Absorptive Properties of Hydrate Silicate Building Materials and Products for Quality and Geoecoprotection Improvement

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Abstract

Background: Two directions of absorption of silica sol usage for construction are shown. The first direction is the usage of silica sol by means of absorption silica sol solution process and the second is obtaining silica sol according to reaction between clay mineral (Al2O3•4SiO2•2H2O) and H3PO4 solution. Methods: Thermodynamically-based method of research is used to study silica soil properties. In addition, experiments were held to illustrate quality and geoprotection improvement due to absorptive properties of hydrate silicate building materials and products. Findings: First, processes can improve the technical properties of the concrete and, second, can strengthen and detoxicate soil (ground) at the same time. The possibility of silica sol absorption by means of capillary porosity of concrete structure and the change of technical properties of absorbed concrete have been shown. Sand and clayish soil strengthening and detoxication by means of silica soil saturation and obtaining silica soil during the reaction have being revealed as well. The reactions between clay and phosphoric acid have productive silica sol. If there are heavy metal ions in the soil, so it is possible to obtain phosphates and silicates with very low solubility product. Silica sol formation in the soil is very important for lithosphere detoxication not only from heavy metal ions but from oil pollutions as well. Improvements: Such a way is possible due to artificial stone formation to improve technical properties of concrete and to prevent lithosphere toxication.

Keywords: Absorption, Geoecoprotection, Improvement, Phosphates, Properties, Silica Sol, Technical

1. Introduction

There are a lot of ways to affect the concrete properties and soil strengthening. Now another way of using silica sol solution or obtaining silica sol due to reactions between clay mineral Al2O3•4SiO2•2H2O and phosphoric acid has been shown. It is possible to use an absorption effect of the concrete stone as a solid material with capillary porosity and transition sol-gel process in the ground that is important for the purpose of soil strengthening.

It is known that clay is a natural product of difference mineral, for example, such as hydrate silicate Al2O3•4SiO2•2H2O. In literature an artificial stone formation (binder system) based on clay and phosphoric acid properties with good enough compressive strength and water resistance has been shown. The attention has
been paid to the fact that clay ground of the railway transport is polluted with oil products and heavy metal ions (Fe(II); Mn(II)) at the same time. The idea of concrete property improvement of soil strengthening and detoxication at the same time to prevent lithosphere pollution due to silica sol by absorbing through capillary porosity or obtaining it by reaction has been put forward. Then, it is necessary to know the thermodynamic basis of property improvement.

### 2. Thermodynamically-Based Method of Research

The main idea of the paper is, first, to illustrate the usage of the Gibbs free energy of the systems to increase the quality of the building material and, second, the geo-protective properties of the building materials including strengthening soil. The Gibbs free energy maybe the result of the reaction between substances of the hydrate silicate

#### Table 1. The calculation of thermodynamics of reactions due to capillary absorption of solution with silica sol

| Reactions of the concrete stone with silica sol, pH>7 | $\Delta G^{0}_{298}$ of the reaction, kJ |
|-----------------------------------------------------|-----------------------------------|
| $\text{Ca(OH)}_2+2(\text{SiO}_2\cdot\text{H}_2\text{O})=\text{CaO} \cdot 2\text{SiO}_2 \cdot 2\text{H}_2\text{O}+\text{H}_2\text{O}$ | -169.1 |
| $2\text{Ca(OH)}_2+\text{SiO}_2\cdot\text{H}_2\text{O}=2\text{CaO} \cdot \text{SiO}_2 \cdot 1.17\text{H}_2\text{O}+1.83\text{H}_2\text{O}$ | -95.32 |
| $5\text{Ca(OH)}_2+6(\text{SiO}_2\cdot\text{H}_2\text{O})=5\text{CaO} \cdot 6\text{SiO}_2 \cdot 2.5\text{H}_2\text{O}+5.5\text{H}_2\text{O}$ | -584.8 |
| $2\text{CaO} \cdot \text{SiO}_2 \cdot 1.17\text{H}_2\text{O}+2\text{SiO}_2\cdot\text{H}_2\text{O}=2\text{CaO} \cdot 3\text{SiO}_2 \cdot 2.5\text{H}_2\text{O}+0.67\text{H}_2\text{O}$ | -180.3 |

#### Table 2. The calculation of thermodynamics of reaction of heavy metal ions in concrete on the hydrate silicate base, due to absorption of solution with heavy metal ions

| No. | Reactions in the concrete | $\Delta G^{0}_{298}$ of the reaction, kJ |
|-----|--------------------------|-----------------------------------|
| 1   | $2\text{CaO} \cdot \text{SiO}_2 (s)+\text{Cu}^{2+}_{aq}+2\text{OH}^-_{aq}+1.17\text{H}_2\text{O}(aq) \rightarrow 2\text{CaO} \cdot \text{SiO}_2 \cdot 1.17\text{H}_2\text{O}(s)+\text{Ca(OH)}_2 (s)$ | -120.56 |
| 2   | $3\text{CaO} \cdot \text{SiO}_2 (s)+\text{Cu}^{2+}_{aq}+2\text{OH}^-_{aq}+2.17\text{H}_2\text{O}(aq) \rightarrow 2\text{CaO} \cdot \text{SiO}_2 \cdot 1.17\text{H}_2\text{O}(s)+\text{Ca(OH)}_2 (s)+\text{Ca(OH)}_2 (s)$ | -188.94 |
| 3   | $5\text{CaO} \cdot 6\text{SiO}_2 \cdot 5.5\text{H}_2\text{O}+\text{Cu}^{2+}_{aq}+2\text{OH}^-_{aq}+5\text{H}_2\text{O}(aq) \rightarrow \text{Ca(OH)}_2 (s)+5\text{CaO} \cdot 6\text{SiO}_2 \cdot 10.5\text{H}_2\text{O}(s)$ | -120.63 |
| 4   | $5\text{CaO} \cdot 6\text{SiO}_2 \cdot 5.5\text{H}_2\text{O}+\text{Ni}^{2+}_{aq}+2\text{OH}^-_{aq}+5\text{H}_2\text{O}(aq) \rightarrow \text{Ni(OH)}_2(s)+5\text{CaO} \cdot 6\text{SiO}_2 \cdot 10.5\text{H}_2\text{O}(s)$ | -108.54 |
Table 2 Continued

|   | Reactions                                                                                                                                                                                                 | ΔG°298 (kJ) |
|---|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------|
| 5 | $2\text{CaO} \cdot \text{SiO}_2(s) + \text{Fe}^{3+} \text{aq} + 3\text{OH}^-(\text{aq}) + 1.17\text{H}_2\text{O}(\text{aq}) \rightarrow 2\text{CaO} \cdot \text{SiO}_2$ $\cdot l,17\text{H}_2\text{O}(s) + \text{Fe(OH)}_3(s)$ | -221.82    |
| 6 | $3\text{CaO} \cdot \text{SiO}_2(s) + \text{Fe}^{3+} \text{aq} + 3\text{OH}^-(\text{aq}) + 2.17\text{H}_2\text{O}(\text{aq}) \rightarrow 2\text{CaO} \cdot \text{SiO}_2$ $\cdot l,17\text{H}_2\text{O}(s) + \text{Ca(OH)}_2(s) + \text{Fe(OH)}_3(s)$ | -290.21    |
| 7 | $5\text{CaO} \cdot 6\text{SiO}_2 \cdot 5.5\text{H}_2\text{O} + \text{Fe}^{3+} \text{aq} + 3\text{OH}^-(\text{aq}) + 5\text{H}_2\text{O}(\text{aq}) \rightarrow \text{Fe(OH)}_3(s) + 5\text{CaO} \cdot 6\text{SiO}_2$ $\cdot 0.5\text{H}_2\text{O}(s)$ | -221.90    |
| 8 | $2\text{CaO} \cdot \text{SiO}_2(s) + \text{Cd}^{2+} \text{aq} + 2\text{OH}^-(\text{aq}) + 1.17\text{H}_2\text{O}(\text{aq}) \rightarrow 2\text{CaO} \cdot \text{SiO}_2$ $\cdot l,17\text{H}_2\text{O}(s) + \text{Cd(OH)}_2(s)$ | -91.35     |
| 9 | $3\text{CaO} \cdot \text{SiO}_2(s) + \text{Cd}^{2+} \text{aq} + 2\text{OH}^-(\text{aq}) + 2.17\text{H}_2\text{O}(\text{aq}) \rightarrow 2\text{CaO} \cdot \text{SiO}_2$ $\cdot l,17\text{H}_2\text{O}(s) + \text{Cd(OH)}_2(s)$ | -159.73    |
|10 | $5\text{CaO} \cdot 6\text{SiO}_2 \cdot 5.5\text{H}_2\text{O} + \text{Cd}^{2+} \text{aq} + 2\text{OH}^-(\text{aq}) + 5\text{H}_2\text{O}(\text{aq}) \rightarrow \text{Cd(OH)}_2(s) + 5\text{CaO} \cdot 6\text{SiO}_2$ $\cdot 0.5\text{H}_2\text{O}(s)$ | -91.42     |
|11 | $2\text{CaO} \cdot \text{SiO}_2(s) + \text{Pb}^{2+} \text{aq} + 2\text{OH}^-(\text{aq}) + 1.17\text{H}_2\text{O}(\text{aq}) \rightarrow 2\text{CaO} \cdot \text{SiO}_2$ $\cdot l,17\text{H}_2\text{O}(s) + \text{Pb(OH)}_2(s)$ | -91.89     |
|12 | $3\text{CaO} \cdot \text{SiO}_2(s) + \text{Pb}^{2+} \text{aq} + 2\text{OH}^-(\text{aq}) + 2.17\text{H}_2\text{O}(\text{aq}) \rightarrow 2\text{CaO} \cdot \text{SiO}_2$ $\cdot l,17\text{H}_2\text{O}(s) + \text{Ca(OH)}_2(s) + \text{Pb(OH)}_2(s)$ | -160.27    |

Table 3. The calculation of the free Gibbs energy reactions between clay and phosphoric acid obtaining silica sol, system I

| Reactions                                                                                     | ΔG°298 (kJ) |
|-----------------------------------------------------------------------------------------------|------------|
| 1. $\text{Al}_2\text{O}_3 \cdot 4\text{SiO}_2 \cdot 2\text{H}_2\text{O}^* + 6\text{H}_3\text{PO}_4 = 4(\text{SiO}_2 \cdot 2\text{H}_2\text{O}) + 2\text{Al(H}_2\text{PO}_4)_3 + \text{H}_2\text{O}$ | -284.24    |
| 2. $\text{Al}_2\text{O}_3 \cdot 4\text{SiO}_2 \cdot 2\text{H}_2\text{O} + 2\text{H}_3\text{PO}_4 + 3\text{H}_2\text{O} = 4(\text{SiO}_2 \cdot 2\text{H}_2\text{O}) + 2\text{Al(OH)}_2\text{H}_2\text{PO}_4$ | -299.49    |
| 3. $\text{Al}_2\text{O}_3 \cdot 4\text{SiO}_2 \cdot 2\text{H}_2\text{O} + 2\text{H}_3\text{PO}_4 + 3\text{H}_2\text{O} = 4(\text{SiO}_2 \cdot 2\text{H}_2\text{O}) + 2\text{AlPO}_4$ | -154.48    |
| 4. $\text{Al}_2\text{O}_3 \cdot 4\text{SiO}_2 \cdot 2\text{H}_2\text{O} + 6\text{H}_3\text{PO}_4 + 3\text{H}_2\text{O} = 4(\text{SiO}_2 \cdot 2\text{H}_2\text{O}) + 2\text{Al(H}_2\text{PO}_4)_3$ | -373.22    |
| 5. $\text{Al}_2\text{O}_3 \cdot 4\text{SiO}_2 \cdot 2\text{H}_2\text{O} + 2\text{H}_3\text{PO}_4 + 7\text{H}_2\text{O} = 4(\text{SiO}_2 \cdot 2\text{H}_2\text{O}) + 2\text{Al(OH)}_2\text{H}_2\text{PO}_4$ | -388.47    |

* the main blue clay mineral
of the artificial stone (Ca (OH)$_2$, xCaO·ySiO$_2$, nH$_2$O) with absorption of silica sol solution, or reaction between clay and phosphoric acid with silica sol formation (Tables 1–4). There are thermodynamically or energetically based results of the reaction of heavy metal ions and Gibbs free energy ($\Delta G^0$) is the base of improvement of properties and it predicts increasing products strength and detoxicating properties. More than that, heavy metal ions may be absorbed by means of capillary porosity and they may be detoxicated, according to the thermodynamically based calculation, Table 2. As the very method of introduction of silica sol in the stone was chosen, the method of absorption of nanosolution of SiO$_2$·nH$_2$O or the result of reaction between clay mineral Al$_2$O$_3$·4SiO$_2$·2H$_2$O and phosphoric acid appeared useful as well.

3. Experiment and Results

There were three parts of research. The first part was connected with the concrete stone properties, the second part – with sand soil strengthening by means of silica sol and the third part dealt with reactions of clay soil with phosphoric acid to obtain silica sol, and heavy metal ions detoxication if such ions are in the system. Table 1 illustrates that the negative value of the Gibbs free energy gives us the information about the possibility of the processes.

| Reactions | $\Delta G^0_{298}$, kJ |
|-----------|------------------|
| FeO + 1/4O$_2$ + Al$_2$O$_3$·4SiO$_2$·2H$_2$O + 3H$_3$PO$_4$ + 7/2H$_2$O = FePO$_4$·2H$_2$O + 2Al(OH)$_2$HPO$_4$ + 4(SiO$_2$·2H$_2$O) | -476.66 |
| FeO + 1/4O$_2$ + 15/2H$_2$O + Al$_2$O$_3$·4SiO$_2$·2H$_2$O + 3H$_3$PO$_4$ = FePO$_4$·2H$_2$O + 2Al(OH)$_2$HPO$_4$ + 4(SiO$_2$·2H$_2$O) | -565.64 |
| Cr$^{3+}$ + FeO + 2O$_2$ + Al$_2$O$_3$·4SiO$_2$·2H$_2$O + 4H$_3$PO$_4$ + 12H$_2$O = FePO$_4$·2H$_2$O + 2Al(OH)$_2$HPO$_4$ + 4(SiO$_2$·2H$_2$O) + CrPO$_4$·6H$_2$O | -876.08 |
| 3Mn$^{2+}$ + FeO + 7/4O$_2$ + Al$_2$O$_3$·4SiO$_2$·2H$_2$O + 5H$_3$PO$_4$ + 23/2H$_2$O = FePO$_4$·2H$_2$O + 2Al(OH)$_2$HPO$_4$ + 4(SiO$_2$·2H$_2$O) + Mn$_3$(PO$_4$)$_2$·7H$_2$O | -1025.19 |
| 3Zn$^{2+}$ + FeO + 7/4O$_2$ + 17/2H$_2$O + Al$_2$O$_3$·4SiO$_2$·2H$_2$O + 5H$_3$PO$_4$ = FePO$_4$·2H$_2$O + 2Al(OH)$_2$HPO$_4$ + 4(SiO$_2$·2H$_2$O) + Zn$_3$(PO$_4$)$_2$·8H$_2$O | -1081.64 |
| 3Cu$^{2+}$ + FeO + 7/4O$_2$ + 15/2H$_2$O + Al$_2$O$_3$·4SiO$_2$·2H$_2$O + 5H$_3$PO$_4$ = FePO$_4$·2H$_2$O + 2Al(OH)$_2$HPO$_4$ + 4(SiO$_2$·2H$_2$O) + Cu$_3$(PO$_4$)$_2$·3H$_2$O | -1119.91 |
| 3Ni$^{2+}$ + FeO + 7/4O$_2$ + 25/2H$_2$O + Al$_2$O$_3$·4SiO$_2$·2H$_2$O + 5H$_3$PO$_4$ = FePO$_4$·2H$_2$O + 2Al(OH)$_2$HPO$_4$ + 4(SiO$_2$·2H$_2$O) + Ni$_3$(PO$_4$)$_2$·8H$_2$O | -1199.98 |
| 3Fe$^{3+}$ + FeO + 7/4O$_2$ + 17/2H$_2$O + Al$_2$O$_3$·4SiO$_2$·2H$_2$O + 5H$_3$PO$_4$ = FePO$_4$·2H$_2$O + 2Al(OH)$_2$HPO$_4$ + 4(SiO$_2$·2H$_2$O) + Fe$_3$(PO$_4$)$_2$·4H$_2$O | -1252.53 |
As a result it there must be a new quantity of calcium silicate hydrates that corresponds with concrete properties improvement. Silica sol solution was used with the concentration of 1.5% and samples of foam concrete stone with average density 400, 500, 600 kg/m$^3$, the concrete setting time took three days. After that the samples were synced into the silica sol solution for saturation during a few hours. Then, after 28 days of the hardening process the properties of the concrete were investigated. Table 5 shows the change of the concrete properties: the calculations of thermodynamics of the reaction between silica sol ($\text{SiO}_2 \cdot \text{nH}_2\text{O}$) and concrete substances help understand silica sol effect.

The second part of research dealt with sandy soil strengthening due to a connection between sol-gel transitions and binding properties of gel. Sandy soil was

### Table 5. The change of the concrete properties due to the absorption of silica sol solution

| Average density, kg/m$^3$ | Ability of absorption, kg/m$^3$, 1.5% silica sol solution | Change of compressive strength, $+\Delta R$ | Frozen resistance, $F$, cycles, | Change of technical properties |
|---------------------------|----------------------------------------------------------|--------------------------------------------|---------------------------------|--------------------------------|
|                           |                                                          | MPa | % | Water-absorbing ability, $B$, % | Contraction, % |
| D400                      | 0.24                                                     | 0.35 | 77 | 10 | 37.7 | 70 |
| D500                      | 0.30                                                     | 1.16 | 124| 20 | 50.9 | 69 |
| D600                      | 0.36                                                     | 1.30 | 94 | 25 | 56.4 | 69 |
| D2000                     | 0.48                                                     | 10.53| 74 | 200| 79.5 | 82 |

### Table 6. Solubility product of heavy metal ion phosphates

| Ions  | Phosphates, formula | Solubility product |
|-------|---------------------|--------------------|
| Fe(III)| $\text{Fe}_3(\text{PO}_4)_2 \cdot 4\text{H}_2\text{O}$   | $9.94 \cdot 10^{-29}$|
| Ni(II)| $\text{Ni}_3(\text{PO}_4)_2 \cdot n\text{H}_2\text{O}$ | $4.73 \cdot 10^{-32}$|
| Mn(II)| $\text{Mn}_3(\text{PO}_4)_2 \cdot n\text{H}_2\text{O}$ | $6.13 \cdot 10^{-39}$|
| Cu(II)| $\text{Cu}_3(\text{PO}_4)_2 \cdot 3\text{H}_2\text{O}$ | $1.39 \cdot 10^{-39}$|
| Zn(II)| $\text{Zn}_3(\text{PO}_4)_2 \cdot 4\text{H}_2\text{O}$ | $9 \cdot 10^{-33}$|
| Cr(III)| $\text{CrPO}_4 \cdot 6\text{H}_2\text{O}$            | $2.4 \cdot 10^{-23}$|
saturated with silica sol solution with 30% concentration as a sample. The system was saturated with silica sol solution, the ratio soil and sol solution equaled to ~3, and then this system was studied. It appeared obvious that this way of strengthening is better than it is used to be as compared to strengthening by means of Na₂SiO₃ solution.

According to Tables 3 and 4, silica sol and heavy metal phosphates were obtained due to the reactions with phosphoric acid and clay and with the presence of heavy metal ions in the system. Table 6 demonstrates that all of them have very low solubility product. But as a rule there is a lot of oil pollution in the ground because of the transport system. Table 7 illustrates that clay system with oil pollution may be transformed in the artificial stone with a good enough strength and oil pollution is locked in the stone and is not dangerous.

Table 7 shows that compressive strength is good enough both for the artificial stone and for soil strengthening that has a special role for environmental soil protection, because it is possible to lock pollution and strengthen soil simultaneously in such a way.

Table 8 shows the ability of concrete objects to have geoecoprotection by means of absorption of solution with heavy metal ions.

| Table 7. Phosphate materials of clay with oil pollution |
|------------------------------------------------------|
| Oil, % in the phosphate binder * | Compressive strength, MPa of the system after being in water during one-year period |
|--------------------------------|-------------------------------------------------------------|
| 1.6 | 3.6 |
| 2.7 | 3.0 |
| 3.7 | 2.5 |
| 5.3 | 1.5 |
| 6.4 | 1.5 |

* material consists of blue clay: sand (1:4), 15% FeO density of acid – 1.25 g/cm³

| Table 8. Geoecoprotective activity of heavy concrete products |
|------------------------------------------------------------|
| Class of concrete products as an example of material made of silicate calcium hydrates | Geoecoprotective activity against Cd(II) and Pb (II)* |
|--------------------------------|--------------------------------|
| | mg/kg | mg/m² | g/m³ |
| Cd(II) | Pb(II) | Cd(II) | Pb(II) | Cd(II) | Pb(II) |
| B40 | 6.32 | 17.32 | 254.5 | 689.72 | 15.27 | 41.38 |

* Initial concentration – 0.1 mmol/l
4. Discussion

The results show the possibility to affect concrete and soil properties by means of silica sol. The difference between two processes is the reactions in the systems – the interaction between silica sol and substances of concrete, clay and phosphoric acid. The main advantage of the new way (the 1st way) to improve the concrete properties is the effect of the capillary porosity and it is possible to obtain the new structure in such a way. Table 9 illustrates the change of the structure of the concrete stone due to silica sol solution impact. As for the soil strengthening, the main advantage of silica sol is its usage for environment.

Table 10 shows that not only silica sol, but sols of difference nature may be applicable.

Tables 11-12 demonstrate simultaneous soil strengthening and detoxication time by means of reaction 1-7 and a new position is detoxication of Kr (a dangerous action of heavy metal ions) and table 12 shows that not only silicates but aluminates of different cement may be useful for simultaneous strengthening and detoxication and it is an innovative way for hardening binder system.

| No | The structure | Average density, kg/m3 |
|----|--------------|------------------------|
|    |              | D400 | D500 | D600 |
|    |              | control | sol | control | sol | control | sol |
| 1  | D1mm         | 3.0 | 2.8 | 2.4 | 2.0 | 1.8 | 1.7 |
| 2  | D2mm         | 0.5 | 0.6 | 0.3 | 0.32 | 0.25 | 0.27 |
| 3  | Dnmicron     | 4.5 | 3.0 | 4.5 | 3.7 | 3.9 | 3.5 |
| 4  | n/ph         | – | + | – | ++ | – | +++ |
| 5  | CaO/SiO2     | 5.2 | 4.8 | 3.5 | 3.2 | 3.0 | 2.6 |

* YSM = 35CF(YEOL) and JNKA = 400 (oxford instruments)
where:
- D₁ mm is the average diameter of pores;
- D₂ mm – the wall between pores;
- Dₙ microns – average diameters of micro pores in the wall between pores;
- n/ph – new phases;
- CaO/SiO₂ – ratio CaO/SiO₂
Table 10. Technologies for transport construction

| Examples of sols for sol-gel transition | Processes of inorganic systems | Technologies for transport construction |
|----------------------------------------|---------------------------------|----------------------------------------|
| SiO$_2$·nH$_2$O; Al$_2$O$_3$·nH$_2$O; Fe$_2$O$_3$·nH$_2$O; | Sol-gel – transition, SiO$_2$·nH$_2$O→SiO$_2$·nH$_2$O | Soling for soil strengthening due to binding properties of gel |
| Reaction SiO$_2$·nH$_2$O+Me$^{2+}$=MeO·SiO$_2$ · Silica sol – solution (n-1)H$_2$O+2H$^+$; | | Soling for simultaneous soil strengthening and detoxication, if Me$^{n+}$ MeO·SiO$_2$·(n-1)H$_2$O has a very low solubility product, less than 10$^{-10}$ |

Table 11. Prediction of simultaneous soil strengthening and detoxication

| Binder | Statically capacity according to heavy metal ions |
|--------|-----------------------------------------------|
|        | Cu(II) | Pb(II) | Cd(II) | Mn(II) | Ni(II) | Fe(III) |
| Cement made of silicate calcium | detocification | 1-3,5 | hardening | - | - | - | + | + | + |
| Aluminates calcium | detocification | production | hardening | + | + | + | + | + | + |
| Expansive cement | detocification | production | hardening | + | + | + | + | + | + |
| Straining cement | detocification | production | hardening | + | + | + | + | + | + |

+ Detoxication process is good for hardening; - Detoxication process prevents hardening
5. Conclusions

1. Concrete stone has a possibility to absorb silica sol solution due to capillary porosity; according to thermodynamic analysis, concrete stone can form new calcium silicate hydrates in such a way.

2. According to the results of the experiments, the main technical properties of the concrete show a great improvement.

3. Thermodynamic analysis of the clay minerals revealed the negative meaning of Gibbs free energy and possibility of the reaction to obtain silica gel and

Table 12. Strengthening and detoxication of soil by means of silicate hydrates and obtaining silica sol

| No. n/n | Minerals                  | Possibilities for soil strengthening by means of binder system                                                                 | pH |
|---------|--------------------------|-----------------------------------------------------------------------------------------------------------------------------|-----|
| 1       | C_2S, C_3S               | (1) xC_3S + nH_2O + K_{Taq} → xK_2O·ySiO_2·nH_2O + K_4(OH)_2 + xNa_2O·ySiO_2·mH_2O                                             | 7   |
|         |                          | (2) xC_3S + nH_2O + K_{Taq} → xK_2O·ySiO_2·nH_2O + K_4(OH)_2 + xNa_2O·ySiO_2·mH_2O                                             | 7   |
|         |                          | (3) C_2S + Na_2SiO_3 (K_2SiO_3) + nH_2O + xK_4(OH)_2 + xK_2O·ySiO_2·nH_2O                                                     | 7   |
| 2       | xMgO·ySiO_2              | (4) xMgO·ySiO_2 + nH_2O + K_{Taq} + K_2O·xSiO_2·yH_2O + xMgO·ySiO_2·nH_2O                                                    | 7   |
| 3       | Al_2O_3·2SiO_2 (Metacaolinit) | (5) Al_2O_3·2SiO_2 + Na_2SiO_3 (K_2SiO_3) + nH_2O + (K_4OH) _aq + K_4(OH)_2 + xNa_2O(K_2O)·yAl_2O_3·2SiO_2·mH_2O + aSiO_2·bH_2O | 7   |
| 4       | Al_2O_3·2SiO_2·2H_2O (clay mineral) | (6) Al_2O_3·2SiO_2·2H_2O + 3K_4(OH) _aq + H_3PO_4 + (K_4PO_3)_3·nH_2O + SiO_2·mH_2O + Al_2O_3·xP_2O_5·nH_2O | <7  |
| 5       | SiO_2·nH_2O sol           | (7) K_2 + SiO_2·nH_2O + 2OH^- → KrO·SiO_2·nH_2O + H_2O                                                                    | 7   |
phosphates with very low solubility product, if there are heavy metal ions in the system.

4. Experiments demonstrated that a system containing clay and phosphoric acid is resistant to the effect of pollution by oil, heavy metal ions and has good enough strength for the purposes of obtaining artificial stone, for ground strengthening and detoxication process simultaneously.

6. References

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