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THE METHOD OF PURIFICATION OF GASES FROM ACIDIC COMPONENTS USING SOLUTIONS OF ALKALINE HYDROXIDES

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ABSTRACT

In the article, the absorption method of cleaning gases "ELSOR" refers to the field of chemical technology, namely to processes of absorption purification of gases from sulphur-containing impurities, and can be used in gas purification processes of different composition and different origin, including natural, associated and process gases, in particular biogas, associated gas of oil fields, fuel gases supplied to facilities of heat and power facilities, ventilation and process gas emissions (salvo and regular) at facilities of the chemical, petrochemical industry, as well as in the production of special equipment and ammunition containing hydrogen sulfide and mercaptans.

Keywords: crude gas, solution, sodium hydroxide, absorbent, flow rate, concentration.
composition and origin, including natural, associated and technological gases, in particular biogas, associated gas from oil fields, fuel gases supplied to thermal power facilities, ventilation and technological gas emissions (volley and regular) at chemical, petrochemical industry facilities, as well as in the production of special equipment and ammunition containing hydrogen sulfide and mercaptans.

The cleaning method "ELSOR" provides the highest quality of cleaning, because solutions of alkali metal hydroxides are the best absorbents of H2 and other sulfur-containing impurities, it is economical, since the consumable material for the cleaning process is only electricity and the cleaning process is carried out at low temperatures, and the production of sodium hydroxide from the initial solution and the regeneration of the solution saturated with acid gases after cleaning carried out using the same electrochemical reactor, i.e. the electric energy spent on obtaining the absorbent also ensures its regeneration. In addition, the "ELSOR" method can be carried out both in stationary and in mobile units.

The method is implemented using the installation shown in the figure.

Figure 1. Installation for gas purification from sulfur-containing impurities contains: diaphragm electrochemical reactor 1, diaphragm-separated 2 to the cathode 3 and anode 4 chambers, capacity 5 for the accumulation of an alkaline solution, capacity 6 for accumulation of sulfuric acid, absorber 7 and desorber 8. The installation also contains a mixer 9, pumps 10 and 11, a throttle valve 12 and gas and hydraulic piping, including inlet and outlet pipes.

The cathode chamber 3 of the reactor 1 and the container 5 are filled with the initial aqueous solution of alkali metal sulfate. The anode chamber 4 of the reactor 1 and the container 6 are filled with the initial solution - an aqueous solution of alkali metal sulfate. The electrodes of the reactor 1 (not shown) are energized and the pumps 10 and 11 are turned on. In the process of electrolysis, the initial solution of alkali metal sulfate is subjected to electrochemical action in the cathode chamber 3, converting it into alkali metal hydroxide, which is accumulated in vessel 5. At the same time, a solution of sulfuric acid formed in the anode chamber 4 of reactor 1 is accumulated in vessel 6. Alkali metal hydroxide solution from vessel 5 is supplied by high pressure pump 10 to the upper part of absorber 7, into the lower part of which enters the raw gas to be purified. The acidic components contained in the gas interact with the absorber - an alkali metal hydroxide solution, and the purified gas is removed from the upper part of the absorber 7.

The saturated absorbent solution is withdrawn from the lower part of the absorber 7 through the throttle valve 12 and sent to the mixer 9, into which the sulfuric acid solution is supplied from the container 6 by the pump 11. In the mixer 6, the processes of regeneration of the absorber and the release of absorbed impurities take place. The gas-liquid mixture from the mixer 6 is fed into the desorber 8, from the upper part of which acid gases are removed, and from the lower part - an alkali metal sulfate solution, which again enters the cathode 3 and anode 4 chambers of the reactor 1.
Table 1.
The amount of NaOH required to remove hydrogen sulfide from a 1000 nm gas at any ratio of CO₂:H₂S

<table>
<thead>
<tr>
<th>Hydrogen sulfide content in gas, %</th>
<th>The content of hydrogen sulfide in 3 1000 nm gas, kilogram</th>
<th>Amount of NaOH for cleaning 1000 nm³ of gas, kilogram</th>
<th>Expenses electricity for NaOH synthesis, kWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1</td>
<td>1.5</td>
<td>5.0</td>
<td>14</td>
</tr>
<tr>
<td>0.2</td>
<td>3.0</td>
<td>10.0</td>
<td>28</td>
</tr>
<tr>
<td>0.3</td>
<td>4.5</td>
<td>15.0</td>
<td>42</td>
</tr>
<tr>
<td>0.4</td>
<td>6.0</td>
<td>20.0</td>
<td>56</td>
</tr>
<tr>
<td>0.5</td>
<td>7.5</td>
<td>25.0</td>
<td>70</td>
</tr>
<tr>
<td>1.0</td>
<td>15.0</td>
<td>50.0</td>
<td>140</td>
</tr>
<tr>
<td>5.0</td>
<td>75.0</td>
<td>250.0</td>
<td>700</td>
</tr>
<tr>
<td>10.0</td>
<td>150.0</td>
<td>500.0</td>
<td>1400</td>
</tr>
</tbody>
</table>

Table 2.
Performance indicators of the installation for the electrochemical synthesis of sodium hydroxide and sulfuric acid from a solution of sodium sulfate with a capacity of 10 kg of NaOH per hour

<table>
<thead>
<tr>
<th>Name</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity consumption for electrochemical synthesis of NaOH and H2SO4, kWh</td>
<td>28</td>
</tr>
<tr>
<td>Electricity consumption for auxiliary work (preparation and purification of make-up solution, supply of cooling water, preparation of a solution for cleaning electrochemical reactors), kWh</td>
<td>2</td>
</tr>
<tr>
<td>Consumption of sodium sulfate at the start-up of the plant, kg</td>
<td>120</td>
</tr>
<tr>
<td>Consumption of sodium sulfate for the preparation of make-up solution, kg/day</td>
<td>5</td>
</tr>
<tr>
<td>Water consumption (of any quality) for cooling electrochemical reactors, l/h</td>
<td>200</td>
</tr>
</tbody>
</table>

Reference:
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THE REACTIVE POWER COMPENSATION IN NONLINEAR ELECTRICAL LOADS

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ABSTRACT

The paper presents and discusses the problems associated with reactive power compensation of nonlinear loads. Analytical results and simulation studies for selected high power drive used in mine when apply dynamic compensation together with active harmonics filters are presented. It was found that application of active power filters allows for compensation high current harmonics in general, and suppression of as reactive power flows as well as current harmonics in the network. On the basis of results conclusions on efficiency of the active on-line compensation of non-linear loads of a high power are formulated. Adequate reactive power control solves power quality problems like flat voltage profile maintenance at all power transmission levels, improvement in power factor, transmission efficiency and system stability.

Keywords: reactive power, compensation, non-linear load, Voltage Profile, Series compensation.

In industrial applications there are high power motor drives which require speed control. In mining, they include mine host drives, the main ventilation and drainage engines, large air compressors and various pumps. As electric motors are used both DC motors, asynchronous and synchronous. In order to provide variable speed control there are used rectifier systems or systems of high power converters (in which rectifiers are also employed). For drives of a low rated power (up to about 300–400kW) uncontrolled rectifiers (diodes type) are commonly used, while for high power the controlled rectifiers respectively. As a result voltage drops along impedances of as transmission, distribution and reception systems are also distorted. [1]. Reactive power management has become a most challenging task in power system operation and management. Some of the characteristics of the power systems and their loads can deteriorate the quality of the supply. An increase in the consumption of reactive power in the network leads to a decrease in the voltage in the network. The voltage drop not only increases the power losses in the network, but also affects the electrical equipment that receives power from this network, especially the operation of electrical machines. It is known that the magnetic driving force and the main magnetic flux created in the motor windings are directly proportional to the voltage value. The requirement of the standard establishes that the change in mains voltage for electrical machines due to the effect of voltage changes on electrical equipment should not exceed ±5% of the total mains voltage. However, the
Voltage at the receiving end in the transmission end is allowed to vary between the range of ±5-10% which further restricts the transfer of the reactive power. [2].

**REACTIVE POWER COMPENSATION OF NON-LINEAR LOADS**

In the case of a linear load RL type, reactive power compensation is performed based on the resolution of the current into two components

\[ I = \sqrt{I_a^2 + I_r^2} \]  

where \( I \) - rms value of the load current; \( I_a \) - active current component (\( I_a = I \cdot \cos \phi \)); \( I_r \) - reactive current component (\( I_r = I \cdot \sin \phi \)).

As devices for compensation are used static battery banks and/or overexcited synchronous motors (rotating compensators). For the non-linear loads current waveform indicates presence of numerous harmonics. Broad spectrum of the current harmonics may result in thermal damage of the capacitors, the insulation of power cables, transformers as well as electrical machines (i.e. capacitive reactance decreases with the increase in frequency therefore, an overload due to high harmonics is a key factor). Thus, for large non-linear loads as an unit to compensate for the negative impact on the network there are used the series connected passive LC filters and capacitive banks together with protective reactors. The series LC filter of resonant frequency

\[ f = \frac{1}{2 \pi \sqrt{LC}} \]  

for given harmonics displays small value of equivalent reactance seen from the terminals of a high power non-linear load. Current (currents) flowing out of this load must be bridged by the filter LC (Fig. 1) without affecting the network itself.

![Figure 1. Equivalent electric circuit with non-linear load](image1)

**In real systems one deals with distorted voltage. However, these deformations are relatively small and their level is determined by the applicable law (THD \( U \leq 2\% \)). In spite of a small voltage waveform deformation the high current harmonics flowing through batteries and passive filters can, in customer installation, reach significant values. Therefore, the only way to limit or to eliminate the high current harmonics is the use of appropriately selected active filters[3].** The main reactive power compensation devices include: synchronous generators, synchronous compensators, static reactive power compensators, capacitor banks. Synchronous generators produce electricity that is supplied to consumers. By influencing the excitations of generators, it is possible to change the generated voltage and thus regulate the transfer of reactive power to the network. Synchronous compensators are synchronous motors that operate without load and perform the function of generating reactive power in overexcited mode. Advances in power electronics made it possible to move from synchronous compensators to static reactive power co-balancing systems, such as the thyristor-switched capacitor bank and the thyristor-controlled reactor. A thyristor-switched capacitor bank allows stepwise regulation of the reactive power that the capacitors supply to the network (figure 2).

![Figure 2. Principle scheme of thyristor-switched capacitor bank](image2)
A thyristor-controlled reactor can smoothly regulate the reactive power consumed by the inductors. By connecting these devices, it is possible to smoothly regulate the generated and consumed reactive power (figure 3).

![Figure 3. Principle scheme of thyristor-controlled reactor](image)

REACTIVE POWER COMPENSATION METHODS

The use of powerful electric motors in the production process leads to a high consumption of reactive power. The reactive power consumed by these motors is compensated in various ways. The reactive power consumed by electric motors is compensated in the following methods:

- Individual compensation;
- Group Compensation;
- Centralized Compensation;
- Combined compensation;
- Automatic compensation.

**Individual compensation** is achieved by connecting a precisely sized capacitor bank to the terminals of the load whose reactive power is to be compensated. **Group compensation** is designed to increase the compensation of a group of loads with similar functional characteristics by connecting a common capacitor bank. **Centralized compensation** is intended in installations with a large number of loads that do not operate simultaneously or are switched on only for a few hours a day. Combined compensation is a compromise between individual and centralized power compensation and takes advantage of both options. In most electrical installations, reactive power consumption is not constant. In such electrical installations, automatic power compensation systems are used. Automatic reactive power compensation systems include:

- current and voltage sensors;
- controller;
- electrical panel with switching and protection devices;
- capacitor batteries.

References:

ENERGY INDUSTRY

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MODELING THE EFFECT OF DIFFERENT TEXTURES ON THE OPTICAL PROPERTIES OF A SILICON-BASED SOLAR CELL IN PVLIGHT HOUSE

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ABSTRACT
This paper analyzes the results obtained by modeling the optical properties of a silicon-based solar cell based on the angle at the base of the straight and inverted pyramidal textures formed on their surface on the PV LIGHT HOUSE online platform. According to the results obtained, when the angle at the base of the correct pyramidal texture is 73.12°, the silicon-based solar cell reaches its maximum absorption coefficient.

Keywords: texture, solar cell, silicon, pyramid, absorption coefficient.

МОДЕЛИРОВАНИЕ ВЛИЯНИЯ РАЗЛИЧНЫХ ТЕКСТУР НА ОПТИЧЕСКИЕ СВОЙСТВА СОЛНЕЧНОГО ЭЛЕМЕНТА НА ОСНОВЕ КРЕМНИЯ В PVLIGHT HOUSE

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АННОТАЦИЯ
В данной работе анализируются результаты, полученные при моделировании оптических свойств солнечного элемента на основе кремния на основе угла в основании на прямы и перевернутых пирамидальных текстур на онлайн-платформе PV LIGHT HOUSE. Согласно полученным результатам, когда угол в основании правильной пирамидальной текстуры составляет 73 12°, солнечный элемент на основе кремния достигает максимального коэффициента поглощения.

Ключевые слова: текстура, солнечный элемент, кремний, пирамида, коэффициент поглощения.
Various textures are created on the surface of the sun's elements to reduce the reflection of light incident on them. [1] [2]. There are two different purposes for this. The first is to increase the incident light surface, the second is to increase the absorption [3] and reduce the reflection coefficient [4] by creating more refractions between the two textures. Silicon with orientation [111] is mainly used in the production of solar cells [5]. When the surface of this silicon is chemically treated with alkalis, straight pyramidal textures with a base angle of 54.7° are formed on the surface [6] - [8]. In this chapter, the optical properties of a silicon-based solar cell coated with straight pyramidal textures with different base angles are studied using a Wafer Ray Tracer. Based on the theory of pure optics, it was found that the absorption coefficient of a silicon-based solar cell is maximal when it is covered with straight pyramidal textures with a surface angle of 73.12° [9]. However, a complex study of a textured silicon-based solar cell using TCAD software found that the absorption coefficient reached a maximum value when covered with textures with a base angle of 72.04° [10]. Figure 1 illustrates the dependence of the optical properties of a silicon-based solar cell covered by straight pyramids with a base angle of 54.7° (a) and 73.12° (b) on the wavelength of light. As the angle at the base of the pyramidal texture increases, the absorption coefficient of the solar element increases and the reflection coefficient decreases. When the base angle of the pyramid is 73.12°, the absorption coefficient in the range of 500-1000 nm of wavelength is close to 100%.

![Figure 1. Dependence of the optical properties of a silicon-based solar cell covered by straight pyramids with a base angle of 54.7° (a) and 73.12° (b) on the wavelength of light](image)

The optimal value of the angle varied when studying the above optical laws and the dependence of the efficiency of the solar cell on the base angle of the straight pyramidal textures formed on the surface of the solar cell using TCAD modeling. This is because surface recombination is not taken into account when calculating efficiency based on the laws of optics. In addition to optical parameters, surface recombination is taken into account when modeling in TCAD. As the angle at the base of the pyramidal texture increases, so does the active surface on which the light falls. Hence, an increase in the active surface leads to an increase in surface recombination. Therefore, the value of the angle calculated in TCAD was 1.08° less than the value calculated based on the laws of optics.

The textures formed on the surface of the solar cell are mainly divided into two types: straight pyramidal and inverted pyramidal textures. Figure 2 shows the photogeneration coefficient of a single-crystal silicon-based solar cell depending on the angle at the base of the straight pyramidal texture formed on the surface. When the angle at the base of a straight pyramid increases from 0° to 30°, the photogeneration coefficient increases slightly by 4%. This is because the light falling between the pyramids is refracted once it falls on the planar surface. The only reason for the increase in the photogeneration coefficient here is the increase in the active illuminated surface. When the angle at the base of the pyramid increases from 30° to 45°, the light no longer begins to test twice, not once. Therefore, the photogeneration coefficient increased sharply by 20%. Between 45° and 54°, the light refracts twice between the two pyramids, 3 times between 55° and 63°, and 4 times at angles above 70°. It breaks 4 times when it falls between the light-based pyramids with an angle of 70° to 80°. Suppose that the photogeneration coefficient is a function of the angle at the base of the pyramid. So this function consists of curves. Therefore, it must have extremes. Based on this idea, a theoretical study found that the maximum absorption coefficient is reached when the angle based on the straight pyramidal texture formed on the surface of a silicon-based solar cell is 73.12°. It was also found that PVLIGHTHOUSE achieves maximum photogeneration coefficient at a pyramid-based angle of 73.12° when modeling a straight pyramidal textured silicon-based solar cell with different base angles using the Wafer Ray Tracer module.
Figure 2. The dependence of the photogeneration coefficient of a single-crystalline silicon-based solar cell on the angle based on a straight pyramidal texture formed on the surface

Unlike straight pyramids, inverted pyramids are becoming more popular. Inverted pyramids are formed using $\text{H}_2\text{O}_2$, $\text{NH}_4\text{HF}_2$ and polyvinyl pyrrollidone. Inverted pyramids are a good anti-reflective agent for thin silicon-based solar cells. Figure 3 shows the coefficient of photogeneration of a single-crystalline silicon-based solar cell depending on the angle at the base of the inverted pyramidal texture formed on the surface. When the angle at the base of the inverted pyramid changes from $0^\circ$ to $45^\circ$, the change in the photogeneration coefficient is almost exactly the same as that of a solar cell covered with a pyramidal texture, with only $45^\circ$-$80^\circ$ differences.

Figure 3. Dependence of the photogeneration coefficient of a single-crystal silicon-based solar cell on the angle based on the inverted pyramidal texture formed on the surface

Above, the photogeneration coefficient of a silicon-based solar cell coated with a straight and inverted pyramidal texture was analyzed as a function of the pyramid-based angle. Table 1 shows the photogenesis coefficients of a silicon-based solar cell with straight and inverted pyramidal textures with different base angles on the surface. The photogeneration coefficient of the straight pyramidal textured solar cell was high at all angles except pyramid-based angles $54^\circ$ and $70^\circ$. As mentioned above, mainly in the experiment, pyramids with an angle of $54.7^\circ$ at the base can be formed by chemical feeding on the surface of a silicon-based solar cell. Therefore, in the experiment, the efficiency of the inverted pyramidal textured silicon-based solar cell is high.
The dependence of the absorption coefficient of a silicon-based solar cell on the angle at the base of the pyramidal textures formed on the surface

<table>
<thead>
<tr>
<th>Angle (°)</th>
<th>Upright pyramid</th>
<th>Inverted pyramid</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>55.39</td>
<td>55.39</td>
</tr>
<tr>
<td>15</td>
<td>56.25</td>
<td>56.60</td>
</tr>
<tr>
<td>30</td>
<td>59.95</td>
<td>59.63</td>
</tr>
<tr>
<td>45</td>
<td>80.39</td>
<td>79.81</td>
</tr>
<tr>
<td>54</td>
<td>82.19</td>
<td>82.99</td>
</tr>
<tr>
<td>60</td>
<td>87.15</td>
<td>87.06</td>
</tr>
<tr>
<td>70</td>
<td>89.68</td>
<td>90.07</td>
</tr>
<tr>
<td>80</td>
<td>92.3</td>
<td>91.99</td>
</tr>
</tbody>
</table>

References:

INFLUENCE OF DIFFERENT ANTI-REFLECTIVE LAYERS ON THE OPTICAL PROPERTIES OF SILICON-BASED SOLAR CELLS IN PVLIGHT HOUSE

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ABSTRACT
In this paper, the effect of SiO$_2$, SiN$_x$, Al$_2$O$_3$ and TiO$_2$ light-reflecting layers with passivation properties on the properties of the solar cell is modeled in PVLIGHT HOUSE and the results obtained are theoretically analyzed. According to the results, for the anti-reflective layers SiO$_2$, SiN$_x$, Al$_2$O$_3$ and TiO$_2$, the maximum thickness at which the solar cell achieves the maximum absorption coefficient is 100 nm, 75 nm, 90 nm and 70 nm, respectively. This means that the optimal thickness of the anti-reflection layer is inversely proportional to the refractive index.

Keywords: solar cell, anti-reflection layer, modeling, complex refractive index

INFLUENCIE РАЗЛИЧНЫХ ПРОСВЕТЛЯЮЩИХ СЛОЕВ НА ОПТИЧЕСКИЕ СВОЙСТВА КРЕМНИЕВЫХ СОЛНЕЧНЫХ ЭЛЕМЕНТОВ В PVLIGHT HOUSE

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АННОТАЦИЯ
В данной работе в программе PVLIGHT HOUSE моделируется влияние светоотражающих слоев SiO$_2$, SiN$_x$, Al$_2$O$_3$ и TiO$_2$ с пассивирующими свойствами на свойства солнечного элемента и проводится теоретический анализ полученных результатов. Согласно результатам, для просветляющих слоев SiO$_2$, SiN$_x$, Al$_2$O$_3$ и TiO$_2$ максимальная толщина, при которой солнечный элемент достигает максимального коэффициента поглощения, составляет 100 нм, 75 нм, 90 нм и 70 нм соответственно. Это означает, что оптимальная толщина просветляющего слоя обратно пропорциональна показателю преломления.

Ключевые слова: солнечный элемент, просветляющий слой, моделирование, комплексный показатель преломления.
To reduce the reflection coefficient of the solar cell, a technology has been developed to cover the surface with anti-reflective coatings [1]. In the selection of anti-reflective layers, attention is paid to their refractive index and light absorption coefficient [2]. The refractive index of the anti-reflection layer should be in the range of the refractive index values of air and silicon, and the light absorption coefficient should be close to zero. In addition, the anti-reflective layer on the silicon surface must be passive [3]. This is because the surface of silicon is an active area, and due to incomplete bonds and oxygen, this area has a high rate of recombination, which is called surface recombination. SiNx [4], SiO2 [5], [6] and Al2O3 [7] are mainly used to reduce surface recombination in silicon. Therefore, the back area of the silicon-based solar cell is also covered with these substances. In this chapter, the optical properties of a single-crystal silicon-based solar cell coated with various anti-reflective layers are studied and analyzed. Figure 1 illustrates the dependence of the absorption, transition, and return coefficients of a 200 μm thick single-crystal silicon-based solar cell coated with SiNx with a thickness of 100 nm (a) and 75 nm (b) on the wavelength of light. When SiNx was 100 nm thick, the main absorption was in the range of 700–1000 nm of light wavelength, and at 75 nm, in the range of 500–800 nm of wavelength. The decrease in the thickness of SiNx caused the absorption spectrum to shift from long wavelengths to short wavelengths. This is due to the formation of a useful internal interference. Therefore, the surface of a silicon-based solar cell is mainly coated with 75 nm thick SiNx.

In addition to SiNx, SiO2 is also used to cover the surface of solar cells with optical layers. Figure 2 illustrates the optical properties of a 200 μm thick single-crystal silicon-based solar cell coated with SiO2 with a thickness of 100 nm (a) and 75 nm (b).

When a silicon-based solar cell is coated with 75 nm thick SiO2, a decrease in the light absorption coefficient and an increase in the reflection coefficient are observed between 500-1000 nm of wavelength. When coated with 100 nm thick SiO2, it was found that the light absorption coefficient remained almost high between these wavelengths. Therefore, for silicon-based solar cells, 100 nm thick SiO2 is one of the optimal anti-reflective layers.

In industry, the surface of silicon-based solar cells is coated with SiNx or SiO2. However, in this dissertation, in addition to SiNx and SiO2, we also analyzed...
the optical properties of silicon-based solar cells coated with these substances, as Al₂O₃ has passivation properties and TiO₂ has an optimal refractive index for a silicon-based solar cell. Therefore, in Figure 3, the graphs of light wavelength dependence of the absorption, transition, and return coefficients of a 200 μm thick single-crystal silicon-based solar cell coated with Al₂O₃ (a) and TiO₂ (b) with a thickness of 100 nm described.

![Graph](image1)

![Graph](image2)

Figure 3. Optical properties of a 200 μm thick single-crystal silicon-based solar cell coated with Al₂O₃ (a) and TiO₂ (b) with a thickness of 100 nm

When the surface of a silicon-based solar cell was covered with a thickness of 100 nm, the light absorption coefficient was high and the reflection coefficient was low between 600-950 nm of wavelength. When coated with 100 nm thick TiO₂, a sharp decrease in the light absorption coefficient and a sharp increase in the refractive index in the range of 400-700 nm of wavelength, and an increase in the absorption coefficient and a decrease in the reflection coefficient in the range of 800-1000 nm. From all the graphs obtained above, it can be seen that the change in the thickness of the light-reflecting jumps mainly affects the light absorption and reflection coefficients of the solar cell. In general, the photogeneration coefficient was used to compare the absorption coefficients of light and to analyze the optical quality of the solar cell. The photogeneration coefficient is the ratio of the light energy used to generate an exciton, or pair of electrons, to the light energy incident on a solar cell. Therefore, the photogeneration coefficients of a silicon-based solar cell coated with two different light-reflecting layers at two different thicknesses of 75 nm and 100 nm are given in Table 1. At 75 nm thickness, SiNx and TiO₂ achieved high photogeneration coefficients, while at 100 nm thickness, Al₂O₃ and SiO₂ achieved high photogeneration coefficients. If we pay attention, the refractive index of SiNx and TiO₂ is almost 2, and the refractive index of Al₂O₃ and SiO₂ is close to 1.5. This means that the value of the optimal thickness of the anti-reflective layer covered by the surface of the solar cell is inversely proportional to the refractive index of this optical layer.

<table>
<thead>
<tr>
<th>Dielectrics</th>
<th>75 nm</th>
<th>100 nm</th>
</tr>
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<tbody>
<tr>
<td>SiNx</td>
<td>77.62</td>
<td>75.97</td>
</tr>
<tr>
<td>SiO₂</td>
<td>70.39</td>
<td>72.91</td>
</tr>
<tr>
<td>TiO₂</td>
<td>76.16</td>
<td>72.27</td>
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<tr>
<td>Al₂O₃</td>
<td>75.58</td>
<td>76.96</td>
</tr>
</tbody>
</table>

Table 1. Photogeneration coefficient of silicon-based solar element coated with anti-reflective layers of different thicknesses

References:


ANALYSIS OF A NEW TYPE OF MICRO-HYDRO POWER PLANT

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ABSTRACT

Various types of micro-hydro power plants are used to provide the population with electricity using hydropower. These hydroelectric power plants differ from each other in design, capacity and installation area. This article analyzes various micro hydroelectric power plants. As a result of these analyses, a new type of micro-hydro power plant was analyzed. As a result of the research, the technical parameters of a new type of micro hydroelectric power plant were analyzed. Based on these parameters, a three-dimensional model of a new type of hydroelectric power plant was created.

Keywords: hydroelectric power plant, power of micro-hydro power plant, hydro turbine.

Micro hydro is one of the solutions, as an important and promising power resource to meets electricity needs in rural areas, due to its ability to penetrate the limitations of transportation and technology access. In fact, micro hydro power plant (MHPP) is able to generate the power up to 100 kW [1].

The choice and installation of micro hydropower plants depends on the selected geographical area. Depending on the selected geographical area, the type of hydroelectric power plant is selected. Micro HPPs are divided into reaction and impulse ones according to the principle of operation.

Bulb turbine: The turbine and generator are a sealed unit placed directly in the water stream.

The bulb turbine is a variation of the propeller-type turbine. In the bulb turbine arrangement, the generator is encapsulated and sealed within a streamlined water-tight steel housing mounted in the center of the water passageway. The generator is driven by a variable-pitch propeller located on the downstream end of the bulb.

Unlike the Kaplan turbine, water enters and exits this unit with very little change in direction. The compact nature of this design allows for more flexibility in powerhouse design. Bulb turbines can, however, be somewhat more difficult to access for service, and they require special air circulation and cooling within the bulb. [2].

Kaplan Turbine: Both the blades and the wicket gates are adjustable, allowing for a wider range of operation. The inlet guide-vanes can be opened and closed to regulate the amount of flow that can pass through the turbine. When fully closed they will stop the water completely and bring the turbine to rest.

Depending on the position of the inlet guide-vanes they introduce differing amounts of 'swirl' to the flow, and ensure that the water hits the rotor at the most efficient angle for the highest efficiency. The rotor blade pitch is also adjustable, from a flat profile for very low flows to a heavily-pitched profile for high flows (see Fig.1). [2].
Francis Turbine: A Francis turbine has a runner with fixed blades, usually nine or more. Water is introduced just above the runner and all around it which then falls through, causing the blades to spin. Besides the runner, the other major components include a scroll case, wicket gates, and a draft tube. Francis turbines are commonly used for medium- to high-head (130- to 2,000-foot) situations though they have been used for lower heads as well. Francis turbines work well in both horizontal and vertical orientations.

Pelton Turbine: A Pelton wheel has one or more free jets discharging water into an aerated space and impinging on the buckets of a runner. Pelton turbines are generally used for very high heads and low flows. Draft tubes are not required for an impulse turbine because the runner must be located above the maximum tailwater to permit operation at atmospheric head. The operation of a Pelton turbine is fairly simple. In this type of turbine, high speed jets of water emerge from the nozzles that surround the turbine. The high speed water jets are created by pushing high head water (such as water falling from high heads) through nozzles at atmospheric head. The maximum output is obtained from a Pelton turbine when the impulse obtained by the blades is maximum, meaning that the water stream is deflected exactly opposite to the direction at which it strikes the buckets at. As well, the efficiency of these wheels is highest when the speed of the movement of the cups is half of the speed of the water jet, as seen in fig. 2[3].

Cross-Flow Turbine: A cross-flow turbine is drum-shaped and uses an elongated, rectangular section nozzle directed against curved vanes on a cylindrically shaped runner. It resembles a “squirrel cage” blower. The cross-flow turbine allows water to flow through the blades twice. On the first pass, water flows from outside of the blades to the inside; the second pass goes from the inside back out. A guide vane at the entrance to the turbine directs the flow into a limited portion of the runner. The cross-flow turbine was developed to accommodate larger water flows and lower heads than the Pelton can handle. In this type of turbine, water enters as a flat sheet instead of a round jet - as is the case in Pelton turbines. The first impact the water has with the blades produces more power than the second hit. [3].

Their main disadvantage is that these micro-hydro power plants require high kinetic and potential energy of water to generate electricity. However, in order to obtain the kinetic and potential energy of water of great value, it is necessary to build a reservoir of a certain height h. Studies have shown that it is possible to create a structure that allows electricity to be generated from the energy of slow-flowing rivers and canals.

As a result of research, a two-turbine two-generator micro-hydro electric power station was built. The advantage of this design is that two-way power can be obtained from a micro hydroelectric power station.

To be more precise, electricity is generated as a result of the parallel operation of generators installed in the input and output turbines of a micro hydroelectric power station. The following fig. 3 shows a drawing and model of a micro HPP with a dual generator with two turbines.
Figure 3. 3D model of a micro HPP with a dual generator with two turbines

Power of input and output turbines of Micro HPP

\[ P_1 = 9,81 \eta_1 Q_1 H_1 \]  
\[ P_2 = 9,81 \eta_2 Q_2 H_2 \]  

(1)  
(2)

where: \( \eta \) - efficiency of micro HPP, \( Q \) - water flow through a certain section, m\(^3\)/s  
\( H \) - head of water supplied to the hydraulic turbine, m

Taking into account the above formulas, the total capacity of the micro HPP is:

\[ P_{\text{total}} = P_1 + P_2 \]  

(3)

When determining the head, it is necessary to take into account the total (static) head and the working (dynamic) head. Total head is the vertical distance between the top of the supply pipe (water intake mark) and the point where water is released from the turbine.

The operating head is the total head minus head or hydraulic losses due to friction and turbulence in the pipeline.

These losses depend on the type, material of the pipe, diameter, length of the pipe, number of bends, etc. To determine the actual power, it is recommended to calculate the working head \( H \).

\[ H = H_{\text{total}} - h_{\text{fr,los}} - h_{\text{ad,los}} \]  

(4)

where: \( h_{\text{fr,los}} \) - friction losses in the conduit; \( h_{\text{ad,los}} \) - additional or local losses associated with clogging of the water intake, bifurcation at constrictions and expansions, gate valves, valves, etc. The magnitude of the head loss due to friction in the conduit can be determined by the expression:

\[ h_{\text{fr,los}} = JL \]  

(5)

where: \( J \) - hydraulic gradient, \( L \) - conduit pipe length

The following practical formula can be used to determine the hydraulic gradient:

\[ J = \alpha V D \]  

(6)

where: \( V \) - flow velocity, \( D \) - diameter of the conduit pipe, \( \alpha \) - coefficients of the material from which the conduit is made.

Additional or local losses in the conduit pipe are determined from the expression:

\[ h_{\text{ad,los}} = \varepsilon_x \frac{V^2}{2g} \]  

(7)

where: \( \varepsilon_x \) - hydraulic resistance
References:


METHOD FOR CALCULATING THE LEVEL OF ENAMELLING AND TEMPERATURE CONDITIONS ON CURRENT CONDUCTORS AT DIFFERENT SPEEDS IN CABLE PRODUCTION PROCESSES

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ABSTRACT
The article presents a methodology for calculating the level of enameling and temperature conditions on conductors at various speeds in the processes of cable production. The technique is intended for solving the analytical problem of specific temperature heating of insulating varnish, which is the determination of the amount of application of protective coatings using heat treatment in the furnace enamel. The functionality of the technique makes it possible to calculate the technological process of the degree of enamel application on current-carrying parts to solve the problem of the degree of baking of wire enamel insulation, and as a result of which an insulating coating is formed for exploiting the insulating capacity of current-carrying parts of electrical installations. Allows you to increase the energy and resource saving of electrical installations, due to the smooth temperature control and increases the energy efficiency of this equipment.

АННОТАЦИЯ
В статьи приведено методика расчета уровня эмалирования и температурных режимов на токопроводах при различных скоростях в процессах кабельного производства. Методика предназначена для решения аналитических задач удельных температурных нагревов изоляционного лака, представляющей собой определение количества...
Wire enamelling is the application of liquid varnish to the surface of the wire, followed by heat treatment in an enamel oven, which results in the formation of an insulating coating. The quality of the resulting insulating coating depends on the physicochemical properties of the lacquer, on the quality of the surface of the enamelled wire, and on the correct modes of applying the lacquer to the wire, followed by heat treatment [1-3].

The productivity of the wire enamelling process and the quality of the resulting wires are largely determined by the temperature conditions of the enamel furnace. Round enamelled wires are usually made in the range of diameters from 0.05 to 2.5 mm, while the minimum insulation thickness (on one side) is on average, respectively, from 0.005 to 0.035 mm (PEV-2, PETV-2). The insulation is applied in 5-12 passes through the varnishing unit and the heat treatment oven.

When a wire with a layer of varnish applied to it is heated, the solvent is first removed, during which energy is spent on its evaporation. This energy should be taken into account when calculating the heating of the wire, especially if the wire diameter is less than 0.1 mm.

The heating of the wire occurs both due to the heat input during convective heat exchange with hot air \( q_a \), and during heat exchange by radiation from the walls of the furnace chamber \( q_r \). Convective heat transfer is the transfer of heat during the movement of a liquid or gas. Convective heat transfer is always accompanied by heat conduction, so one of the problems encountered in solving problems of convective heat transfer is the problem of assessing the influence of each of the two heat transfer mechanisms. Determination of the contribution of thermal conductivity and convection to the overall process of heat transfer greatly facilitates the construction of a mathematical model of the process under study [4-5].

Convective heat transfer - convective heat transfer between the surface of a solid body and a liquid. The calculation of the heat transfer process is based on the ratio of the Newton–Richmann law:

\[
dQ_c = \alpha (T_c - T_w)dF
\]  

where \( \lambda \) - the coefficient of thermal conductivity of the gas; \( \beta \) - the gas volume expansion coefficient; \( \Delta T \) - the temperature difference between the wire and the gas; \( v \) - the coefficient of kinematic viscosity of the gas; \( \Pr \) - the Prandtl criterion; \( d \) - the wire diameter.

The use of equation (3) for practical calculations is difficult, since most of the quantities included in it are variables that depend on the air temperature \( \lambda, \beta, v, \Pr \) or on the temperature difference between the wire and air \( \Delta T \).

Convective heat transfer coefficient \( \alpha \) is called the heat transfer coefficient (measured in W/(m²·K)). Transforming relation (1), we obtain:

\[
\alpha = \frac{\Delta T}{\frac{dQ_c}{F}} = \frac{q}{\Delta T}
\]  

Relation (2) allows us to determine the heat transfer coefficient as the heat flux density \( q \) at the boundary of the liquid (gas) and the body being washed, referred to the temperature difference between the surface of this body and the environment. The calculation of convective heat transfer is associated with the determination of the heat transfer coefficient

If we take into account that the heat transfer from the heated gas to the wire in enamel furnaces occurs under conditions close to heat transfer with the free movement of the coolant, then using the criterion similarity equations, we can obtain an expression for the convective heat transfer coefficient:

\[
\alpha = 1,18(\lambda\beta\Delta T/\rho v^{0,625})^{1,25} (3)
\]  

where \( \lambda \) - the coefficient of thermal conductivity of the gas; \( g \) - the acceleration of the composite fall; \( \beta \) - the gas volume expansion coefficient; \( \Delta T \) - the temperature difference between the wire and the gas; \( v \) - the coefficient of kinematic viscosity of the gas; \( \Pr \) - the Prandtl criterion; \( d \) - the wire diameter.

The use of equation (3) for practical calculations is difficult, since most of the quantities included in it are variables that depend on the air temperature \( \lambda, \beta, v, \Pr \) or on the temperature difference between the wire and air \( \Delta T \).

When enameling a wire, both the air temperature and the temperature of the wire change over a wide range; in addition, when solving a number of practical problems, the gas temperature along the length of the furnace, as well as the wire temperature, which must be known to determine \( \Delta T \), are not known in advance.

**Keywords:** enameling, temperature regime, cable products, thermal energy, wire, enameling speed.

**Ключевые слова:** эмалирование, температурный режим, кабельная продукция, тепловая энергия, проволока, скорость эмалирования.
The problem can be simplified by introducing a new notation into the equation

\[ E = \frac{g\beta\Delta T r^{0.125}}{k^{0.625}} \]  

(4)

then

\[ \alpha = \frac{1.18}{d^{0.625}}E \]  

(5)

The value of E is a function of the temperature of the gas and wire. Despite the change in air and wire temperature, within a wide range, the value of E along the height of the enamel oven does not change much and averages 0.39, and when enameled with polyester varnishes, E = 0.41. Similar calculations when using polyurethane varnishes give E = 0.38.

Thus, under different thermal conditions of enameling, the value of E changes insignificantly. In this regard, for the conditions of wire enameling, we can take the average value of \( E_{cp} = 0.39 \). Taking into account \( E_{cp} \) and equation (3), one can obtain a simple formula for \( \alpha_{cp} \)

\[ \alpha = 0.47/\alpha_{cp} \]  

(6)

Calculations by (6) give an error with respect to the values obtained by (3) within \( \pm 6\% \). It should be emphasized that according to (6) the average value of \( \alpha_{av} \) is determined in the process of heating the wire.

Comparison of the \( \alpha_{cp} \) values obtained by (6) with the experimental data shows that the calculated and experimental results are quite close.

The heat input due to convection is determined by the formula

\[ q_c = p\alpha_c(T_b - T_w). \]  

(7)

where \( p \) - the outer perimeter of the wire; \( T_b \) - air temperature in the furnace chamber; \( \alpha_c \) - the heat transfer coefficient.

The heat input due to radiation thermal

\[ q_r = p\alpha_r(T_c - T_w) = \rho\varepsilon\varphi_{cp}C_{\text{d}}(\frac{1}{T_b^4} - \frac{1}{T_c^4}), \]  

(8)

where \( \alpha_r = \rho\varepsilon\varphi_{cp}C_{\text{d}}; T_c \) - the temperature of the furnace chamber walls; \( C_{\text{d}} = 5.7\times10^{-8} \text{ Jmk}^{-1}\text{K}^{-2} \) - absolute black body radiation constant; \( \varepsilon \text{d} = 0.05 \ldots 0.1 \) is the emissivity of the surface of pure metals; \( \varphi_{cp} = 0.8 \ldots 0.9 \) - angular coefficient of wire ir-radiance.

If \( d > 0.1 \text{ mm} \), then in furnaces without forced gas convection (old designs), the gas velocity is low, and formulas (7) are used to calculate the coefficient \( \alpha_k \). With free convection

\[ \alpha_k = 0.47d^{0.625} \]  

(9)

At an air velocity of more than 0.5 m/s in furnaces with forced circulation of gases, the formula is used

\[ \alpha_f = 1.43v^{0.41}d^{0.59} \]  

(10)

\( v_s \) - air velocity, m/s. In the furnace chamber of enamel units, hot air moves at a significant speed (from 0.2 to 5 m/s), so the temperature difference between the air and the heated inner walls of the furnace can reach several tens of degrees. To measure the air temperature in the furnace, a thermocouple is pulled through and some effective temperature of the thermocouple sensor is determined, which differs from the air temperature in the furnace.

If a stationary thermocouple is placed in the furnace chamber, then

\[ q_n + q_i + q_p = q_{rst}, \]  

(12)

where \( q_n, q_i, q_p \) - the consumption of thermal energy for heating the metal of the wire, the enamel layer and removing the solvent.

The energy consumption for heating the wire metal and enamel per unit length of the wire is:

\[ q_n = (C_n + C_a)\Delta T_d/\Delta t = k_nC_n\Delta T_d/\Delta t, \]  

(13)

energy consumption for solvent removal:

\[ q_p = -r_dG_p/\Delta t = -r_pS_d\mu W/\Delta t, \]  

(14)

where \( T_n \) - the temperature of the wire.

The consumption of thermal energy for heating the enamel film to the boiling point of the solvent \( T_n \) and its evaporation per unit length of the wire is:

\[ q_s = m_s(T_n - T_{boiling}) = m_s(T_n - T_r + x_r). \]  

(15)
Let us determine the consumption of thermal energy for heating the metal of the wire and the enamel film per unit of its length:

\[ q_u = m_u c_u \Delta T_u = \pi / 4 d^2 \rho_u c_u \Delta T_u, \quad (16) \]

\[ q_1 = m c_s S, \quad (17) \]

where \( S_u \) and \( S_e \) are the cross section of metal and enamel; \( c_u \) and \( c_e \) - their specific heat capacities; \( W, x \) - respectively, the mass of the solvent and its proportion contained in the enamel; \( S_e \) is the section of the enamel layer applied in one pass; \( \rho_e \) - enamel density; \( T_u \) - the specific heat of evaporation of the solvent from the lacquer.

If the temperature in the leak were maintained constant and greatest along the entire length of the heating zone, then \( T_u \) in equation (11) would not depend on the length of the furnace. Under these conditions, this equation takes the form

\[ T_u = T_s - (T_s - T_n) e^{-\mu t}, \quad (18) \]

where \( T_s \) is the initial temperature of the wire when it enters the furnace; \( t \) - the time spent by the wire at a constant temperature \( T_s \); \( 1/\mu = \tau \) - wire heating time constant.

For rectangular wire

\[ \mu = \alpha P / k c_u S \rho_u, \quad (19) \]

For round wire

\[ \mu = 4 \alpha / k c_u \rho_u, \quad (20) \]

where \( \alpha = \alpha_u + \alpha_e; k = 1 \) dimensionless coefficient.

As the wire is heated, its temperature will reach the specific heat of evaporation of the solvent from the lacquer. With further heating of the wire in the area from \( x = L_1 \) to \( x = L \) (L is the total length of the furnace), the process of film formation occurs. At the end of heating, at \( x = L \), the temperature of the wire is maximum, \( T_e = T_{e_{max}} \).

Since the air temperature along the length of the furnace is in practice unevenly distributed, therefore, equation (15) makes it possible to calculate only an approximate value of the wire temperature in each section of the furnace. The greatest difference between the temperature of the wire and its calculated value will take place in the initial heating section.

In the literature, there is a method for calculating the temperature of the wire and the average rate of its heating based on the degree of completion of the baking process. With a linear law of temperature change in the areas of solvent evaporation and film formation, the total residence time of the wire in the furnace \( t = L / v \) and the enameling rate \( v \) are determined

\[ v = L \mu (T_s - T_n) / (T_s - T_e). \quad (21) \]

The above equation gives an underestimated enameling rate, which is mainly due to an underestimated value of \( T_e \).

**Determination of thermal parameters of enameling wires PET 155 with a diameter of 1.25 mm**

We determine the coefficient of convective heat transfer by the formula (10):

\[ \alpha_c = 1,43 \nu_0^{0.41} t^{0.59} \]

where \( \nu_0 = 1 \text{ m/s} \) is the air velocity in the furnace; \( d = 1.25 \) - enamelled wire diameter, mm; then

\[ \alpha_c = 1,43 \cdot 1^{0.41} (1.25 \cdot 10^{-3})^{0.59} = 73.8 \text{ Bt/m}^2 \cdot ^\circ C \]

We determine the radiation coefficient based on formula (11) for the stationary mode:

\[ \alpha_r = (T_u - T_s) + \alpha_c (T_e - T_s) = 0, \]

\[ \alpha_r = (T_u - T_s) + \alpha_c (T_e - T_s) = 73.8 \text{ (500-525)/(550-525)} = 73.8 \text{ Bt/m}^2 \cdot ^\circ C, \]

We find the constant of the heating rate of the wire \( \mu \) according to the equation (20):

\[ \mu = 4 (\alpha / \alpha_u) k c_u d = 4 \cdot (73.8 + 73.8) / 1 \cdot 385 \cdot 1.25 \cdot 10^{-3} = 1227.1 \text{ kg/s} \]

where \( c_u = 385 \text{ Дж/кг·К} \) - удельная теплоемкость меди; \( k = 1 \) - безразмерный коэффициент; \( d = 1.25 \text{ мм} \) - диаметр провода.

The time constant for heating a wire with a diameter of 1.25 mm is:

\[ \tau = 1 / \mu = 1 / 0.138 = 7.25 \text{ c} \]

Let's determine the amount of heat to heat 1 m of copper wire to a temperature \( T_{max} = 525 \)

\[ q_u = c_u m_u (T_{max} - T_u) = c_u m_u \pi R^2 \Delta (T_{max} - T_u) = 385 \cdot 8900 \cdot 3.14 \cdot (0.625 \cdot 10^{-3})^2 \cdot 1 \cdot (525 - 252) = 2101 \text{ J} \]

where \( m_u \) - the mass of 1 m of wire, kg.

Let's determine the amount of heat to heat 1 m of the enamel film to a temperature of \( T_{max} = 525 \text{ °C} \):

\[ q_e = c_e m_e (T_{max} - T_u) = c_e m_e \pi R^2 \Delta = 1300 \cdot 1200 \cdot 3.14 \cdot 0.625 \cdot 10^{-3} \cdot 1 \cdot 1 \cdot 10^{-3} \cdot (525 - 252) = 30.6 \text{ J} \]

where \( m_e \) - the mass of enamel on a wire length of 1 m, kg; \( \rho_e, c_e \) - density specific heat of enamel; \( \Delta \) is one-sided enamel thickness.
Let us determine the amount of heat for the evaporation of the solvent over a wire length of 1 m:

\[ q'_{\text{pen}} = m_{\text{pen}} q_{\text{pen}} = \rho_p S l q_{\text{pen}} = 1030 \cdot 3.14 \cdot 1.25 \cdot 1 \cdot 10^{-5} \cdot 1 \cdot 420 = 16.98 \text{ J}, \]

where \( m \) - the mass of the solvent per 1 meter of wire, kg; \( \rho_p \) - the density of the solvent (Tricresol technical coal); \( q_{\text{pen}} \) - the specific heat of evaporation of the solvent. However, in real conditions, the enamel film contains from 60 to 65% of the solvent, then

\[ q_{p} = 60...65 \%; q'_{p} = 0.6 \cdot 16.98 = 10.19 \text{ J}. \]

In table. 1 shows the calculated data on thermophysical properties for a wire diameter of 1.25 mm.

### Table 1.

<table>
<thead>
<tr>
<th>Parameter name</th>
<th>Parameter value, for wire diameter</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1.25 mm</td>
</tr>
<tr>
<td>Convective heat transfer coefficient, W/m²</td>
<td>73.8</td>
</tr>
<tr>
<td>Emissivity, W/m²</td>
<td>73.8</td>
</tr>
<tr>
<td>Wire heating rate constant ( \mu ), c⁻¹</td>
<td>0.138</td>
</tr>
<tr>
<td>The amount of heat required to heat 1 m of wire, J</td>
<td>2101</td>
</tr>
<tr>
<td>The amount of heat required to heat the enamel per 1 m of wire, J</td>
<td>30.6</td>
</tr>
<tr>
<td>The amount of heat required to evaporate the solvent, J</td>
<td>10.19</td>
</tr>
</tbody>
</table>

**Calculation of the temperature of a wire with a diameter of 1.25 mm along the length of the furnace in a vertical line type "YL 7100" for various enameling speeds**

The calculation of the temperature distribution of the wire with a diameter of 1.25 mm along the length of the furnace passage is carried out according to the formula (18). We divide the air temperature distribution curve in the furnace into time intervals (Fig. 1) and calculate the wire temperature in sections for an enameling speed of 25 m/min. Formula (1) is valid for a stationary mode, that is, when the air temperature in the furnace has a constant value and does not change along the entire length. However, in real conditions, the air temperature in the furnace is not constant and has a non-linear distribution (Fig. 1). In contrast to the Kholodny method, in order to increase the accuracy when calculating the wire temperature, we divide the air temperature distribution curve into sections with a duration of 0.6 s. That is, we replace the curve with a stepped distribution (Fig. 1), and in each section we find the average value of the air temperature \( T_r \). Then the initial temperature of the wire at the entrance to the next section \( T_n \) will be equal to the temperature of the wire at the end of the previous section. At an enameling speed of 25 m/min, an elementary section of wire passes through the furnace in 14.4 s. We divide the curve into sections with a duration of 0.6 s (Fig. 1) and for each section we calculate the temperature of the wire at the exit from this section according to expression (1).
For the initial heating section of the wire \((t_0)\) over a length of 0...25 cm, the initial data are:

\[
t_0 = 0...0.6 \text{ c}, \quad T_i = 40 \degree \text{C}, \quad T_u = 22 \degree \text{C}, \quad \mu = 0.138 \text{ c}^{-1}, \text{ then } \]

\[
T_u = T_i - (T_i - T_u) e^{\mu t} = 40 - (40 - 22) e^{0.138 \cdot 0.6} = 23 \degree \text{C}
\]

For the first \((t_1)\) section:

\[
t_1 = 0.6...1.2 \text{ c}, \quad T_i = 80 \degree \text{C}, \quad T_u = 23 \degree \text{C}, \quad \mu = 0.138 \text{ c}^{-1}, \text{ then } \]

\[
T_u = T_i - (T_i - T_u) e^{\mu t} = 80 - (80 - 23) e^{0.138 \cdot 0.6} = 28 \degree \text{C}
\]

For the second \((t_2)\) section:

\[
t_2 = 1.2...1.8 \text{ c}, \quad T_i = 175 \degree \text{C}, \quad T_u = 28 \degree \text{C}, \quad \mu = 0.138 \text{ c}^{-1}, \text{ then } \]

\[
T_u = T_i - (T_i - T_u) e^{\mu t} = 80 - (80 - 28) e^{0.138 \cdot 0.6} = 40 \degree \text{C}
\]

For the third \((t_3)\) section:

\[
t_3 = 1.8...2.4 \text{ c}, \quad T_i = 227.5 \degree \text{C}, \quad T_u = 40 \degree \text{C}, \quad \mu = 0.138 \text{ c}^{-1}, \text{ then } \]

\[
T_u = T_i - (T_i - T_u) e^{\mu t} = 227.5 - (227.5 - 40) e^{0.138 \cdot 0.6} = 55 \degree \text{C}
\]

The results of \(T_p\) calculations for enameling speeds of 25 and 20 m/min are presented for all subsequent sections in Table. 2. Similarly, we divide the air temperature distribution curve in the oven into time intervals and perform the calculations indicated above for any enameling speeds. On Fig. 2 shows temperature dependences of PET 155 wire with a diameter of 1.25 mm along the length of the furnace of the YL 7100 enamel unit for various enamelling speeds.

Based on the calculated data, the dependences of the maximum wire temperature on the enameling rate for a wire with a diameter of 1.25 mm are plotted.

The results of \(T_p\) calculations for enameling speeds of 25 and 20 m/min are presented for all subsequent sections in Table. 2. Similarly, we divide the air temperature distribution curve in the oven into time intervals and perform the calculations indicated above for any enameling speeds. On Fig. 2 shows temperature dependences of PET 155 wire with a diameter of 1.25 mm along the length of the furnace of the YL 7100 enamel unit for various enamelling speeds.

Based on the calculated data, the dependences of the maximum wire temperature on the enameling rate for a wire with a diameter of 1.25 mm are plotted.

\[\text{Figure 2. Temperature distribution of a wire with a diameter of 1.25 mm along the length of the furnace "YL 7100" at various enameling speeds, m/min: 1 – 25; 2 – 20; 3 – 15; 4 – 10}\]

From fig. 2 it follows that with an increase in the enamelling rate, the wire heats up more slowly and its maximum temperature decreases. This is due to the fact that the higher the enamelling speed, the shorter the time it is in the oven, being subjected to less temperature stress.

If the enamelling rate is slow, the wire will stay in the oven for too long and its insulation will age quickly due to the high temperatures in the oven. However, if the enamelling speed is too high, the wire will not have time to heat up enough, the rate of the chemical reaction will slow down and, consequently, the degree of completion of the process of structuring the enamel coating will decrease. In both cases, the wire will not meet the necessary requirements. It is necessary to choose an enamelling speed at which the wire would withstand all the foreseen tests on the product and ensure the rational use of materials and electricity. From the foregoing, the most energy-intensive system is temperature control, since the installation does not provide for smooth temperature control and the task is to increase both the reliability and energy efficiency of this equipment.
References:


ALGORITHM FOR DETERMINING THE NOSINUSOIDALITY COEFFICIENT OF ELECTRICAL QUALITY INDEX FOR WELDING EQUIPMENT

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ABSTRACT

In this state description of the quality of electricity, voltage non-sinusoidality, the percentage limit of the non-sinusoidal coefficient at rated voltages, formulas for finding harmonic currents of DC and AC electric arc welding machines. An algorithm has been developed for determining the total coefficient of supply network nonlinearity during the operation of electric arc welding equipment, developed on the basis of the formula.

KEYWORDS: power quality indicators, GOST 13109-97, voltage nosinusoidality, electric arc welding equipment, higher harmonics, algorithm, coefficient of nosinusoidality

АЛГОРИТМ ОПРЕДЕЛЕНИЯ КОЭФФИЦИЕНТА НЕСИНУСОИДАЛЬНОСТИ ЭЛЕКТРИЧЕСКОГО КАЧЕСТВА СВАРОЧНОГО ОБОРУДОВАНИЯ

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АННОТАЦИЯ

В данной государственной описания качества электроэнергии, носинусоидальности напряжения, процентный предел коэффициента носинусоидальности при номинальных напряжениях, формулы для нахождения гармонических токов аппаратов электродуговой сварки постоянного и переменного Разработан алгоритм определения суммарного коэффициента нелинейности питающей сети при работе оборудования электродуговой сварки, разработанного на основе формулы.

Ключевые слова: показатели качества электроэнергетики, ГОСТ 13109-97, носинусоидальность напряжения, электродуговой сварки оборудования, высшие гармоники, алгоритм, коэффициент носинусоидальности

As a result of accelerating production processes, improving and introducing new technologies, valve converters, single-phase and three-phase electric welding equipment, high-power electric arc and contact welding equipment, volt-ampere nonlinear loads are increasingly used. Power transformers, magnetic amplifiers and gas discharge lamps have such features. The feature of these devices is that they consume nonsinusoidal currents in the network when a sinusoidal voltage is applied to their terminals.

Nonsinusoidal current curves can be considered as complex harmonic oscillations consisting of a set of simple harmonic oscillations of different frequencies. The high harmonic currents flowing through the network elements lead to a voltage drop across the resistance of these elements, which, in addition to the main sinusoidal voltage, distorts the shape of the voltage curve, deteriorating the quality of electricity in the supply network, i.e. an electromagnetic compatibility problem is created with the power supply.

Nonsinusoidal voltage is characterized by the following parameters:

- Nonsinusoidal distortion coefficient of voltage sinusoid $K_u$;
- The coefficient of the nth harmonic component of the voltage is $K_{u(n)}$.

The distortion coefficient of the voltage sinusoid is determined by the ratio of the base value of the harmonic composition of the nonsinusoidal voltage to the base frequency voltage:

$$K_u = \frac{\sum_{n=1}^{\infty} u_n^2}{U_{nom}} \cdot 100\% \approx \frac{\sum_{n=1}^{\infty} u_n^2}{U_{nom}} \cdot 100\% \quad (1)$$

where $U_{nom}$ is the voltage value of the nth harmonic; $n$ is the number of the last recorded harmonics.

It is allowed to exclude harmonics with a value of less than 0.1% in the calculation of $K_u$.

The normal allowable and maximum allowable values of the voltage sinusoidal distortion coefficient in different voltage power grids [2] are given in Table 1 as a percentage.

### Table 1.

<table>
<thead>
<tr>
<th>Normal allowable values, $U_{nom}$, kV</th>
<th>Allowable threshold values, $U_{nom}$, kV</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.38 6...20 35 110...220</td>
<td>0.38 6...20 35 110...330</td>
</tr>
<tr>
<td>8.0 5.0 4.0 2.0</td>
<td>12.0 8.0 6.0 3.0</td>
</tr>
</tbody>
</table>

Permissible values of the coefficient of the nth harmonic component of the voltage at the common connection points to the power grids of different nominal voltage $U_{nom}$ are given in Table 2 (in percent).

### Table 2.

<table>
<thead>
<tr>
<th>$U_{nom}$ Single harmonics not exceeding 3, kV</th>
<th>$U_{nom}$ Single harmonics exceeding 3, kV</th>
<th>$U_{nom}$ couple harmonics, kV</th>
</tr>
</thead>
<tbody>
<tr>
<td>n 0.38 6...20 35 110...330</td>
<td>n 0.38 6...20 35 110...330</td>
<td>n 0.38 6...20 35 110...330</td>
</tr>
<tr>
<td>5 6.0 4.0 3.0 1.5</td>
<td>3 5.0 3.0 1.5 1.5</td>
<td>2 2.0 1.5 1.0 0.5</td>
</tr>
<tr>
<td>7 5.0 3.0 2.5 1.0</td>
<td>9 1.5 1.0 1.0 0.4</td>
<td>4 1.0 0.7 0.3 0.3 0.3</td>
</tr>
<tr>
<td>11 3.5 2.0 2.0 1.0</td>
<td>15 0.3 0.3 0.3 0.3</td>
<td>6 0.5 0.3 0.3 0.2 0.2</td>
</tr>
<tr>
<td>13 3.0 2.0 1.5 0.7</td>
<td>21 0.2 0.2 0.2 0.2</td>
<td>8 0.5 0.3 0.3 0.2 0.2</td>
</tr>
<tr>
<td>17 2.0 1.5 1.0 0.5</td>
<td></td>
<td>10 0.5 0.3 0.3 0.2 0.2</td>
</tr>
<tr>
<td>19 1.5 1.0 1.0 0.4</td>
<td>12 0.2 0.2 0.2 0.2 0.2</td>
<td>12 0.2 0.2 0.2 0.2</td>
</tr>
<tr>
<td>23 1.5 1.0 1.0 0.4</td>
<td></td>
<td>12 0.2 0.2 0.2 0.2</td>
</tr>
<tr>
<td>25 1.5 1.0 1.0 0.4</td>
<td></td>
<td>12 0.2 0.2 0.2 0.2</td>
</tr>
</tbody>
</table>

The normal values given for $n = 3$ and 9 belong to single-phase networks. In three-phase networks, it is taken as half of the values given in Table 2.

The allowable limit values of the n-th harmonic component are 1.5 times higher than those shown in Table 2.

According to their impact on the non-sinusoidal of the supply network, welding loads can be divided into two categories: installations for arc and resistance electric welding of alternating current, installations for electric arc welding of direct current.
Figure 1. Algorithm for determining the nosinusoidality coefficient in the network for welding equipment
In the general case, for a single installation of AC electric welding, the harmonic currents (it is recommended to take into account only the third and fifth harmonics [6]) are equal to:

\[ I_n = \frac{S_{nom}}{n} \sqrt{\frac{PV}{2}} \frac{\beta_{CV}}{n^2 U_{nom}^2} \]

Here \( S_{nom} \) is the nominal power of the transformer, \( \beta_{CV} \) is the load factor; \( PV \) - duration of inclusion.

The definition of harmonic currents generated by DC electric arc welding installations is similar to the definition of harmonics for valve converters. Harmonic currents (it is recommended to take into account only the 5th, 7th, 11th, 13th harmonics) of a single installation of DC electric arc welding are determined by the formula

\[ I_n = \frac{I_{SV}}{n} \]

where \( I_{SV} \) is the rated primary current of the installation.

For a group of electric welding installations, regardless of the operating mode, the total individual harmonic currents are determined according to [6]

\[ I_{n, r} \approx \sqrt{\sum_{i=1}^{N} I_{n_i}^2} \]

where \( I_n \) is the current of the n-th harmonic of the i-th installation; \( N \) is the total number of operating installations.

To assess the impact of welding loads on the enterprise network, the overall coefficient of non-sinusoidal is determined by the formula, %,

\[ k_U = \frac{\sqrt{\sum_{i=1}^{N} U_{i, r}^2}}{U_{nom}} \times 100 \]

Here \( U_n = \frac{\sqrt{\sum_{i=1}^{N} U_{i, r}^2}}{S_K} \) is the voltage of the n-th harmonic.

Algorithms are used to generalize the sequence of technological processes. The following is an algorithm for determining the nosinusoidality coefficient in a network of welding equipment. Based on this algorithm, the sequence of determining the coefficient of nosinusoidality of voltage in a network connected to alternating current and constant current welding devices is expressed.

In this case, according to the initial data, using formulas (2,3,4,5,6) n-3, 5 harmonic currents \( I_n \) for alternating current welding equipment are determined. Determines the harmonic voltages of n-3, 5 under the influence of the welding machine on the mains. To assess the effect of the welding device on the quality of electricity, the total coefficient of nosinusoidality is determined.

When the nominal voltage is \( U_{nom} \leq 0.38kV \), the nosinusoidality coefficient in the power grid is equal to \( Ku \leq 8\% \), the nosinusoidality coefficient in the power grid is normal, if not equal, the filter device in the power grid installation is recommended. When the nominal voltage is \( 6 \leq U_{nom} \leq 20 \), when the nosinusoidality coefficient in the power grid is equal to \( Ku \leq 5\% \), the nosinusoidality coefficient in the power grid is normal, if not equal, the filter device in the power grid installation is recommended. When the nominal voltage is \( U_{nom} \leq 35 \), when the nosinusoidality coefficient in the power grid is equal to \( Ku \leq 4\% \), the nosinusoidality coefficient in the power grid is normal, if not equal, the filter device in the power grid installation is recommended. When the nominal voltage is \( 110 \leq U_{nom} \leq 220 \), when the nosinusoidality coefficient in the power grid is equal to \( Ku \leq 2\% \), the nosinusoidality coefficient in the power grid is normal, if not equal, the filter device in the power grid installation is recommended. When the nominal voltage is \( U_{nom} \geq 220 kV \), the voltage is not checked for nosinusoidality coefficient.

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POWER, METALLURGICAL AND CHEMICAL ENGINEERING

ENERGY-SAVING "PYROLYSIS OVEN"
AND ITS MAIN ADVANTAGES AND DISADVANTAGES

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ABSTRACT

This article presents methods for determining the energy efficiency of pyrolysis furnaces used in heating systems, and an analysis of the efficiency, advantages, and disadvantages of pyrolysis furnaces.

Keywords: pyrolysis, heating system, furnace, efficiency, energy efficiency.

Introduction

It is known that the pyrolysis process is used in the chemical industry as the main technology for the production of products, as an energy-saving technology for heating buildings and structures in housing and communal services. In the oil industry, pyrolysis is the only technology for the separation of some products, but it is the process that ensures the optimal combustion of combustible products in heating devices [1-2]. The complex gas released during the pyrolysis process was actively used as a fuel for internal combustion engines in the 30s to 60s of the last century [1]. Today, pyrolysis gas is still used as a fuel for forestry vehicles. Pyrolysis furnaces for heating homes on individual farms are notable for their ease of operation and low fuel consumption[2]. In Central Asia, pyrolysis furnaces are almost never used in individual systems of households and small enterprises and institutions. In areas with limited natural gas resources, along with solar installations and micro-hydro power plants [3-8, 22-25], complexes of pyrolysis furnaces and gas generators operating on this energy-saving technology can solve the problem of electricity and natural gas shortages [1]. Therefore, the study of these pyrolysis furnaces and gas generators can be considered a topical issue.

Research method

For 70 years, various scientific research has been carried out at the Fergana Polytechnic Institute in the fields of technology, such as economics, chemistry, construction, mechanics, energy, electronics,
instrumentation, specific research methods have been developed and applied [9-25]. We use process analysis when choosing a research method to successfully solve a given problem.

A pyrolysis furnace is the main energy source of the heating system, its energy efficiency is determined by determining the consumption of the "conventional fuel unit", calculating the energy balance of the heated object, and integrated assessment of the amount of energy required to maintain this energy balance in changing natural conditions methods. The final integral is needed to determine the energy capacity of the pyrolysis furnace (in terms of heat). It is also necessary to take into account the heat and electricity consumed by the control system.

It is known that it is not possible to directly measure the heat energy given off by a fuel product during combustion, this energy can only be found by multiplying the relative combustion heat of that fuel by the weight of the fuel. Typically, the relative heat of combustion of the fuel is obtained from references and different GOSTs for different fuels, for example, GOST 10062-75 - for natural gas, 21261-91 - for liquid petroleum products, 147-95 - for coal, for peat and others. However, given that the composition of the fuel used in practice is constantly changing, and that the heat energy that this composition produces during combustion also changes, the amount of energy calculated is approximate. Nevertheless, we need to evaluate the energy efficiency of the pyrolysis furnace. To solve this problem, experimentally determine the weight of the energy-supplying fuel that provides the energy balance of the heated object and calculate the energy consumption by multiplying the relative combustion heat of that amount of fuel by the weight of the fuel, and finally, the ratio of energies can be calculated. The size obtained by this method depends on the heating system tested, but mainly on the energy efficiency of the furnace under test.

Of course, an artificial heating system can be used as the object of the above experiment, but it is preferable to use a real object because this experiment is associated with much higher energy consumption.

The difference between pyrolysis furnaces and conventional furnaces is that the combustion process in this furnace consists of two stages, in the first stage the coking produces solid residues of fuel and gas, and in the second stage, the solid residues of the separated gas and fuel are completely burned.

This type of stove burns the wood completely and produces very little ash. As a result, the fuel burns in the pyrolysis furnace for a long time. In practice, the ash from such furnaces is cleaned once every few days.

In addition, the useful life of any heating system is several decades, during which time it is desirable to use the literature data to account for large-scale changes in the operating modes of the heating system due to climate change.

So, we choose the data analysis method as the research method.

According to the manufacturers, medium-capacity (10-20 kW) furnaces installed in a 100 m² apartment building can burn 10-12 hours of fuel per refill. Daily fuel consumption can be 10-11 kg of solid wood. Compared to conventional furnaces, this is 2 or more times the fuel-saving efficiency.

Depending on the moisture content of the fuel, this efficiency varies widely:

- burning 1 kg of wood with a moisture content of 20% - 4 kW
- burning 1 kg of wood with a moisture content of 50% - provides 2 kW of power.

Advantages of pyrolysis furnaces:
- High fuel efficiency due to long and complete combustion
- Environmental safety, which emits very little smoke, mainly SO and water vapor, resulting in clean and dry smoke ducts,
- The fuel heats up very quickly.
- Has a high efficiency (85% - 90%).
- Ability to operate in a large power range (5% to 100% of maximum power).
- Possibility to connect to any heating system - with natural circulation and forced circulation.
- Possibility to use different types of fuel, solid wood, liquid fuel ...
- Ease of use, once a day wood burning and once a few days ash removal.

These ovens have the following disadvantages:
- The size is too big.
- Need a place to store firewood.
- Water pump, fan, and thermocouple are required for proper operation and control, which in turn creates an electrical connection.
- Condensate can build up in the smoke path, so the smoke path needs heat protection.

Pyrolysis furnaces are divided into two depending on the type of smoke:
- natural smoke extraction;
- Compulsory smoking.

Natural smoke extraction is created using a high smoke extraction pipe. Forced smoke extraction is generated using an electric motor fan. Forced smoke weighing furnace is more efficient but depends on electricity.
Figure 1. Construction of a long-burning pyrolysis furnace

The following are the disadvantages and advantages of forced and natural smoke kilns:

<table>
<thead>
<tr>
<th>Smoke</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compulsory</td>
<td>1. The combustion chamber and the heating system heat up quickly</td>
<td>Depends on electricity</td>
</tr>
<tr>
<td></td>
<td>2. Accelerates the transition to pyrolysis</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3. Combustion products come out of the oven quickly</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4. Pyrolysis and combustion process is controlled automatically</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5. The combustion time of the fuel is large</td>
<td></td>
</tr>
<tr>
<td>natural</td>
<td>1. Relatively easy to use</td>
<td>1. Needs to be cleaned relatively often</td>
</tr>
<tr>
<td></td>
<td>2. breakdown are rare</td>
<td>2. The installation cost is high</td>
</tr>
<tr>
<td></td>
<td>3. The price is much cheaper</td>
<td></td>
</tr>
</tbody>
</table>

Conclusion

With the advantages and disadvantages listed above, these stoves are the second most energy-efficient after gas heating systems.

References:


ДЛЯ ЗАМЕТОК