Geosphere Protection on the Base of Foam Building Systems

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Abstract. Geosphere purification from pollutions demands new solutions. The new technology application is one of them. It is based on new geoecoprotective properties of soils in building systems. The main aim of the study is to present a new technology of geosphere protection both for strengthening and detoxication of soils. This technology is to use building foam on the protein base. Experimental methods were carried out during the research. Taking into account the results of the experiments, two different techniques of foam application in building systems have been developed. The first one is to use foam concrete on the cement base. Due to its high flowability foam cement can be injected into a soil and after hardening the system is like the load bearing joint which has absorption properties. The second technique is to produce the foam soil cement material which results in detoxication during its hardening. Technical and geoecoprotection properties of both the foam soil cement material and the load bearing joint are described in the paper.

1. Introduction

There are different problems of soil strengthening as geosphere protection technology during construction but the most important of them is ignoring lithosphere pollution. Moreover, some strengthening agents are dangerous to lithosphere. Inorganic material like cement is considered to be good one for strengthening. What is more, it is safe to lithosphere. Detoxicating properties of cement systems have been already known [1-6]. Now foam cement systems can be used for soil strengthening and detoxication due to their good technical properties, e.g. high flowability.

The main aim of the paper is to present two techniques of foam cement use both for strengthening and detoxication of soils as a protector of geosphere. The foam cement mixture forms the load-bearing joint without mixing with a soil after cement hardening while the foam soil cement material is produced and hardened by mixing with a soil. The first technique is soil strengthening with the use of load bearing joints and it is equivalent to reinforcement and detoxication of soils by means of foam concrete. The second technique is to mix a soil with foam cement. The material obtained is like foam concrete but it is the foam soil concrete (material). When applying this technique pollution detoxication occurs because of the material hardening. So, detoxication must take place when applying the first and the second technologies, with heavy metal ions being detoxicated through geoecochemical reactions. In the case of the use of the load-bearing joint which has an absorption ability during its operation heavy metal ions can be absorbed by an artificial stone like foam concrete.
When applying the foam soil cement material heavy metal ion detoxication takes place during hardening process. It should be noticed that in both cases the detoxicated products are inside of an artificial stone. Such technologies are named geosphere preservation technologies on the base of building systems. That is why foam cement use technology both for strengthening and detoxication is progressive in the terms of geoecoprotective properties of building systems. The Table 1 presents two techniques of foam system use for geosphere protection.

### Table 1. Foam systems for geosphere protection.

| Foam systems | Object of an impact | Results of an impact | Impliable mechanism of an impact | Technique of a foam system use |
|--------------|---------------------|----------------------|----------------------------------|-------------------------------|
| 1) foam cement or foam concrete | sandy soil as the load bearing joint in a soil | 1. protection from heavy metal ion pollution | 1. formation of substances with very low solubility product | injection of foam cement into a soil due to high flowability |
| | | 2. strengthening of sandy soils | 2. formation of heavy metal ion complex with protein foam | |
| | | | 3. strengthening thanks to formation of the load bearing joint and foam concrete hardening | |
| 2) foam soil cement material | soil, void cement material | both strengthening and detoxication of soil systems | 1. cement hardening | mixing with a soil |
| | | | 2. formation of substances with very low solubility product | |
| | | | 3. formation of heavy metal ion complex with protein foam | |

However, foam concrete and foam cement are known to have brittleness and it is possible to raise durability of the material by means of crack resistance increase. On the other hand, detoxication can be increased using a special additive. The Table 2 presents the ideas of improvement of foam concrete properties such as bending strength and detoxication ability.

### Table 2. Substances used to improve the properties of foam systems.

| Property to be improved | Substances used for improvement | Mechanism of the action |
|-------------------------|---------------------------------|-------------------------|
| bending strength        | substances containing Mg(II), Al(III) | electron nature of cations Mg(II) – sp² and Al(III) – sp³ – structural motives possibilities to obtain bonds and contacts with solid phases Possible reactions: 1)3Cu²⁺+2PO⁴³⁻=Cu₃(PO₄)₂↓ 2)3Pb²⁺+2PO⁴³⁻=Pb₃(PO₄)₂↓ |
| detoxication            | substances containing amylose (natural product such as starch) Na₃PO₄ | |

It is important to say that Na₂CO₃, Na₃PO₄ can increase detoxicating properties of foam systems due to sediment formation. The base of such an increase is very low solubility product for Cu₃(PO₄)₂ – 1.26·10⁻³⁷; for Pb₃(PO₄)₂ – 7.9·10⁻⁴²; for Cd₃(PO₄)₂ – 2.5·10⁻³³.
2. Methods
The experimental methods were used. Protein foam, cement and sand were mixed according to the standards of the Russian Federation. Then for strengthening and detoxication the model soil system was saturated in two different techniques:

1. Foam concrete on the cement base was injected into the sandy soil in any way. The model soil was polluted by heavy metal ions such as Cd(II), Cu(II), Pb(II) with nearly 1000 TC (tolerable concentration, mg/kg): for Cu(II) – 3, for Pb(II) – 20 (32), for Cd(II) – 0.5. After foam concrete hardening the systems were watered. After 28 days the aqueous extract was taken and examined for heavy metal ion presence by means of selected electrodes. Foam concrete was used without any additives to improve bending strength (samples 40x40x160 mm), while the other samples contained additives up to 5% of the cement mass to increase crack resistance and up to 5% of substances to raise detoxication. 28 days later the samples were tested.

2. Foam and cement were mixed with the soil polluted by heavy metal ions such as Cu(II), Cd(II) with nearly 1000 TC. Then the foam soil cement material hardened and after 28 days the aqueous extract was taken and tested using selected electrodes for heavy metal ion presence. Substances which increase crack resistance and detoxication were added. 28 days later all the samples were examined. The Table 3 demonstrates the techniques of foam building system use in soils.

| Technique of a foam system production | Technique of the interaction with the soil |
|---------------------------------------|------------------------------------------|
| 1. foam concrete with cement           | injection into the sandy soil due to high flowability |
| 2. foam soil concrete material         | mixing foam cement concrete with any soil |

3. Results and discussion
The Tables 4, 5 and 6 illustrate the results of the research.

| Examples of the foam concrete mixture per 1 m³ of the material | Compressive strength of the samples, MPa | Heavy metal ion pollution in the soil | Tolerable concentration (TC), g/t | Polluted soil, nearly 1000 TC |
|---------------------------------------------------------------|-----------------------------------------|-------------------------------------|-----------------------------------|-------------------------------|
| 1. average density – 0,500 t/m³                               | 1.5-1.7                                 | Cu(II)                             | 3                                 | heavy metal ions were not found in the aqueous extract |
| Cement – 320 kg                                               |                                         | Cd(II)                             | 0.5                               | heavy metal ions were not found in the aqueous extract |
| Sand – 130 kg                                                 |                                         | Pb(II)                             | 32                                | heavy metal ions were not found in the aqueous extract |
| Protein foam additive – 1.8 litre Water for high flowability  |                                         |                                    |                                    |                  |
| 2. average density – ≈ 0,800 t/m³                             | ≈2-3.5                                  | Cu(II)                             | 3                                 | heavy metal ions were not found in the aqueous extract |
| Cement – 460                                                  |                                         | Cd(II)                             | 0.5                               | heavy metal ions were not found in the aqueous extract |
| Sand – 280                                                   |                                         | Pb(II)                             | 32                                | heavy metal ions were not found in the aqueous extract |
| Protein foam additive – 1.6 litre Water for high flowability  |                                         |                                    |                                    |                  |
Table 5. Properties of the protein foam concrete having an average density 0,600 t/m³ with the complex additive.

| Additive                  | Density of the foam soil mixture kg/m³ | w/c | Flowability, cm | Bending strength, MPa 28 days | Heavy metal ions in the aqueous extract |
|---------------------------|----------------------------------------|-----|-----------------|-------------------------------|----------------------------------------|
| Complex: MgSO₄·7H₂O industrial starch – 3% | 740 | 0,42 | 24              | 1,3/100                      | not found                              |
|                           | 787 | 0,55 | 24              | 2,79/214,4                  | not found                              |

Table 6. Properties of the protein foam soil cement material having an average density 0,800 t/m³ with Al₂O₃.

| Additive | ΔH°₂⁹⁸, kJ/mol | Density of the foam concrete mixture, g/m³ | w/c | Flowability, cm | Bending strength, MPa/% | Heavy metal ions in the aqueous extract |
|----------|----------------|-------------------------------------------|-----|-----------------|------------------------|----------------------------------------|
| -        | -              | 970                                       | 0,38| 20              | 1,36/100               | not found                              |
| Al₂O₃ – 3% | -1676,8         | 970                                       | 0,38| 20              | 1,78/130               | not found                              |

Table 7. Improvement of the foam soil cement material having detoxication properties.

| Foam soil system, average density, kg/m³ | Heavy metal ions in lithosphere | Additive in the foam soil cement mixture, 1-3% | Detoxication properties of the foam soil cement material, g/kg/% |
|----------------------------------------|---------------------------------|-----------------------------------------------|---------------------------------------------------------------|
| 400-600                                | Cu(II);Cd(II);Pb(II)            | -                                            | ≈0,3/100                                                     |
| 400-600                                | Cu(II);Cd(II);Pb(II)            | Na₂CO₃; Na₃PO₄                                 | ≈0,45/150                                                    |

According to the Tables 4, 5, 6, 7 it was possible both to strengthen and detoxicate the soil as well as to improve the results. The Table 8 shows that the reactions between cement substances and foam resulted in formation of the substances with very low solubility product, less than 10⁻¹⁵. These substances were heavy metal ion hydrates and hydroxides. What is more, protein took heavy metal ions in the complex. That is why detoxication effects were better. In real railway conditions there are nearly 20-200 TC pollutions and the obtained result is quite good for detoxication.

Table 8. Foam soil cement systems and heavy metal ion reactions.

| Reactions                                                                 | ΔG of the reaction | Solubility product (SP), hydroxides |
|--------------------------------------------------------------------------|--------------------|------------------------------------|
| 2(CaO·SiO₂·H₂O)(s)+2Cd²⁺(l)+H₂O(l)=                                      | ΔG°₂⁹⁸<0           | Cd(OH)₂=3.4·10⁻¹⁵                  |
| CdO·SiO₂·H₂O(s)+Cd(OH)₂(s)+SiO₂·H₂O(s)+2Ca²⁺(l)                         |                    |                                    |
| 2(CaO·SiO₂·H₂O)(s)+2Cu²⁺(l)+2H₂O(l)=                                   | ΔG°₂⁹⁸<0           | Cu(OH)₂=5.6·10⁻²⁰                  |
| CuO·SiO₂·2H₂O(s)+Cu(OH)₂(s)+SiO₂·H₂O(s)+2Cu²⁺(l)                       |                    |                                    |
| 2(CaO·SiO₂·H₂O)(s)+2Pb²⁺(l)=PbO·SiO₂+Pb(OH)₂                              | ΔG°₂⁹⁸<0           | Pb(OH)₂=1.2·10⁻²⁰                  |
| SiO₂·H₂O+2Ca²⁺                                                        |                    |                                    |
As a model solution contained up to 1000 TC of Cd(II) or Cu(II) the soil was mixed with foam cement. Then the soil sample (1m of the surface depth) was taken and tested by selected electrodes. Cd(II), Cu(II) ions were not found. The papers [6-10] examine different problems of the solid body surface and according to the papers [11-20] technologies which are capable to affect a surface should be recognized progressive and useful.

4. Conclusions
1. Foam building systems on the protein base are suggested both for detoxication and strengthening of a soil.
2. To detoxicate heavy metal ions such as Cu(II), Cd(II), Pb(II) properties of the foam soil cement systems can be increased using some additives, namely: Na₂CO₃, Na₃PO₄.
3. Bending strength of the foam soil systems can be improved using Al(III) and Mg(II)-based additives.

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