Строительство уникальных зданий и сооружений. ISSN 2304-6295. 3 (66). 2018. 30-40


Construction
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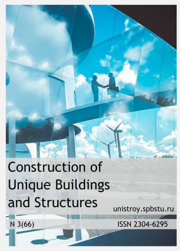
journal homepage: www.unistroy.spbstu.ru`




doi: 10.18720/CUBS.66.3

# Protective coatings of reinforced cooling towers

# Устройство защитных покрытий железобетонных башенных градирен

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**КЛЮЧЕВЫЕ СЛОВА**

железобетонная градирня;
антикоррозионное покрытие;
расчет расхода материалов;
экономический расчет;
сравнение вариантов

**KEYWORDS**

reinforced concrete cooling tower;
anticorrosion coating;
calculation of materials consumption;
economic calculation;
comparison of options;

**ИСТОРИЯ**

Подана в редакцию: 08.02.2018
Принята: 13.05.2018

**ARTICLE HISTORY**

Submitted: 08.02.2018
Accepted: 13.05.2018

## АННОТАЦИЯ

Рассмотрены применяемые в современном строительстве технологии антикоррозионной защиты железобетонных градирен башенного типа. Выполнен анализ технических и технологических характеристик защитных систем компаний Sika, MC-Bauchemie, BASF и Hempel. Применительно к конструкциям железобетонных градирен Н = 150 м произведен расчет расхода материалов на основе норм расхода производителей, а также по методике VGB-R 612 Ue (Германия). Выбор рекомендуемых вариантов защитных покрытий железобетонных градирен выполнен на основе анализа их технических характеристик, общего расхода материалов и стоимостных показателей антикоррозионной системы.

## ABSTRACT

The technologies of anticorrosive protection used in modern construction of reinforced concrete cooling towers are considered. The analysis of technical and technological characteristics of protective systems of companies Sika, MC-Bauchemie, BASF and Hempel is performed. The calculation of the consumption of materials based on consumption rates from manufacturers and from the method of VGB-R 612 Ue (Germany) was carried out for the constructions of reinforced concrete cooling towers H = 150 m. The choice of recommended options for protective coatings of reinforced concrete cooling towers is made on the basis of an analysis of their technical characteristics, total consumption of materials and cost indicators of the anticorrosion system.

**Содержание**

# *1. Introduction*

Reinforced concrete cooling towers operate under conditions of force and temperature-humidity influences. The most significant factors of influence are the temperature and humidity gradients along the wall thickness, the stresses of which are bigger, then the total effect of loads from the weight of the structure and wind [1-5].

The parameters of temperature and humidity are variable in time and cause deformation of concrete, which inevitably leads to damage to its structure [1,6-9]. Therefore, the issue of reliable protection of concrete structures of cooling towers is actual.

Current design standards in the Russian Federation [10] assume a comprehensive protection of shells of cooling towers, including constructive (primary protection) and additional palliative (secondary protection). Constructive protection is provided by selection of concrete of the appropriate composition [11], secondary - by device of hydrophobic and waterproofing coatings [11-14].

Such protection should be applied during the building of cooling towers and updated during their operation.

As the experience of operation of concrete cooling towers [7-9,15] shows, the most vulnerable places are the zones of horizontal working seams of concreting, mainly in the upper part of the shell. Therefore, the process of repairing the shell includes: repair damaged joints of concreting, places of defects and chips of the protective layer of concrete, repair of protective coatings. High-altitude repair and restoration work, as a rule, is expensive, which makes high demands on the quality and durability of the repair compounds used.

To date, the repair compositions and technologies of the companies Sika, MC-Bauchemie and BASF are most often used in the repair of reinforced concrete shells of cooling towers. [16-20]. In the Russian Federation, repair connections manufactured under the license of BASF are used: Emaco polymer cement repair mixtures, MasterSeal waterproofing materials [19,21].

The issue of renewal of the anticorrosive protection of reinforced concrete structures on the cooling towers No. 1 and No. 2 of Kalininskaya NPP (cooling towers of the same type, the height of the structures is 150 m) is considered (Figure 1).

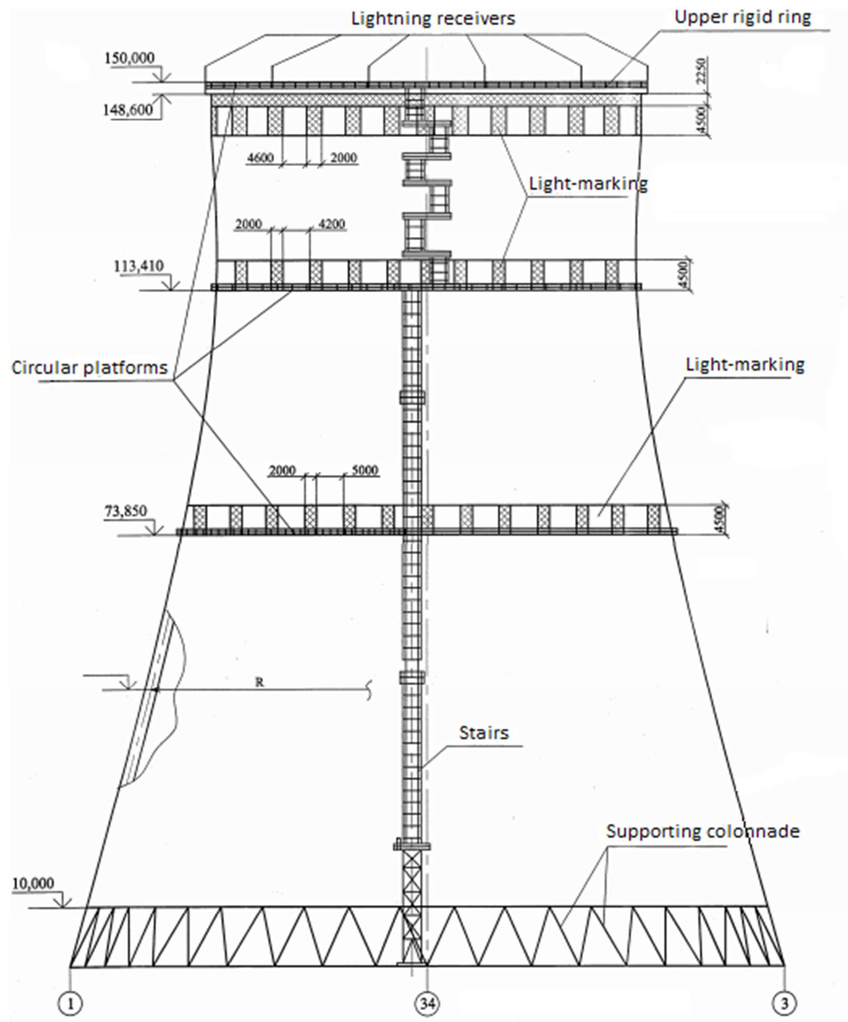


**Figure 1. General view of the cooling towers No. 1 and No. 2 of Kalinin NPP**

While developing the project to renew the protective coating, it became necessary to made pre-select materials for protection systems. The suppliers of four companies offered protective coating systems: Hempel, Sika, MC-Bauchemie and BASF [17, 18, 20].

One of the important criteria for assessing the effectiveness of protective coatings is the cost criterion, which is largely determined by the cost of the materials used. At the same time, it was taken into account that protective coatings of different manufacturers have a different consumption of paint materials per unit area of the surface being repaired. This circumstance determines the need to calculate the costs for the entire amount of work on the construction of a protective coating on the structure.

As a rule, manufacturers declare the technical characteristics of their materials, including the consumption per square meter of the surface to be protected. As the experience of practical application of waterproofing compounds testifies [6, 12, 22-24] manufacturers give the norms of the consumption of materials, obtained in laboratory conditions, which are insufficient for high-quality performance of works in full-scale conditions at height.Two results are achieved. First, an illusion of higher economic efficiency is created with a lower cost of repair work, and secondly, it is "tied" the consumer to the supplier, forcing him to purchase the missing material for a qualitative completion of the entire amount of repair work. At the same time, there are methods for calculating the consumption of building materials on the basis of taking into account the characteristics of their physical properties, presented in various regulatory documents.In particular, the methodology for calculating the flow rate of anticorrosion coatings for cooling towers is presented in the German document VGB-R 612 Ue "Means for protecting reinforced concrete cooling towers and chimneys against operational and environmental impacts" [25].

The purpose of this work is to analyze the known technologies for repair of concrete shells of cooling towers and to choose the optimal version of the protective coating for the reinforced concrete cooling towers No. 1 and No. 2 of the Kalinin NPP (H = 150 m).

To achieve this goal, the following tasks have been accomplished:

Selection of the system of waterproofing protective coatings for concrete cooling towers among the numbers of materials on the Russian market;

Calculation of the scope of work on the create of a protective anticorrosive coating on the shell of the cooling tower H = 150 m;

The necessary need for materials for the work has been determined based on the manufacturers' data, taking into account the experience of practical application.

## 2. M□t□ri□ls □nd M□th□ds

Shells of cooling towers, depending on the intensity of the impact of technological and climatic factorsare traditionally divided into two parts: the inner and outer surfaces of the shell. Investigations of processes of corrosion damage of reinforced concrete in cooling towers have shown that it is expedient to divide the shell of the cooling tower into three zones: the outer surface of the shell (zone A) and the two zones B and C, respectively, the lower and upper surfaces inside the cooling tower.

The protective coating systems of the inner surface of the shell include a multi-layer coating device consisting of a hydrophobic coating and a 2-3-layer protective waterproofing coating based on epoxy resins.

Epoxy coating inside the cooling tower, as shown by the results of full-scale studies [11,16,17,26-28], is not resistant to the effects of solar ultraviolet rays. This necessitates additional protection of epoxy coating layers with polyurethane materials resistant to ultraviolet rays [17].

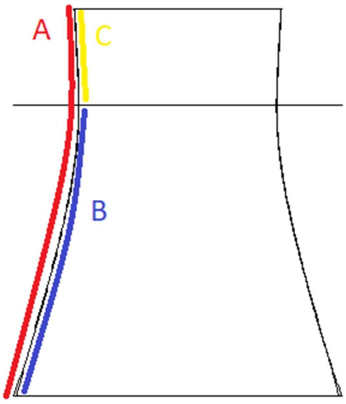


**Figure 2. Zones of anticorrosion protection of cooling tower shell**

The coating system for zone A (for the outer surface of the shell) should be resistant to CO2, to ultraviolet rays and to atmospheric influences. Also, it must be vapor-permeable. It should consist of primer and outer cover layers (acrylate, copolymer or polysiloxane coatings).

The coating system for zone B is the coating of the inner surface of the shell below the neck of cooling tower, as well as the structures of the frame of the water-spray system. It must be resistant to water and condensation and waterproof. It consists of an impregnating primer and an upper protective coating layer based on epoxy, copolymers or polysiloxanes.

Protective system for zone C is covering the inner surface of the shell above the neck of cooling tower, as well as the structures of the colonnade. In addition to the requirements for system B, this coating must also be resistant to ultraviolet radiation. It consists of three layers: primer, intermediate epoxy and top polyurethane.

It is also necessary to establish compliance of products offered by suppliers with the requirements for protective systems for zones A, B, and C.

Calculation of areas for repair of the internal and external surface of the cooling tower is made according to the projected geometric dimensions of the shell at the corresponding elevations.

The area of the sections of the shell of the cooling tower was calculated as the areas of the trapezium with bases equal to the lengths of two adjacent arcs, respectively, from the inner or outer side of the shell at a height equal to the height of the tiers of concreting.

Vertical stiffeners on the outer surface of the shell of cooling towers were also taken into account when calculating the amount of work.

According to German regulations VGB-R 612 Ue [25], the consumption of materials for protective coatings is determined by the formulas:

$$m'' = (S_{min} + 1{,}64 \cdot rsd) \cdot \frac{\rho}{SV} \cdot (1+\alpha) \cdot (1+\beta) \tag{1}$$

$$A = S_{min} + (1{,}64 \cdot rsd) \tag{2}$$

$$z_1 = (1+\alpha) \tag{3}$$

$$z_2 = (1+\beta) \tag{4}$$

$$m'' = A \cdot \frac{\rho}{SV} \cdot z_1 \cdot z_2, \tag{5}$$

Terms and values:

m'' – consumptionrate, kg / m2;

Smin – minimum dry film thickness, µm (table 2);

A – average dry film thickness, µm;

rsd – standard deviation of the dry film thickness, µm;

$\rho$–density of the liquid coating material, g / cm3;

SV – solid volumeof the liquid coating material;

$\alpha$– factor referring to application losses of coating material;

$\beta$–factor referring to surface roughness of component.

***Table 1. Calculated parameters to formulas (1) ÷ (5) [25] for calculating the thickness of the protective coating on the shell surface of the cooling tower***

| Component | Coating tower inside | | | Coating tower outside | | |
|---|---|---|---|---|---|---|
| | New construction | | Retrofitting | New construction | Retrofitting | |
| | Shell | Fill support structure | Shell | Shell | | |
| Application method | Airless | | | Rolling | Airless | Rolling |
| Parameter | | | | | | |
| *rsd* | 50 | 40 | 50 | 40 | 50 | 50 |
| $\alpha$ | 0.1 | 0.1 | 0.1 | 0.02 | 0.1 | 0.03 |
| $\beta$ | 0.1 | 0.2 | 0.5 | 0.3 | 0.1 | 0.3 |
| | | (0.15…0.25) | (0.2…1.0) | (0.15…0.25) | (0.1…0.15) | (0.2…0.4) |

***Table 2. The values of Smin and A for calculating the thickness of the protective coating [25]***

| $S_{min}$, μm | Standard deviation = 40 μm | Standard deviation = 50 μm |
|---|---|---|
| 80 | A=145 μm | A=165 μm |
| 100 | A=165 μm | A=185 μm |
| 200 | A=265 μm | A=285 μm |
| 300 | A=365 μm | A=385 μm |
| 400 | A=465 μm | A=485 μm |

The calculated material consumption is rounded to a highervalue, so as to be a multiple of 50 g / m2.

The minimum film thickness of the protective coating is 200 μm, the decorative coating is 80 μm.

Calculation of the consumption of priming (impregnating) layers is not carried out, since their thickness is not regulated. Their application rate is adopted according to the manufacturers information.

The value of the coefficient $\beta$ in the calculation is taken as minimally possible according to Table 1.

# *3. Results and Discussion*

## 3.1. Results

Based on data provided by suppliers of companies [17, 18, 20], the following systems of protective coatings were compared.

1. Sika coating systems (Switzerland):

– System for zone A: hydrojet preparation of the surface under pressure + hydrophobic primer in 2 layers (Sikagard-700S) + primer (Sikagard-680S TopCoat) + finishing coat (Sikagard-680S TopCoat);

– System for zone B: hydrojet preparation of the surface under pressure + primer (Icosit 2406 Primer) + finishing coat (Icosit 2406 Deck);

– System for zone C: hydrojet preparation of the surface under pressure + primer (Icosit 2406 Primer) + finishing coat (Icosit 2406 Deck) + polyurethane coating (Sikagard-363).

2. Coating systems of MC-Bauchemie (Germany):

– System for zone A: hydrojet preparation of the surface under pressure + leveling (in case of emergency) + hydrophobic primer (MC-Schutzüberzug 702SX) + primer (MC-Schutzüberzug 702) + finishing coat (MC-Schutzüberzug 702);

– System for zone B: hydrojet preparation of the surface under pressure + primer (MC-DUR 1277 WV) + 1-layer coating (MC-DURVSNR3) + 2-layer coating (MC-DURVSNR3);

– System for zone C: hydrojet preparation of surface under pressure + primer (MC-DUR 1277 WV) + 1-layer coating (MC-DURVSNR3) + 2-layer coating (MC-DURVSNR3) + polyurethane coating layer (MC-DURVS-PUR) .

3. BASF coating systems (Germany):

– System for zone A: hydrojet preparation of the surface under pressure + primer (MasterProtect 330 EL) + finishing coat (MasterProtect 330 EL).

– System for zone B: hydrojet preparation of the surface under pressure + primer (MasterSealP 385) + 1-layer coating (MasterSealM 336) + 2-layer coating (MasterSealM 336);

– System for zone C: hydrojet preparation of surface under pressure + primer (MasterSealP 385) + 1-layer coating (MasterSealM 336) + 2-layer coating (MasterSealM 336) + polyurethane coating (MasterSealTC 259).

4. Hempel coating systems (Denmark):

– System for zone A: hydrojet preparation of the surface under pressure + hydrophobic primer (Hempel'sContexSealer 26600) + primer (Hempel'sContexSmooth 46600) + finishing coat (Hempel'sContexSmooth 46600);

– System for zone B: hydrojet preparation of the surface under pressure + primer (Hempadur Sealer 05990) + 1-layer coating (Hempadur Multi-Strength 45753) + 2-layer coating (Hempadur Multi-Strength 45753);

– System for zone C: hydrojet preparation of surface under pressure + primer (Hempadur Sealer 05990) + 1-layer coating (Hempadur Multi-Strength 45753) + 2-layer coating (Hempadur Multi-Strength 45753).

Considering that in the latter case there is no polyurethane layer in the C coating system, it can be concluded that this coating system will be vulnerable to ultraviolet rays.

As can be seen from the comparison, the coating system for zone C is a coating system for zone B, coated on top with a polyurethane-based material. This solution simplifies the technology of applying protective coatings.

Due to the fact that the manufacturer of Hempel does not provide a suitable protective layer on a polyurethane basis, the use of such systems for cooling towers is not advisable.

According to the documentation for the cooling tower its average area is 38 433 m2.

The estimated area of the inner surface of the shell was 38 282.90 m2; external - 38 587.28 m2. Taking into account the meridional edges, the surface of the shell of the cooling tower is 43 665.68 m2. The part of the inner surface area of the cooling tower above the neck is 8339.06 m2.

The results of calculating the consumption of materials for the device of protective coatings for a cooling tower of height H = 150 m from the companies Sika, MC and BASF are presented in Tables 3 and 4.

***Table 3. Consumption of materials for the device of protective coatings depending on the consumption declared by the manufacturer***

| Company | System | Materials | Consumptionrate, kg / m$^2$ | Consumption, kg |
|---|---|---|---|---|
| Sika | A | Sikagard-700S | 0.3x2 | 26 199.41 |
| | | Sikagard-680STopCoat | 0.2x2 | 17 466.27 |
| | B | Icosit 2406 Primer | 0.4 | 15 313.16 |
| | | Icosit 2406 Deck | 0.5 | 19 141.45 |
| | C | Sikagard-363 | 0.4 | 3 335.62 |
| MC | A | MC-Schutzüberzug 702SX | 0.35 | 15 282.99 |
| | | MC-Schutzüberzug 702 | 0.3x2 | 26 199.41 |
| | B | MC-DUR 1277 WV | 0.25 | 9 570.72 |
| | | MC-DURVSNR3 | 0.3x2 | 22 969.74 |
| | C | MC-DURVS-PUR | 0.25 | 2 084.76 |
| BASF | A | MasterProtect 330 EL | 0.31x2 | 27 072.72 |
| | B | MasterSealP 385 | 0.6 | 22 969.74 |
| | | MasterSeal M 336 | 0.3x2 | 22 969.74 |
| | C | MasterSealTC 259 | 0.2 | 1 667.81 |

***Table 4. Results of calculating the consumption of materials based on VGB-R 612 Ue [25]***

| Company | System | Materials | Consumptionrate, kg / $m^2$ | Consumption, kg |
|---|---|---|---|---|
| Sika | A | Sikagard-680STopCoat | 1.1 | 48 032.25 |
| | B | Icosit 2406 Deck | 0.6 | 22 969.74 |
| | C | Sikagard-363 | 0.8 | 6 671.25 |
| BASF | B | MasterSeal M 336 | 0.5 | 19 141.45 |
| | C | MasterSealTC 259 | 0.8 | 6 671.25 |

The calculation is not possible for all materials, since not all manufacturers inform about the value of the solids content by volume.

Economic indicators of calculation are presented in Tables 5 and 6.

***Table 5. Indicators of consumption and cost of materials for coating systems***

| Material | Cost of 1 kg, rub | Consumption, kg | Total cost, rub | Cost of the system, rub |
|---|---|---|---|---|
| Sikagard-700S | 441.90 | 26 199.41 | 11 577 519.28 | 21 081 790.10 |
| Sikagard-680STopCoat | 544.15 | 17 466.27 | 9 504 270.82 | |
| Icosit 2406 Primer | 1 022.32 | 15 313.16 | 15 654 949.73 | 33 859 999.99 |
| Icosit 2406 Deck | 951.08 | 19 141.45 | 18 205 050.26 | |
| Sikagard-363 | 892.05 | 3 335.62 | 2 975 539.82 | 2 975 539.82 |
| MC-Schutzüberzug 702SX | 733.06 | 15 282.99 | 11 203 348.65 | 30 413 280.05 |
| MC-Schutzüberzug 702 | 733.22 | 26 199.41 | 19 209 931.40 | |
| MC-DUR 1277 WV | 865.36 | 9 570.72 | 8 282 118.26 | 33 026 959.77 |
| MC-DURVSNR3 | 1 077.28 | 22 969.74 | 24 744 841.51 | |
| MC-DURVS-PUR | 1 123.88 | 2 084.76 | 2 343 020.07 | 2 343 020.07 |
| MasterProtect 330 EL | 453.87 | 27 072.72 | 12 287 495.43 | 12 287 495.43 |
| MasterSealP 385 | 423.33 | 22 969.74 | 9 723 780.03 | 27 048 017.33 |
| MasterSeal M 336 | 754.22 | 22 969.74 | 17 324 237.30 | |
| MasterSealTC 259 | 1 192.95 | 1 667.81 | 1 989 613.94 | 1 989 613.94 |

***Table 6. Parameters of consumption and cost of materials for coating systems, calculated by the method of VGB-R 612 Ue [25]***

| Material | Cost of 1 kg, rub | Consumption, kg | Total cost, rub |
|---|---|---|---|
| Sikagard-680STopCoat | 544.15 | 48 032.25 | 26 136 748.84 |
| Icosit 2406 Deck | 951.08 | 22 969.74 | 21 846 060.32 |
| Sikagard-363 | 892.05 | 6 671.25 | 5 951 088.56 |
| MasterSeal M 336 | 754.22 | 19 141.45 | 14 436 864.42 |
| MasterSealTC 259 | 1 192.95 | 6 671.25 | 7 958 467.69 |

## 3.2. Discussion

When choosing protective materials, one should be guided not only by their cost, but also by experience of using them on similar objects. The economic benefit derived from the use of cheap materials can be offset by the subsequent costs of repair and renewal of the coating.

Based on the data in Table 5, among the protective coating systems for zone A, the most costly system is the system of the company MC-Bauchemie, the cheapest – BASF. Sika products take an intermediate position.

From the comparison of the cost of protective coatings for zones B and C, it follows that the most expensive is the coating system of Sika, the cheapest – BASF.

10-year experience of monitoring the condition of protective coatings on internal and external surfaces of reinforced concrete shells H = 150m of cooling towers No. 1 and No. 2 of Zuevskaya TPP (Donetsk region, Ukraine) [6] indicates that the coating systems of Sika company, consisting of the 1st layer hydrophobic impregnation Sikagard 720 Aquaphob + 1 layer Icosit 2406 Primer + 2 layers Icosit 2406 Deck, for the first 4 years reliably protected concrete surfaces. There were no signs of bursting and peeling. After 10 years of operation, the layers on the epoxy binder had lost their elasticity, showed signs of cracking and peeling mainly in the zone of the upper cooling tower cup above the throat mark.

The manufacturer provides information that the systems Icosit 2406 Primer + Icosit 2406 Deck and Sikagard-700S + Sikagard-680S were used on the cooling towers of the Turov power plant in Poland. In 2008, a study of these coatings was carried out, it turned out that in 16 years since the application, they have not lost their protective properties [29-32].

The MC-DUR 1277 WV + MC-DUR VS NR3 system was used in 2001 to protect the cooling tower of the Lignite Thermal Power Plant in Lippendorf, Germany [19]. The study, conducted after 7 years of operation, showed that the coating, subject to the preservation of environmental conditions, would require replacement after only 20 years. All of the above MC-Bauchemie products were used in the cooling towers of the coal-fired power plant in Detmarowice (Czech Republic) [19].

In 2013-2014, the MasterProtect 330 EL and MasterSeal P 305 + MasterSeal M 336 systems were used on the cooling tower of the Troitskaya GRES. MasterProtect 330 EL material was also used for external protection of the Minsk thermal power plant-4 cooling tower [18,21].

The experience of using Hempel's products to protect reinforced concrete cooling towers is unknown.

It should be noted that MasterProtect 330 EL material for external protection does not require a special primer layer, which distinguishes it from competitive systems.

According to [6], the practical consumption of materials for the waterproofing of the cooling tower shell H = 150 m with Sika materials showed an increase in the consumption of main components to 10% in comparison with the supplier's data. Such additional consumption was due, in the main, to additional spraying in conditions of strong wind impact at high altitude.

## *4. Conclusions*

Protective coatings are multi-layer systems, including hydrophobic impregnation of concrete, as well as impregnating and protective layers of waterproofing materials.

With regard to reinforced concrete cooling towers, the most widely used protective systems are produced by the companies Sika, MC-Bauchemie and BASF.

There is a problem of determining the practical consumption of waterproofing materials. The data provided by the suppliers is not always correct, and the calculation methods presented in the normative documentation are based on the properties of the materials that are not always known. Sufficiently justified values of material consumption are available only for materials based on epoxy resins.

With regard to the reinforced concrete shells of the Kalinin NPP cooling towers No. 1 and No. 2, the following coating systems are the most optimal: for the outer surface of the shell, MasterProtect 330 EL material (BASF company), and for the internal surface, the MC-Bauchemie production system consisting of layers MC-DUR 1277 WV + MC-DUR VS NR3 + MC-DUR VS-PUR.

When choosing a coating system for zone A produced by BASF, its cheapness and simplicity of creation were taken into account (only one component in the system). When choosing protective coatings for zones B and C, it was taken into account that their repair is associated with the shutdown of the operation of the structure. Therefore, the selection is made in favor of the option with guaranteed durability. Between the products of the companies Sika and MC-Bauchemie, the choice is preferable in favor of less expensive.

# 5. Acknowledgement

The authors are grateful to Mikhail Presman, head of the design group of cooling towers, “Atomproekt” corporation, for consulting and assistance in collecting the information.

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