEMICAL TECHNOLOGY
МАТЕМАТИЧЕСКИЕ МЕТОДЫ И ИНФОРМАЦИОННЫЕ СИСТЕМЫ В ХИМИЧЕСКОЙ ТЕХНОЛОГИИ

ISSN 2686-7575 (Online)

https://doi.org/10.32362/2410-6593-2020-15-6-77-83

UDC 666.1:004.942

RESEARCH ARTICLE

Information method for control of green glass production

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Objectives. *The technological process for the production of sheet glass by the float method is continuous and large-scale. Most European cars (up to 90%) are factory-tinted green; the bulk of the glass is painted in the desired color during the production process. The introduction of modern information technologies and digitalization has opened up opportunities for a significant increase in the efficiency of glass production. Accounting for the amount of drawn and cut glass allows you to evaluate an important indicator of the production work—the glass utilization rate, which determines the percentage of quality glass in the total output. The yield of the quality glass depends on the technological waste in the production process. To assess the effect of waste arising at the production stages on the glass utilization rate, an analysis of the statistical data of the float line operation was carried out. These statistical data differ from the normal law of probability distribution, which limits the use of traditional statistical control methods. Regression models do not always give an accurate mathematical description of the process since the variance of the conditional mathematical expectation of the output variable relative to the input is not a consistent characteristic of the relationship between the input and output variables. The purpose of this work is to study the application of information modeling theory for the analysis and control of the technological process of green glass production in terms of its utilization rate.*

Methods. *The technique of modeling technological chains has some peculiarities with that for operations modeling. It analyzes operations to identify possible information links between parameters. Thus, the process of obtaining the utilization rate of green glass in the production process can be followed. This study analyzes the influence of the paired and triple interactions of waste on the process of affording the utilization rate of glass at the stages of green glass production.*

Results. *Information modeling of the technological process of affording the utilization rate of green glass in the production process has been carried out. Informational analysis results in a conclusion about the sufficiency of the control of the utilization rate of green glass in the production process according to informatively related parameters—waste at the stages of glass melting, annealing, and flanging.*

Conclusions. *The selected method of information control of the glass utilization rate can be used in quality management systems in the production of green glass by the float method.*
Keywords: *technological process, green sheet glass, glass utilization rate, information, modeling*

For citation: Makarov R.I., Khorosheva E.R. Information method for control of green glass production. *Tonk. Khim. Tekhnol. = Fine Chem. Technol.* 2020;15(6):77-83 (Russ., Eng.). https://doi.org/10.32362/2410-6593-2020-15-6-77-83

НАУЧНАЯ СТАТЬЯ

Информационный метод контроля производства зеленого стекла

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Цели. *Технологический процесс производства листового стекла флоат-способом является непрерывным и крупнотоннажным. Европейские автомобили в большинстве (до 90%) имеют зеленую заводскую тонировку стекол, поэтому в процессе производства стекло в своей массе окрашивается в желаемый цвет. Внедрение современных информационных технологий и цифровизация открывают возможности существенного повышения эффективности стекольных производств. Учет количества вытянутого и нарезанного стекла позволяет оценить важный показатель работы производства – коэффициент использования стекла, определяющий долю качественного стекла в процентах в общем объеме выработки. Выход годного стекла зависит от технологических отходов в процессе производства. Для оценки влияния отходов, возникающих на стадиях производства, на коэффициент использования стекла проводился анализ статистических данных работы флоат-линии. Эти выборки отличаются от нормального закона распределения вероятностей, что ограничивает использование традиционных статистических методов контроля. Регрессионные модели не всегда дают точное математическое описание процесса, поскольку дисперсия условного математического ожидания выходной переменной относительно входных не является состоятельной характеристикой связи между входными и выходными переменными. Целью данной работы является исследование применения информационной теории моделирования для анализа и контроля технологического процесса производства зеленого стекла по коэффициенту его использования.*
Методы. *Методика моделирования технологических цепей имеет некоторые особенности по сравнению с моделированием операций. В ней проводится анализ операций для выявления возможных информационных связей между параметрами, что позволяет проследить за формированием коэффициента использования зеленого стекла в процессе производства. Анализируется влияние на величину коэффициента использования стекла парных и тройных взаимодействий отходов на стадиях производства зеленого стекла.*
Результаты. *Проведено информационное моделирование технологического процесса формирования коэффициента использования зеленого стекла. Информационный анализ позволяет сделать заключение о достаточности контроля коэффициента использования зеленого стекла в процессе производства по информативно связанными с ним параметрами – отходами на стадиях стекловарения, отжига и отбортовки.*
Выводы. *Выбранная методика информационного контроля коэффициента использования стекла может применяться в системах менеджмента качества в производстве зеленого стекла флоат-способом.*

Ключевые слова: *технологический процесс, зеленое листовое стекло, коэффициент использования стекла, информация, моделирование*

Для цитирования: Макаров Р.И., Хорошева Е.Р. Информационный метод контроля производства зеленого стекла. *Тонкие химические технологии.* 2020;15(6):77-83. https://doi.org/10.32362/2410-6593-2020-15-6-77-83

The float method, a chemical technology, is used for the production of sheet glass. The production process is continuous and large-scale. Sheet glass is the most important product in the glass industry. Sheet glass is mostly used in industrial, civil, residential, and agricultural constructions. The major consumers are the automotive industry, railway coach manufacturing, and railway transport[1].

Most European cars (up to 90%) are factory-tinted green; the bulk of the glass is painted in the desired color during the production process[2]. The production of green glass has been mastered at Russian glass factories, including AGC Bor Glassworks (Russia)[3] [1].

Over the past 10–15 years, the production and consumption of glass in Russia have significantly increased. This has led to increased requirements for sheet glass quality. The planning and management of large-scale production, which includes the production of polished sheet glass, has special aspects [2]. The technological processes of such industries are continuous, multistage, interdependent, and inertial. The introduction of modern information technologies and digitalization has opened up opportunities for a significant increase in the efficiency of glass production [3–6].

Accounting for the amount of drawn and cut glass makes it possible to estimate an important indicator of the production: the glass utilization rate, which determines the percentage of high-quality glass in the total out-turn. The yield of suitable glass depends on the technological waste in the production process[4,5]. The type of waste that depends on the quality of melting and producing sheet glass includes smelting defects (bubbles, striae, glass stones, etc.), glass ribbon forming defects (crystallization, tin flakes, poly thickness, optical distortions visible in translucent light ("zebra"), stepwise rubbings and cuts from the shafts, lack of border width, etc.,), annealing quality (residual stresses, flection, poor glass cutting), and waste from cutting and shaping glass strip (crizzles, cracks, cutter breaks, scratches from transverse cutting, etc.).

To assess the effect of the waste arising in the production on glass utilization rate, an analysis of the statistical data of the float line operation was carried out. These statistical data differ from the normal law of probability distribution, which limits the use of traditional statistical control methods. Regression models do not always give an accurate mathematical description of the process since the variance of the conditional mathematical expectation of the output variable relative to the input is not a justifiable characteristic of the relationship between input and output variables [7–9].

The informational approach based on the principles of discretization and diversity makes it possible to single out the main part, which is essential in complex technical systems [10, 11].

This study aims to applicate the information modeling theory for analyzing and controlling the technological process of green glass production in terms of its utilization rate.

MATERIALS AND METHODS

To identify the influence of waste arising at different stages of production on glass utilization rate, an analysis

[1] Semenov S. *Rossiiskii rynok stekla: tendentsii, lidery i perspektivy* (Russian glass market: trends, leaders and prospects). Available from URL: https://tybet.ru/content/articles/index.php?SECTION_ID=597&ELEMENT_ID=108091 (Updated January 29, 2020; accessed September 23, 2020) (in Russ.).

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[5] Shchukin M.V. Research and development of management of the production of sheet glass, taking into account environmental aspects. Vladimir: Izd VlGU; 2007.19 p. URL: https://new-disser.ru/_avtoreferats/01003327407.pdf (in Russ.).

was carried out using retrospective data related to the operation of a float line for 60 days. The production of green glass was characterized by an average productivity of 168 tons per shift with a standard deviation of 15 tons. The average thickness of the produced glass was 3.1 mm with a standard deviation of 1.0 mm.

To carry out the analysis, a transition from continuous random variables to discrete ones was made. Four partition ranges were chosen for optimal filtration [10, 12]. Entropy was estimated for the obtained discrete random variables.

The values of the entropy of the analyzed variables calculated based on the experimental data were outside the confidence interval of the normal distribution curve. This confirmed that they differ from the normal distribution law.

Information analysis of the technological process of glass production at individual stages consists of the sequential determination of the amount of information with the use of the following equation:

$$I(X_i \to Y) = H(X_i) + H(Y) - H(X_i Y), \quad i = 1,2,3,4. \quad (1)$$

where $H(X_i)$ and $H(Y)$ are estimates of the entropy (the quantitative measure of uncertainty) of X_i and Y, respectively, i.e., estimates of information content; $H(X_i,Y)$ is the entropy of interdependent systems (the entropy of the co-appearance of statistically dependent magnitudes X_i and Y).

The system of equation (1) makes it possible to estimate the influence of each technological operation on the glass utilization rate.

The degree of the influence of information about waste at the production stages on the glass utilization rate is estimated using data connection coefficients:

$$R_i(X_i \to Y) = I(X_i \to Y) / H(Y), \quad i = 1,2,3,4\,. \quad (2)$$

The method for technological chain modeling has some peculiarities with operations modeling. According to this method, operations are analyzed to identify possible information links between parameters. Thus, the process of affording green glass utilization rate in the production can be traced [10].

The influence of the paired and triple interactions of parameters associated with waste at different production stages on the formation of glass utilization rate was analyzed. Information analysis resulted in a conclusion on the sufficiency of the control of green glass utilization rate in the production process, according to informatively related parameters.

RESULTS AND DISCUSSION

Let us carry out information modeling of the technological process of forming green glass utilization rate.

The technological chain of green glass production (production stages) is presented as an information channel receiving information about waste at production stages X_i (i = 1, 2, 3, 4). The information is sequentially transformed into information about glass utilization rate Y at the technological chain output.

Let us estimate the amount of information contained in the parameter of green glass produced at production stages: melting waste $H(X_1)$, molding waste $H(X_2)$, annealing waste $H(X_3)$, and flanging waste $H(X_4)$. The amount of information contained in the parameters of the produced glass is $H(X)$ = 1.38 {nat}. (Here, {nat} is the logarithmic unit for measuring the amount of information).

Let us determine the impact of waste from individual production stages (X_1, X_2, X_3, X_4) on the glass utilization rate (Y). Calculating the information model parameters is reduced to determining the amount of information transmitted to the glass utilization rate Y from the waste at the production stages (X_1, X_2, X_3, X_4). The analysis comprises the sequential determination of the amount of mutual information I between the parameters using the system of equation (1). The calculation results are shown in the table below.

The information transmitted from parameters X_2 and X_3 to Y turned out to be statistically insignificant. This indicates that there is no influence of waste from the glass strip molding and annealing stages on the green glass utilization rate. The information transmitted from the parameter X_1 (glass melting waste) and X_4 (flanging waste) to the glass utilization rate Y turned out to be statistically significant. This indicates the influence of glass melting and flanging waste on the green glass utilization rate in the production process.

The degree of influence of the information on wastes at the stages of production on the glass utilization rate was determined using the data connection coefficients (2). These results are also shown in the table.

The data connection between the parameters is interpreted as follows: parameter X_1 (melting waste) transfers 16% of information to parameter Y (glass utilization rate); parameter X_4 (flanging waste) transfers 20% of information to Y. Calculation showed a weak data connection between waste at certain production stages and green glass utilization rate.

Analysis of the impact of waste from individual stages of production on the glass utilization rate

Stages of sheet glass production	Amount of information transmitted to the glass utilization rate $I(X \rightarrow Y)$	Impact of waste information on the glass utilization rate $R(X \rightarrow Y)$	Statistical significance of transmitted information
Melting waste, X_1	0.23	0.16	significant
Molding waste, X_2	0.05	0.04	insignificant
Annealing waste, X_3	0.13	0.10	insignificant
Flanging waste, X_4	0.27	0.20	significant

Using the basic provisions of information theory let us determine the sequential increment of information transmitted to the output parameter Y after each operation [10]:

$$I(X_1 \rightarrow Y) = 0.23;$$
$$I(X_4 \rightarrow Y / X_1, X_3) = 0.52.$$

The degree of influence of the information increment on the glass utilization rate Y is determined using the data connection coefficient:

$$R_1(X_1 \rightarrow Y) = 0.16;$$
$$R_4(X_4 \rightarrow Y / X_1, X_3) = 0.38.$$

Let us analyze the effect of the paired and triple interactions of the parameters associated with wastes at different production stages on the formation of the glass utilization rate [10]:

$$I(X_1, X_4 \rightarrow Y) = 0.52;$$
$$R_{14}(X_1, X_4 \rightarrow Y) = 0.38;$$
$$I(X_1, X_3, X_4 \rightarrow Y) = 1.04;$$
$$R_{134}(X_1, X_3, X_4 \rightarrow Y) = 0.75.$$

Thus, information from the paired interaction of parameters X_1 and X_4 makes up 38% of the information of parameter Y; information from the triple interaction of parameters X_1, X_3, and X_4 makes up 75% of the information of Y.

The works presented in the monograph [10] are devoted to the application of information methods in quality management. The obtained research results are consistent with previously published works [13, 14].

CONCLUSIONS

The carried-out information analysis leads to the conclusion that it is sufficient to control green glass production according to three parameters: waste at the stages of glass melting X_1, annealing X_3, and flanging X_4, as they are the most informative concerning the glass utilization rate.

The proposed method of information control of the green glass utilization rate can be used in quality management systems in the production of glass by the float method.

Financial support

This study did not have any financial support from outside organizations.

Authors' contribution

All authors equally contributed to the research work.

The authors declare no conflicts of interest.

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The article was submitted: September 21, 2020; approved after reviewing: November 12, 2020; accepted for publication: November 18, 2020.

Translated from Russian into English by M. Povorin
Edited for English language and spelling by Enago, an editing brand of Crimson Interactive Inc.