Journal of Applied
Technical and Educational Sciences
Engineering, Vocational and Environmental Aspects
www.jates.org
ISSN 2560-5429
Volume 9, Issue 1
doi: 10.24368/jates.v9i1.87
http://doi.org/10.24368/jates.v9i1.87
JATES
Journal of Applied Technical and Educational Sciences

Effect of industrial sludge-soil mixtures on germination of white mustard and wheat

Éva Kovács-Bokor[a], Endre Domokos[b], Endre Kiss[c]

[a]*University of Dunaújváros, 1/A M. Táncsics St, Dunaújváros 2400, Hungary, kovacsbe@uniduna.hu*
[b]*University of Pannonia, 10 Egyetem St, Veszprém 8000, Hungary, domokose@uni-pannon.hu*
[c]*University of Dunaújváros, 1/A M. Táncsics St, Dunaújváros 2400, Hungary, kisse@uniduna.hu*

Abstract

Many industrial process produce different kind of sludge as by-product. Those various sludge-types can contain heavy metals or other valuable or reusable elements (as rare-earth metals). Our aim is to determine the accumulation rate of these elements in the plant-tissues and establish the phytoremediaton potential of the plants. Laboratory experiment was conducted in seedling growth tests with various mixtures of red mud, converter sludge and different soil-type-peat mixtures. White mustard *(Sinapis alba)* and wheat (*Triticum aestivum)* seeds were applied for the experiments. According to these tests we determined that among the mixtures the most capable ones were the red mud mixed with slightly saline or slightly acidic brown forest soils. In case of the converter sludge, mixtures with chernozem and loess soil showed the best results for germination. The presence of the used sludge-types could stimulate the germination of seeds and the growth of plumules of plants, however the results are highly depends on the type of the soils. The results highlight the importance of seedling tests in determining the phytoextraction possibility when using industrial waste materials, such as the tested sludge-types.

Keywords: red mud; converter sludge; plants; germination; bioremediation

1. Introduction

Industrial factories are fighting with the problem of disposing produced by-products nowadays. These by-products, industrial sludge-types are generally stored in huge dumps as hazardous wastes. The dumps might create huge risk for the environment. The sludge on the other hand can contain reusable or valuable elements not only toxic components. Due to the valuable elements (e.g. the calcium) the sludge alternatively might be used for improving soil quality *(Újaczki, 2013).* Aim of our research is to decrease the harmful components of the tested sludge-types of using potential phytoextraction methods. It is known that many plant-types are applicable, such as the *Thlaspi, Alyssum, Sebertia, Berkheya* …etc. *(Simon, 2004),* which can tolerate the harmful elements, or they can hyperaccumulate them in their biomass. Seedling growth tests were used to decide which concentration of sludge might be adequate for planting. For this test, converter sludge and red mud were chosen.

Converter sludge is produced during the steel making process. This sludge is the by-product of the wet cleaning technology of the converter gas. It contains heavy metal oxides (e.g. zinc oxide, lead oxide) and other oxides according to the used scrap iron quantity of the raw material. Zinc concentration can be 0.67–5%, and the total annual production of this element can reach 1185 ton/year *(Márkus, Grega, 2011)*. The used samples were produced by ISD-Dunaferr Ltd. in Dunaújváros.

Red mud is the by-product of the alumina making process. This kind of sludge is a highly alkaline (pH>12) waste product *(Lockwood, Stewart, Mortimer, Mayes, Jarvis, Gruiz, Burke, 2015)*. The risks of red mud are its highly caustic nature and its fine particle size. In spite of these harmful properties, red mud has also potential benefits. It can be used for critical raw material recovery (e.g. Ga, V, rare earth metals), carbon sequestration, and used as a soil ameliorant *(Mayes, Burke, Gomes, Anton, Molnár, Feigl, Ujaczki, 2016)*. But the high sodium (Na) content and fine structure of this waste can deteriorate soil structure. The salinity and alkalinity of red mud can affect plant growth. For example, low red mud concentration could stimulate the barley root elongation and the trace elements concentrations in plant shoots increased with increasing the ratio of red mud in soil mixtures *(Ruyters, Mertens, Vassilieva, Dehandschutter, Poffijn, Smolders, 2011)*.

In case of red mud of Ajka, two main types, the wet and dry were used. Wet type was produced with the wet technology before 2011. Dry type was produced with dry technology since the end of 2011. The main mineral sources of red mud are ferric oxides and hydroxides, aluminium-hydroxides and sodium silicates, calcium carbonate, quartz and gypsum. Additional compounds are TiO_2 (4-6%), V_2O_5 (0.2-0.4%), P_2O_5 (0.5-1.0%), Ga, and Ge, as well as rare-earth metals can be found in it. *(Feigl, Újaczki, 2014)*. The used samples were produced by MAL Ltd. (Hungarian Aluminium Production and Trading Company).

2. Materials and methods

Seedling growth test was made by using white mustard seeds *(Sinapis alba)* and wheat seeds *(Triticum aestivum)* as test plants according to MSZ 21 976-17:1993 Hungarian standard. For these experiments, dried red mud and converter sludge and their mixtures with different kinds of soils were calibrated into Petri dishes. The mixtures of the sludge and soils were used at the rates of 20-, 40-, 60-, 80 and 100%. In each Petri dish 20 seeds were dispersed. Three series for each mixture were prepared. After setting the moisture content the samples were covered and incubated for 72 hours in a dark place. At the end of the experiment the number of the germinated seeds and the length of radicles and plumules were counted (Fig. 1.).

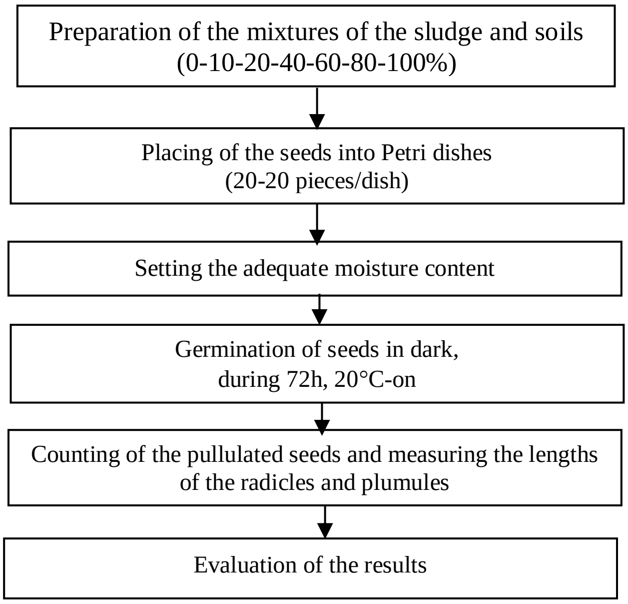

Fig. 1. Steps of the seedling growth test

3. Results

3.1. Industrial sludge mixtures with different soils affected for seed-germination

First of all, we wanted to compare the effect of 100% industrial sludge on the germination of white mustard seeds. Three kinds (old, wet and dry type) of red mud and converter sludge were used. Old type red mud (oRM) was deposed about 15 years ago into the 5th spoil-dump and it was produced from Hungarian bauxite by MAL Ltd in Ajka. Dry type red mud (dRM) had been taken from the 7th, wet type (wRM) sample had been collected from the 8th spoil-dump of this company.

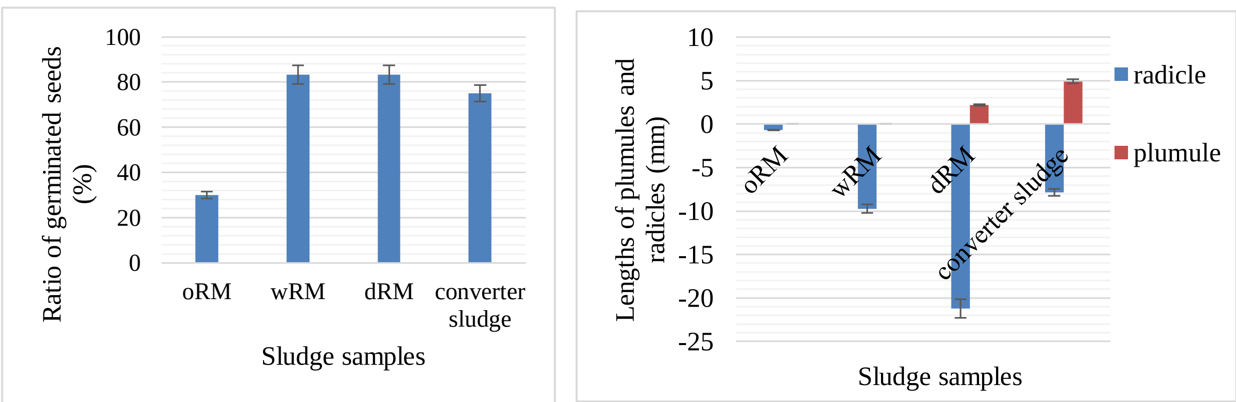

Fig.2. (a) Germinated ratio of white mustard seeds on 100% red mud and 100% converter sludge; (b) Results of germination parameters of white mustard seedlings

We can see on Fig. 2., that the white mustard seeds began to germinate 83% in the case of wet (wRM) and dry (dRM) type of red mud samples. In spite of the high ratio of the germinated seeds, longer radicles and plumules were observed on the dry red mud than on the wet red mud. The highest plumules grew from the converter sludge. The efficiency of the germination was the lowest in the case of old red mud.

Seedling growth tests were also made with mixtures of industrial sludge and soils. Among soils four kinds were used: 1) acidic brown forest soil, 2) chernozem soil, 3) loamy soil and 4) saline soil. Brown forest soil was collected in Sopron Mountain, chernozem and loamy soil samples were taken in Dunaújváros and saline soil was collected from Kiskunság. The mixture rate of the sludge was 20-40-60-80-100%. We also made this test on 100% soils as controls. The pH values of the test soils are shown in Fig. 3. We tried to include soils with low pH, due to the high alkalinity of used old type red mud. Between the test soils the acidic brown forest soil had the lowest pH value. On the basis of the germination results it is possible to decide which mixtures can be adequate for future phytoaccumulation experiments.

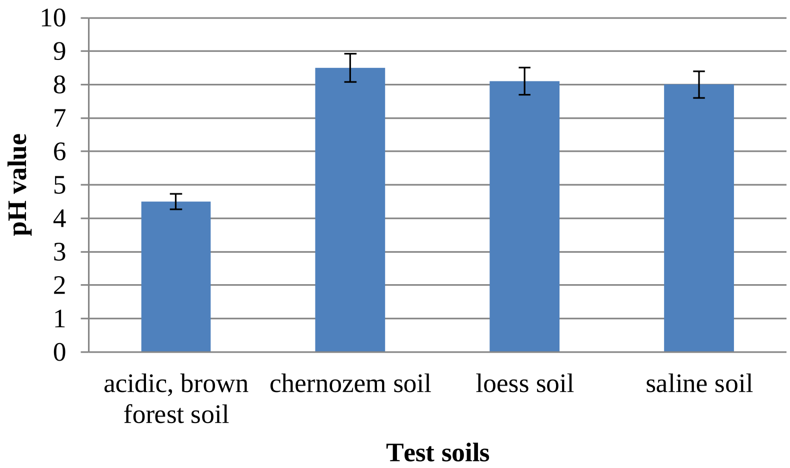

Fig.3. pH values of the tested 4 soil-types

Germination results of the white mustard seeds showed that in the case of old type red mud the mixtures of the acidic brown forest soil and the saline soil represented the best results. When these two kinds of soils were mixed to red mud, the ratio of the germinated seeds were higher (Fig. 4.) and longer radicles and plumules were also observed (Fig. 5.). When the ratio of old type red mud was increased in the mixture, the lengths of radicles and plumules were decreased.

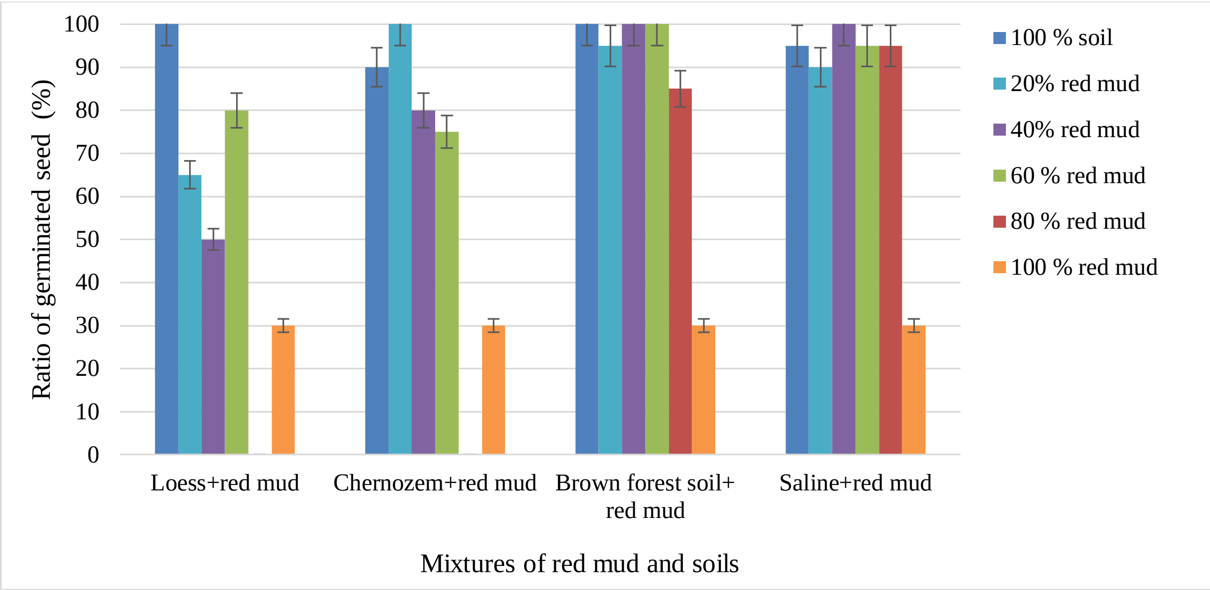

Fig. 4. The ratio of the germinated seeds on the mixtures of red mud and different soils

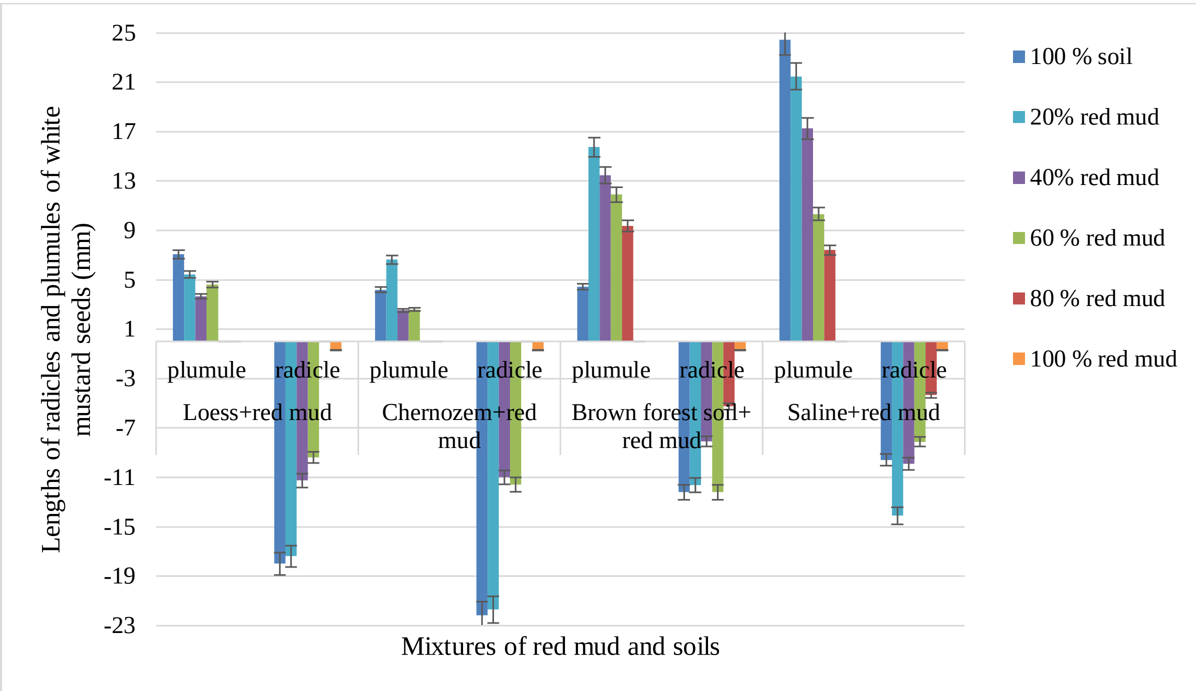

Fig. 5. The length of radicles and plumules, germinated on the mixtures of red mud and soils

The germination results of the mixtures of converter sludge and soils showed that between the four kinds of soils, loess and chernozem soils were the most effective. When these two kinds of soils were mixed to converter sludge, the ratios of the germinated seeds were higher (Fig. 6.) in the case of 20- and 40% mixtures. Longer radicles and plumules were observed in these mixtures (Fig. 7.). When we compared the controls to their 20% mixtures with converter sludge, it can be determined that the presence of this sludge could stimulate the growth of the seedlings.

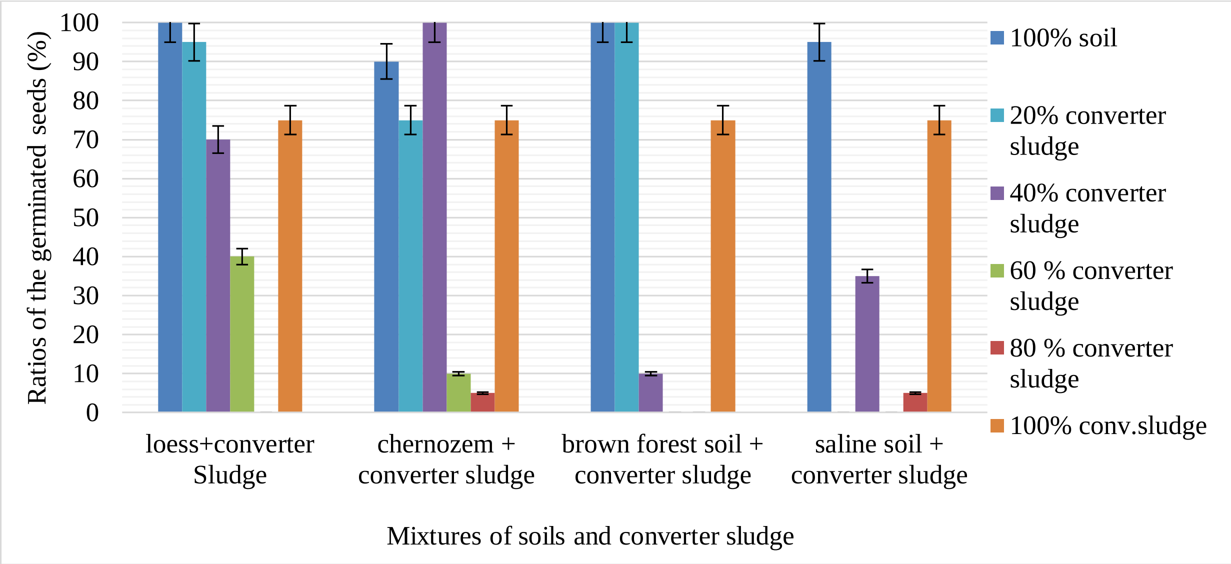

Fig. 6. The ratio of the germinated seeds, grown on the mixtures of converter sludge and soils

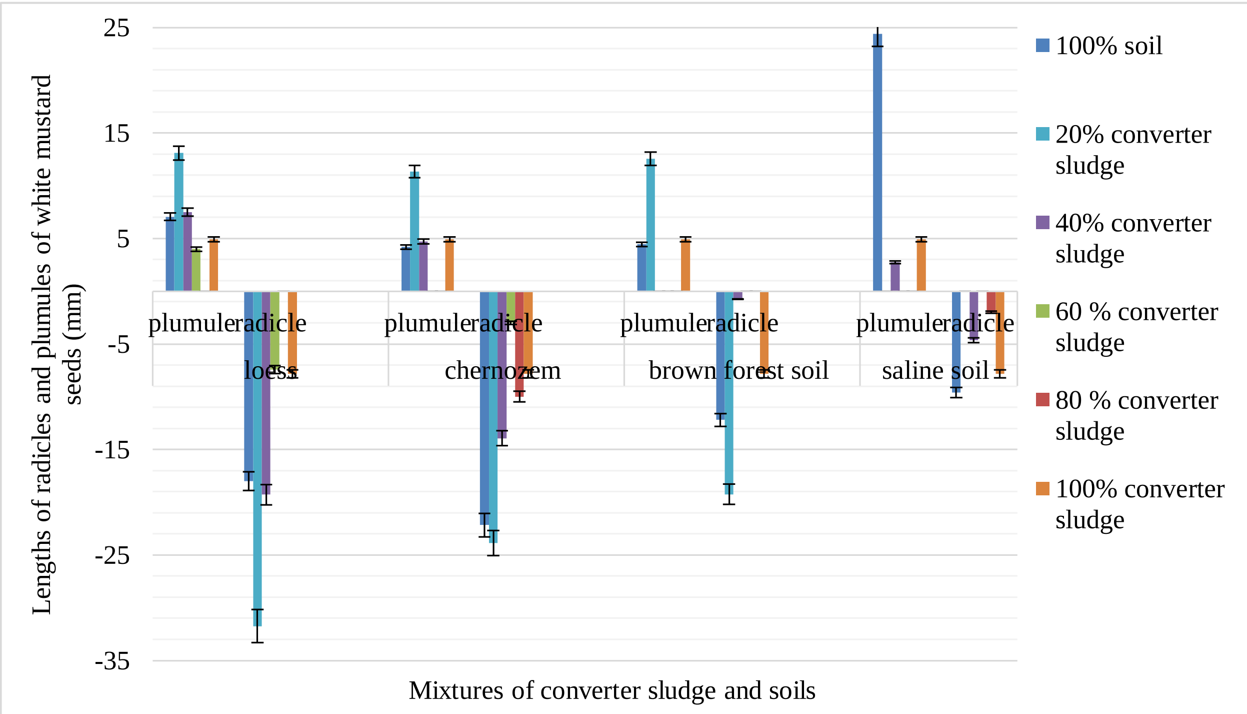

Fig. 7. The length of radicles and plumules, when the seeds were grown on converter sludge - soil mixtures

3.2. Effects of red mud on the germination of white mustard and wheat seeds

Beside the soils, peat was also used for the seedling growth tests, because we tried to compensate the high alkalinity of red mud. The pH value of the peat was around 6. Longer radicles and plumules were measured on the dry red mud sample (dRM) than the wet red mud sample (wRM). Wheat seeds could germinate better than white mustard seeds (Fig.8.).

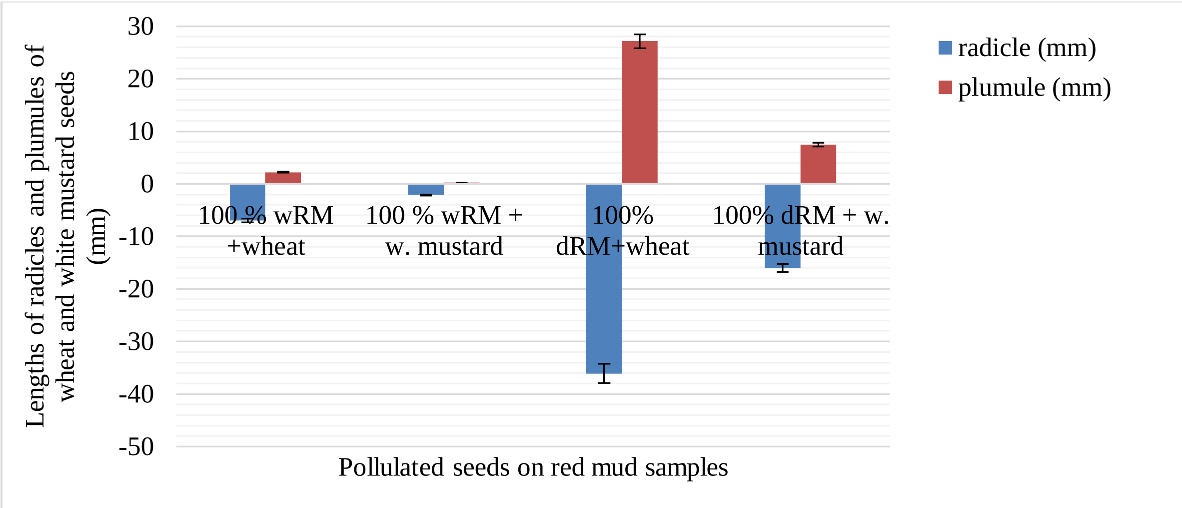

Fig. 8. The germination results of white mustard and wheat seeds, grown on dry (dRM) and wet (wRM) red mud.

When the ratios of the germinated seeds were compared, it can be seen that the 80-100% of the seeds have begun to germinate (Fig. 9.).

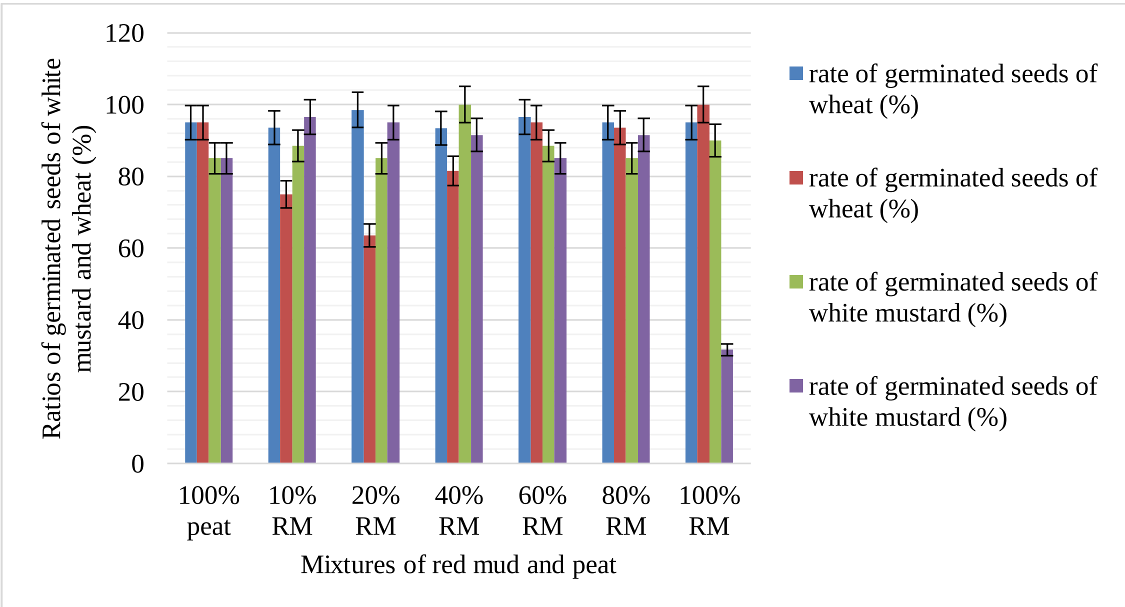

Fig. 9. Ratios of the germinated seeds in the mixtures of red mud and peat

In Fig. 10. it can be seen that increasing of the ratio of red mud a higher negative effect develops on the lengths of radicles and plumules of white mustard seeds. Inhibition was observed in the germination when the ratio of red mud was higher in the mixtures. Between the red mud samples wet type (wRM) was more effective.

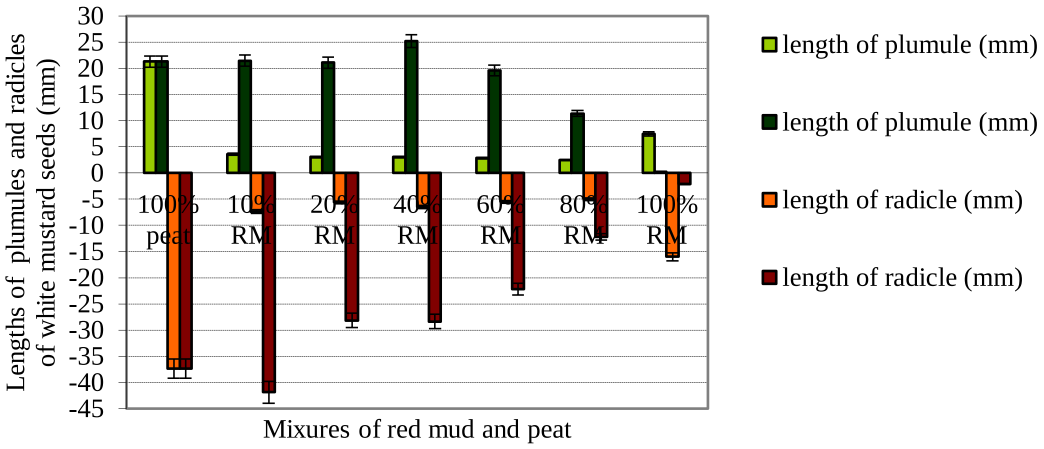

Fig. 10. The length of radicles and plumules of white mustard seedlings, grown on the various mixtures of red mud and peat

In the case of wheat seeds the mixtures of dry type red mud (dRM) were more effective. The higher ratio (60-80%) of dry red mud had a positive effect (stimulation) on the growth of radicles but has a negative effect (inhibition) on the growth of plumules (Fig. 11.).

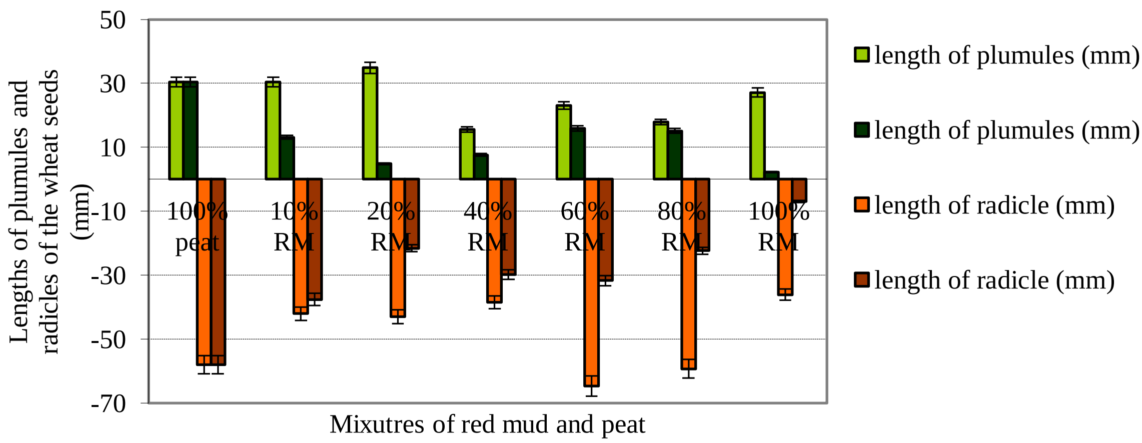

Fig. 11. The length of radicles and plumules of wheat seedlings, grown on the various mixtures of red mud and peat

According to the data of the lengths of the radicles and plumules in the mixtures and the controls, the inhibition of growth *(Milinki, 2013)* was also calculated with this equation (1):

$$X = \left(\frac{K-M}{K}\right) * 100 \tag{1}$$

Where:

X: Inhibition of the growth of radicles or plumules (%)

K: The lengths of the radicles or plumules in the controls (mm)

M: The lengths of the radicles or plumules in the mixtures (mm)

We can see in Fig. 12. that in the case of white mustard the inhibition of the growth of plumules and radicles was low in the 10-20-40% wet red mud (wRM) mixtures. The inhibition was higher in the mixtures of dry red mud (dRM).

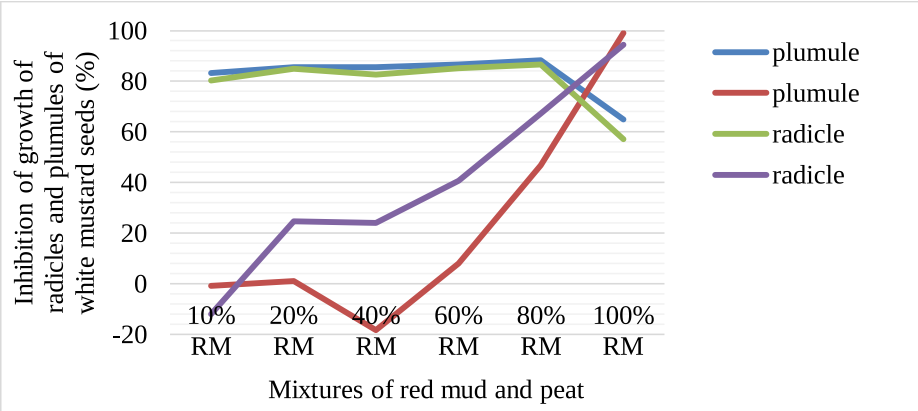

Fig. 12. The inhibition of the growth of radicles and plumules of white mustard seedlings, grown on various mixtures of red mud and peat

Fig. 13. shows the results of inhibition of growth by using wheat seeds in the mixtures. The results represented that the inhibition in the mixtures of wet red mud (wRM) was higher than in the mixtures of dry red mud.

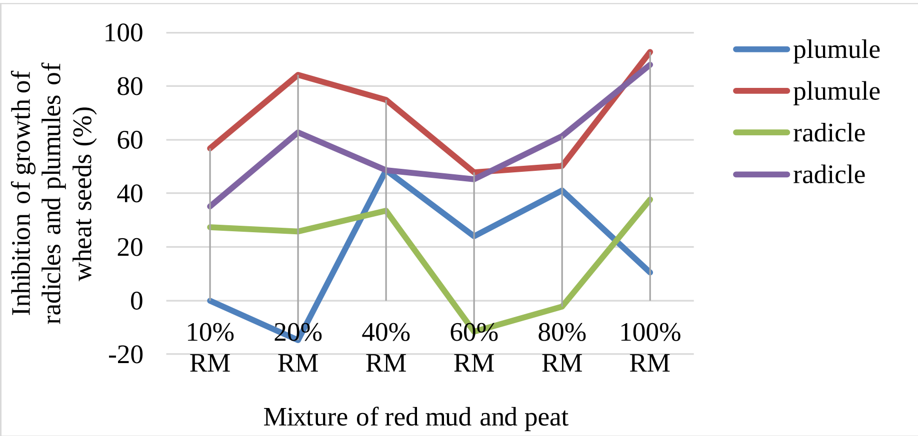

Fig. 13. The inhibition of the growth of radicles and plumules of wheat seedlings, grown in various mixtures of red mud and peat

Beside the above measurements the number of the radicles of wheat seeds were also counted during the seedling growth tests. In the case of wet type red mud (wRM), the mixture of 60 and 80% showed better results (Fig. 14.). In these mixtures, wheat seeds grew more than three radicles. In most of the mixture wheat seeds grew 3 pieces of roots.

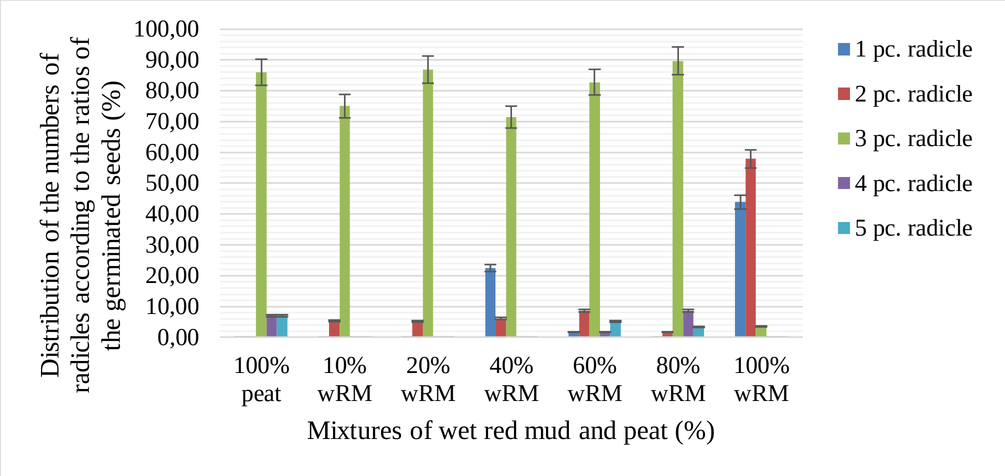

Fig. 14. The distribution of the numbers of the radicle of wheat seedlings, gown on the mixtures of dry red mud (wRM) and peat

In the case of dry type red mud (dRM), the smaller ratio (10-20%) of red mud were already effective. In the mixtures of the dry type red mud, 3-4 pieces of radicles appeared at almost every mixture (Fig. 15.). Dry red mud stimulated the growth of radicles.

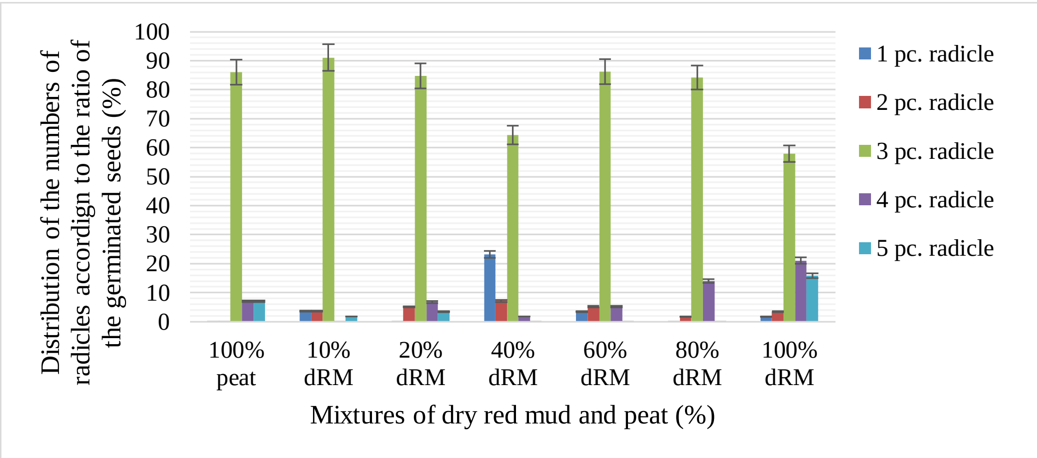

Fig. 15. The distribution of the numbers of the radicle of wheat seedlings, gown in the mixtures of wet red mud (dRM) and peat

According to the results of the mixtures of the industrial sludge-types and soils, the lengths of the wheat plumules were measured a month later. Among the mixtures loess and converter sludge, saline soil and brown forest soil and red mud mixtures were used for this experiment. In the case of the control sample (100% loess) wheat could grow smaller plumules than the mixtures of converter sludge (Fig.16.). Stimulation were observed in these mixtures, perhaps because for example zinc is an essential element for plants. The highest plumules were measured in the 15% and 25% mixtures.

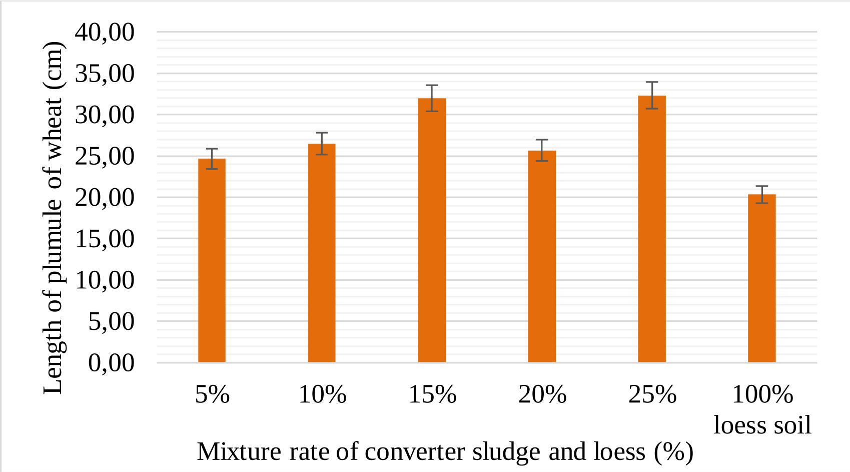

Fig. 16. The length of plumules of wheat seedlings, grown on various mixtures of converter sludge and loess

Fig. 17. shows the results of the red mud and soil mixtures. In the mixtures of red mud and saline soil the lengths of plumules of wheat were higher than in the control (100% saline soil). The highest plumules were measured in the 5% mixture. Small inhibition were observed when the ratio of red mud increased in these mixtures. In the case of the mixtures of acidic brown forest soil and red mud the 5% mixture showed the best result. In the other mixtures small inhibition was observed. Comparing to the controls the mixtures with saline soil showed better results.

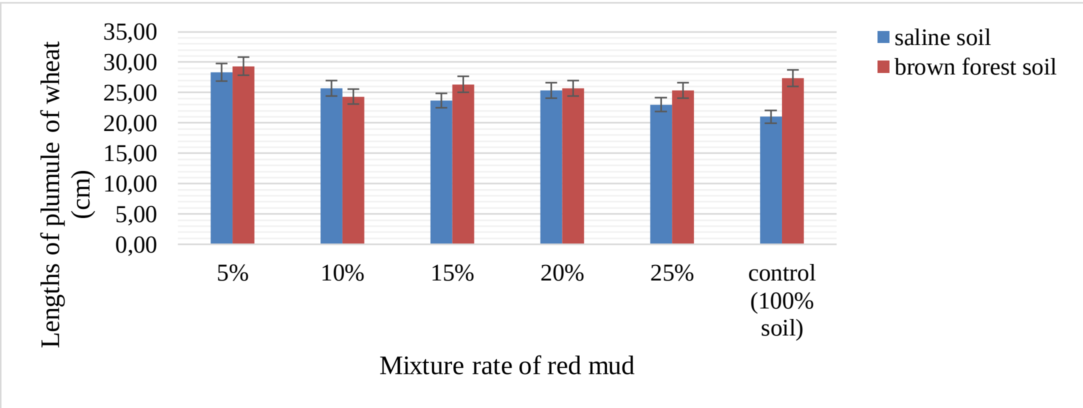

Fig. 17. The length of plumules of wheat seedlings, grown on the mixtures of red mud and saline soil or acidic brown forest soil

4. Conclusions

According to the seedling growth tests of the industrial sludge-types it can be determined that red mud (dRM) showed the best results, when testing the germination of white mustard seeds.

Red mud and soil mixtures could support seed-germination better on saline soil and on acidic brown forest soil. In case of converter sludge, the mixtures with chernozem and loess soil produced longer radicles and plumules. According to the ratio of the sludge-types in soils, we will use the 40-60% mixtures of red mud and saline or acidic brown forest soil and 20-40% mixtures of converter soil and loess or chernozem, regarding the further laboratory experiments.

The result of the red mud and peat mixture was that white mustard seeds preferred the wet red mud, on the other hand wheat seeds preferred of the dry red mud for the germination. The number of the radicles of wheat seeds was higher in dry red mud mixtures.

According to the measurement of the length of plumules of wheat we can determine that in the case of saline soil, the presence of red mud stimulated the plant growth. This can be told about the experiment of converter sludge and loess soil, where the 15% and 25% mixtures showed the best results.

We observed that the components of converter sludge and red mud were able to stimulate the germination of seeds and growth of plumules, however its value is highly dependent on the soil-types, used.

5. Acknowledgements

The authors are grateful for the support of EFOP-3.6.2-16-2017-00018 „*Produce together with the nature – agroforestry as a new outbreaking possibility*" project.

6. References

Újaczki É. (2013) Vörösiszap talajjavító hatásának környezettoxikológiai elemzése mikrokozmosz kísérletekben. Retrieved from http://docplayer.hu/958257-Vorosiszap-talajjavito-hatasanak-kornyezettoxikologiai-elemzese-mikrokozmosz-kiserletekben.html

Simon L. (2004) Fitoremediáció. Budapest. Hungary. BMKE OMIKK. ISBN: 963 593 429 0

Márkus R., Grega O. (2011) „Veszélyes hulladéknak minősülő ipari eredetű porok és más hulladékok veszélyességének megszüntetése, hasznosítási lehetőségeik kidolgozása." Retrieved from https://www.kfki.hu/~anyag/tartalom/2011/1/osszefoglalo.pdf

Lockwood C.L., Stewart D. I., Mortimer R. J.G., Mayes W. M., Jarvis A.P., Gruiz K., Burke I.T. (2015). Leaching of copper and nickel in soil-water systems contaminated by bauxite residue (red mud) from Ajka, Hungary: the importance of soil organic matter. Environ Sci Pollut Res 22: 10800-10810. DOI 10.1007/s1356-015-4282-4.

Mayes W.M., Burke I.T., Gomes H.I., Anton Á.D., Molnár M., Feigl V., Ujaczki É. (2016). Advances in Understanding Environmental Risks of Red Mud After the Ajka Spill, Hungary. J. Sustain. Metall. 2:332-343. DOI 10.1007/s40831-016-0050-z.

Ruyters S., Mertens J., Vassilieva E., Dehandschutter B., Poffijn A., Smolders E., (2011). The Red Mud Accident in Ajka (Hungary): Plant Toxicity and Trace Metal Bioavailability in Red Mud Contaminated Soil. Environmental Science and Technology, 2011, 45. 1616-1622. DOI 0.1021/es104000m.

Feigl V., Újaczki É. (2014.) Ajkai vörösiszap (nedves technológiából származó) (konkrét hulladék, melléktermék jellemzése. Retrieved from http://www.mokkka.hu/db1/rec_list.php?db_ type=mysql&lang=hun&sheet_type=36&datasheet_id=1059&sorszam=1059&order=user&sheet_type_filter=0&sheet_lang_filter=HU&alluser_filter=

Milinki É. (2013) Ökotoxikológia és környezetvédelem. Retrieved from https://www.tankonyvtar.hu/hu/tartalom/tamop412A/2011-0038_03_milinki_hu/ar01s06.html

Short professional biography

Éva Kovács-Bokor is working at the University of Dunaújváros as an assistant research fellow. Responsibilities: Control and coordinate of laboratory practices for student on the field of physics and environmental protection. Teaching Renewable energy resources, Waste management, Conservation, Environmental Protection and Safety engineering subjects. Take part in national and EU's grant applications and research work. Consulting final thesis of students on the field of environmental science. She graduated as a teacher of environmental studies – (2008 – 2009) at University of Szeged, Faculty of Natural Sciences and Informatics. PhD education: from 2016 at University of Pannonia. Her PhD topic and research field: Monitoring of the mobilization of heavy metal content of sediments, and the reduction of its heavy metal content with chemical and biological methods (phytoextraction).

Endre Domokos, PhD is Asssociate Professor and Head of Institute at the Institute of Environmental Engineering, Faculty of Engineering, University of Pannonia, Hungary. He graduated at University of Pannonia. His PhD topics were: computer simulation, modelling, energy management, sewage cleaning technologies. His research projects focuses on the modelling of sewage water plants with special emphasis of the practices of the optimizations processes. He has extensive experience from methodical investigations which are related to the construction of e-learning curriculums. He is a member of the Hungarian Sewage Cleaning Association and the Chemical Technological and Environmental Protection Working Committee of MTA (Hungarian Academy of Sciences).

Endre Kiss, PhD, professor of Physics, Heat and fluid dynamics, and Environmental protection, graduated at the University of Szeged, and made PhD degree at the same university. His research fields are decomposition of hazardous gas content of exhaust and flue gases using fast electric discharges, utilization of red mud using bio-mining methods, and treatment of plastic and metallic surfaces by silent electric discharges.