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Chapter 14

Biomass Production on Reclaimed Areas Tailing Ponds

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Additional information is available at the end of the chapter

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Abstract

This chapter presents the results of a multiannual systematic research and development of essentially new environmental safety technology of overlapping tailing pond modelled in terms of Vojany thermal power plant (EVO), Slovakia. Re-cultivated tailing area can be used to produce biomass (Swedish willow) and this biomass is used again for subsequent incineration with coal. Laboratory and small plot experiments conducted directly in the tailing pond area resulted in the development of another new dimension of environmental technology of decontamination of tailing ponds. This technology connects technical, safety, economical and environmental effects for biomass production.

Keywords: biomass, willow, tailing pond, re-cultivation, energy

1. Introduction

Nowadays the world is facing a global problem, which has an effect of plants on the environment. Slag (dross ashes mixture) and fly ash are formed by the combustion of coal. In the wider vicinity of power plants, it is a waste that burdens the environment. The problem of landfill sites must be effectively addressed because they are in terms with the landscape stability and severe environmental and safety problems.

There is a real danger of breaking up the dam especially, in the case of dumping large quantities of such wastes in an area of huge tailings ponds. Therefore, it can have serious consequences on the population, components of the environment and property, in general. The tailings ponds are stores of very fine waste containing significant amounts of water. Their mobility from the pond is high, if they are released. Subsequently, they can have trans-boundary impacts, also impact on the landscape areas and protected areas of European importance because they migrate long distances, particularly over the surface water flows.

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Especially by using environmentally sound technologies, it is necessary to ensure adequate management of these wastes, for security and long-term stability of tailing ponds.

2. Tailing ponds

2.1. Tailing ponds in the Middle Europe

Industrial production generates some kind of waste (by-product) toxic substance, which contaminates the sites and often degrades the surroundings of human living including air, ground water and surface.

From the viewpoint of environmental safety of deposited materials, there are 56 tailing ponds of various levels and types in Slovakia (**Figure 1**). They are in different stages of their existence or life cycles (**Tables 1–3**). They contain mainly wastes from coal gangue, ore processing products (floating sludge), heating plants (slag, ash) and power plants. Safe closing or re-cultivation of tailing ponds is a current problem in the Slovak Republic and also for the environmental safety in Europe because generally the tailing ponds, as watery building constructions, are considered immensely dangerous objects, in terms of environment [1].

Types of tailing ponds in Slovakia:

- 15 with ash material,
- 27 with ore and
- 14 others (industrial).

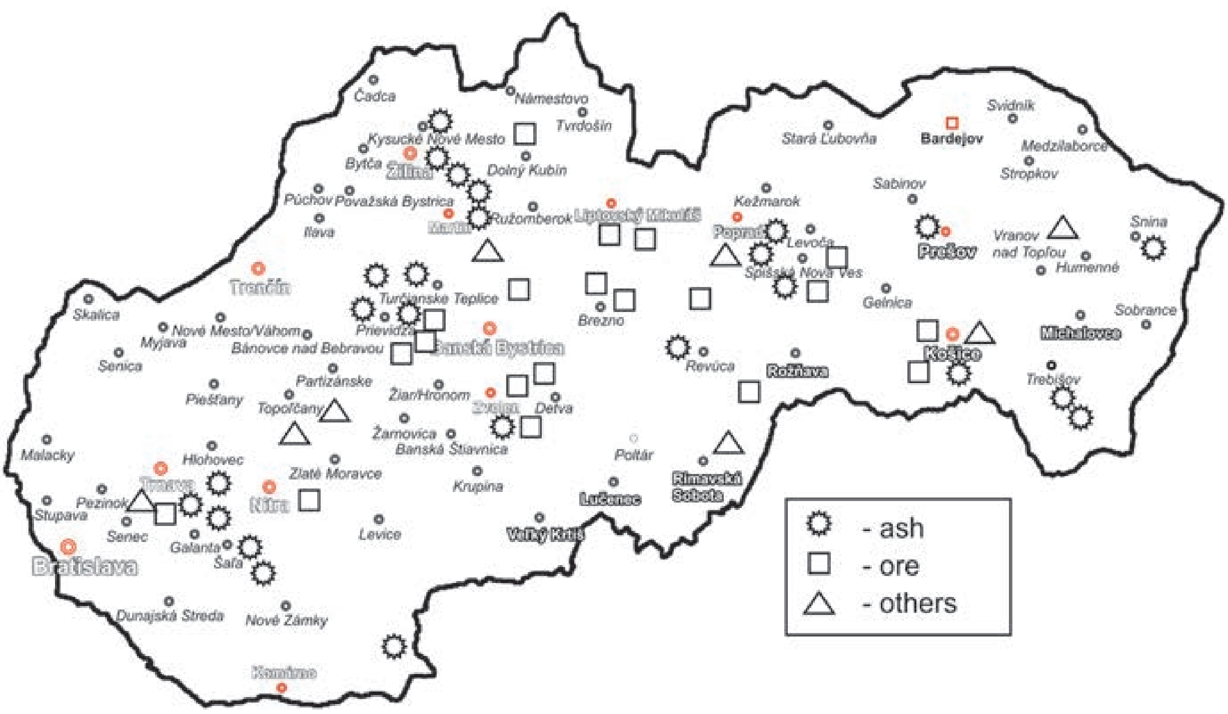

Figure 1. Registered tailing ponds in Slovakia.

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No.	Name	Place	District	Category
1.	**Tailings pond ENO— new**	Zemianske Kostol'any	Prievidza	I
2.	**Tailings pond ENO —old**	Zemianske Kostol'any	Prievidza	II
3.	**Tailings pond ENO**	Bystričany —Chalmová	Prievidza	II
4.	**EVO Vojany**	Vojany - Drahnov	Mihalovce	II
5.	**Tailings pond KAPPAs.**	Štúrovo- časť Obid	Nové Zámky	II
6.	**Martin—old tailings pond**	Martin	Martin	II
7.	**Martin—new tailings pond**	Bystrička	Martin	II
8.	**Tailings pond Poša**	Poša-Nižný Hrabovec	Vranov n. T.	II
9.	**Tailings pond Snina**	Snina	Snina	II
10.	**Tailings pond DUSLO**	Tmovec n. Váhom,	Šal'a	II
11.	**Tailings pond Žilina**	Bytčica	Žilina	II
12.	**Tailings pond Košice**	Krásna nad Hornádom	Košice	III
13.	**Sered'**	Dolná Streda	Galanta	III
14.	**Zvolen**	Zvolen	Zvolen	III
15.	**Ash tailings pond**	Homé Opatovce	Žiar n. H.	III

Table 1. The list of ash tailing ponds in Slovakia.

No.	Name	Place	District	Category
1.	**Hačava**	Hačava	Rimavská Sobota	II
2.	**Hodruša Hámre**	Hodruša Hámre	Ziar nad Hronom	II
3.	**Jelšava**	Jelšava	Rožňava	II
4.	**Nižná Slaná**	Nižná Slaná	Rožňava	II
5.	**Rudňany**	Závadka	Spišská Nová Ves	II
6.	**Sedem žien**	Banská Belá	Žiar n. Hronom	II
7.	**Tailings pond Slovinky**	Slovinky	Spišská Nová Ves	II
8.	**Baňa Cígel' II.**	Sebedražie	Prievidza	III
9.	**Dúbrava 01**	Dúbrava	Liptovský Mikuláš	III
10.	**Dúbrava 02**	Dúbrava	Liptovský Mikuláš	III
11.	**Dúbrava 03**	Liptovský Mikuláš	Liptovský Mikuláš	III
12.	**Žiar nad Hrouom**	Žiar n. H.	Žiar n. H.	III
13.	**Košice – Bankov**	Košice	Košice	III
14.	**Lintych**	B. Štiavnica	B. Štiavnica	III
15.	**Pezinok**	Pezinok	Pezinok	III
16.	**Podrečanv**	Podrečany	Lučenec	III

No.	Name	Place	District	Category
17.	**Smolník**	Smolník	Spišská Nová Ves	III
18.	**Široká**	Široká	Dolný Kubín	IV
19.	**Baňa Cígel' I.**	Sebedražie	Prievidza	IV
20.	**Košice Bankov**	Košice	Košice	IV
21.	**Horná Ves (Kremnica)**	Horaá Ves	Žiar nad Hronom	IV
22.	**Hronský Beňadik,**	Hronský Beňadik	Nová Baňa	IV
23.	**Lubeník**	Jelšava	Rožňava	IV
24.	**Pezinok**	Pezinok	Pezinok	IV
25.	**Rožňava**	Rožňava	Rožňava	IV
26.	**Sered'**	Sered'	Galanta	IV
27.	Špania dolina	Špania dolina	B. Bystrica	IV

Table 2. The list of ore tailing ponds in Slovakia.

No.	Name	Place	District	Category
1.	**Čifáre**	Čifáre	Nitra	II
2.	**Bukocel**	Hencovce	Vranov n. T.	III
3.	**Dubová**	Dubová	B. Bystrica	III
4.	**Novácke odkalisko 7**	Nováky	Prievidza	III
5.	**Stabilizačný násyp Handlová**	Handlová	Prievidza	III
6.	**Odkalisko ČOV Sokol'anv**	Sokol'any-Bočiar	Košice	IV
7.	**Fámeš**	Pastuchov	Hlohovec	IV
8.	**Plešivec- Gemerská Hôrka**	Plešivec	Rožňava	IV
9.	**Nádrže oceliarenských kalov**	Vel'ká Ida	Košice	IV
10.	**Mokrá halda**	Vel'ká Ida	Košice	IV
11.	**Novácke odkalisko 6**	Nováky	Prievidza	IV
12.	**Sal'a RSTO**	Sal'a	Galanta	IV
13.	**Šulekovo**	Šulekovo	Trnava	IV
14.	**Veronika**	Dežerice	Topol'čany	IV

Table 3. The list of industrial tailing ponds in Slovakia.

According to the summary records of water cannons, 28 tailings of I–IV categories were located in the Czech Republic as on 1.1.2014, all listed in the following **Table 4**.

Not only red mud is produced in tailings, but there are also ash and uranium tailings in Hungary. Some of them are already being re-cultivated and prepared for liquidation. In Hungary, there are 20 tailing ponds as characterised below, in **Table 5**.

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No.	Name	Place	Category
1.	**Hodějovice**	České Budějovice	III
2.	**Mydlovary**	České Budějovice	III
3.	**Zbrod North 1/4**	Hodonín	III
4.	**Nové Chalupy**	Karlovy Vary	III
5.	**Tailing ponds П.**	Ostrov	III
6.	**Dolní Radechová**	Náchod	III
7.	**Debrné**	Trutnov	III
8.	**Odkaliště TDK IV/3**	Trutnov	III
9.	**Stráž p. Ralskem**	Česká Lipa	II
10.	**Dřiteč**	Pardubice	III
11.	**Lhotka**	Pardubice	II
12..	**Semtín no. 7**	Pardubice	II
13.	**Chvaletice I.**	Přelouč	III
14.	**Božkov**	Plzeň	III
15.	**Panský les**	Mělník	II
16.	**Odkaliště Spolana**	Neratovice	III
17.	**Bvtíz**	Přibram	III
18.	**Rýzmburk**	Vlašim	III
19.	**Ušák**	Kadaň	II
20.	**SEPAP no. 4**	Litoměňce	III
21.	**Třískohipy**	Louny	III
22.	**Barbora III.**	Ústi nad Labem	III
23.	**Užin - old tailing ponds**	Ústi nad Labem	III
24.	**Dolni Rožinka**	Bystřie nad Pemštejnem	II
25.	**Zlatkov**	Bystřice nad Pemštejnem	II
26.	**Tailing ponds Synthesia a.s.**	Pardubice	IV
27.	**Tailing ponds**	Mladá Boleslav	IV
28.	**Ústí – new tailing ponds**	Ústi nad lab em	IV

Table 4. The list of registered tailing ponds in the Czech Republic.

On the presented maps (**Figures 1–3**.) are shown tailing ponds of middle European countries—Slovakia, the Czech Republic and Hungary. Even though Slovakia is the smallest country, it has the most tailing ponds (56) compared to the Czech Republic (28) and Hungary (20). Of course, this is also closely related with 'energy policy' of individual countries.

No.	Name	Type
1.	**Pellérd**	Uranium
2.	**Ajka**	Red mud
3.	**Almásfüzítő**	Red mud
4.	**Kurityán**	Red mud
5.	**Mosonmagyaróvár**	Red mud
6.	**Neszmély**	Red mud
7.	**Bokod**	Ash
8.	**Borsodnádasd**	Ash
9.	**Borsodszirák**	Ash
10.	**Estergom/Dorog**	Ash
11.	**Dunaújváros**	Ash
12.	**Gyöngyösoroszi**	Ash
13.	**Inota**	Ash
14.	**Kazincbarcika**	Ash
15.	**Múcsony**	Ash
16.	**Pécs**	Ash
17.	**Tatabány/Bánhida**	Ash
18.	**Tiszapalkonya**	Ash
19.	**Tiszaújváros**	Ash
20.	**Visonta**	Ash

Table 5. The list of tailing ponds in Hungary.

It is shown on the maps that locations of tailing ponds in Slovakia and the Czech Republic are distributed almost equally on the whole area of the countries. In Hungary, tailing ponds are placed mostly in the northern part of the country, near the border with the Slovakia.

The present tailing ponds are still considered environmentally dangerous and are also expensive to maintain; therefore, nowadays, a higher attention is given to them in Slovakia. This is demonstrated by the example. There was an accident in the Hungarian village Ajka, where on 4 October 2010, the dam pond broke after heavy rains. Subsequently, more than 0.7 million cubic meters of toxic mud struck in seven towns and villages and red sludge flooded the neighbourhood. The environmental disaster has claimed up to 10 human victims and over 150 people were injured and it destroyed dozens of homes. Other accidents at tailings ponds that are fatal and environmental devastation are shown in **Table 6**. Therefore, the discussion about closing these ponds is very important.

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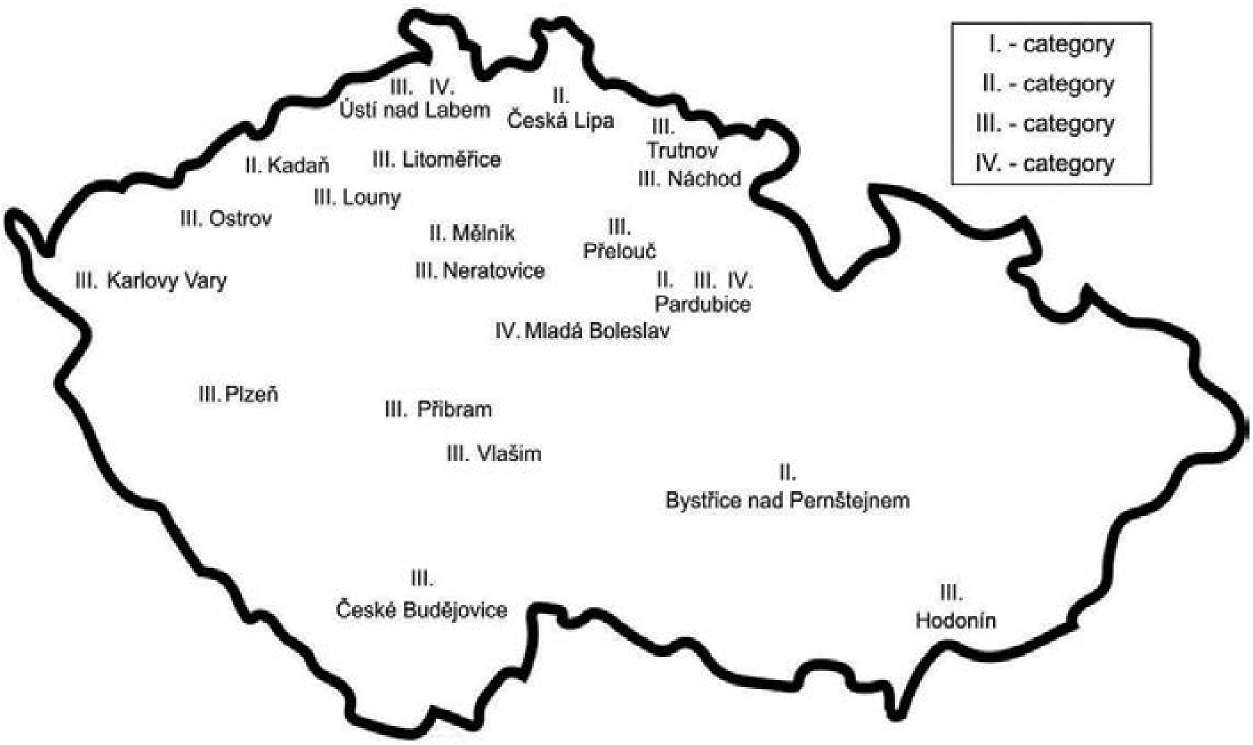

Figure 2. Registered tailing ponds in Czech Republic.

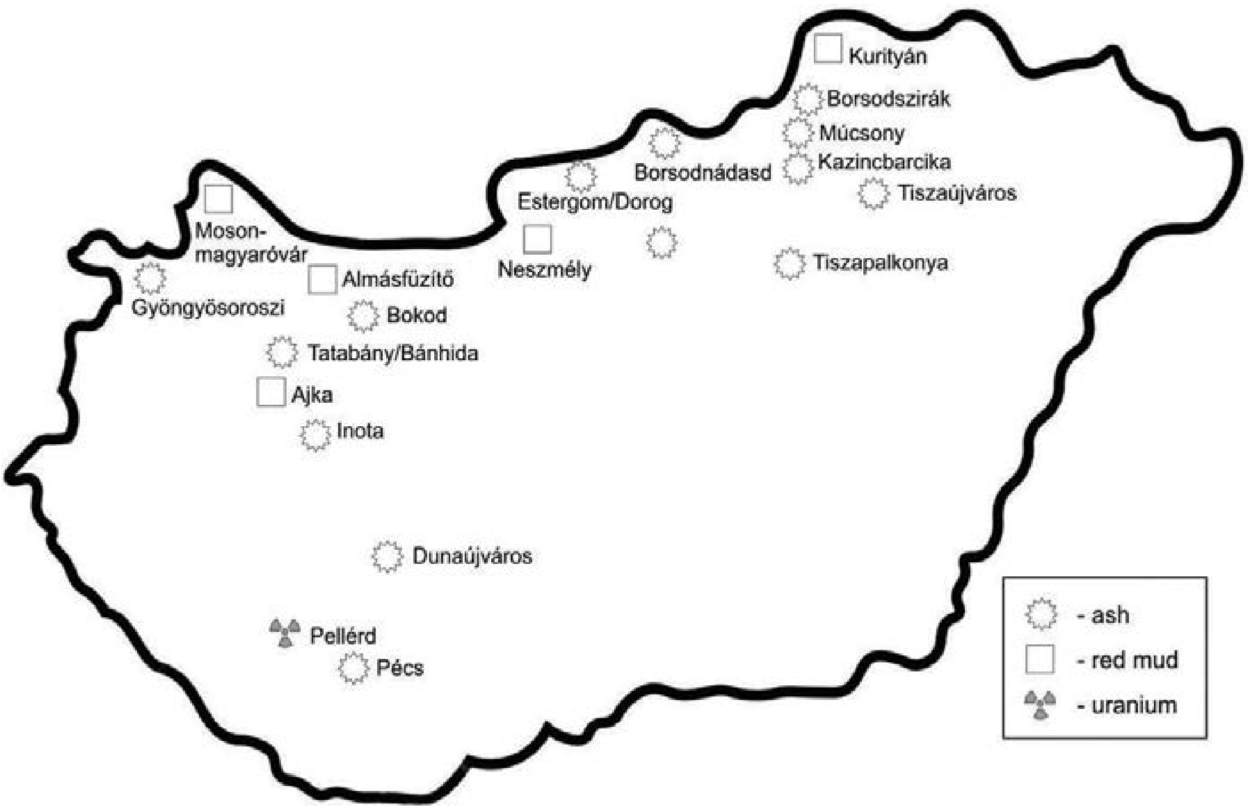

Figure 3. Registered tailing ponds in Hungary.

Town (Country)	Date	Number of death	Type of pond
Zemianske Kostol'any (Slovakia)	26.5.1965	4	Ashes from heat power plant
Stava (Italy)	19.7.1985	268	Fluorite sludge
Harmony (South Africa Republic)	6.2.1994	10	Cyanide pond
Placer (Philippines)	2.9.1995	12	Sludge
Ajka (Hungary)	4.10.2010	10	Red sludge

Table 6. Examples of tailing ponds from the world of accidents resulting in death.

Figure 4. Filling tailing pond.

For member countries, the European Union currently allocates huge funds in development projects. This is to prevent and rectify environmental damage; hence, the restoration and rehabilitation of tailing ponds dross ashes biological mixtures are important [1].

2.2. Tailing pond of EVO Vojany

The biggest fossil fuel plant in Slovakia is Vojany power plant, where mainly semi-anthracite coal from Ukraine and Russia is used as the fuel. Currently, for disposal of waste products from coal combustion the plant operates two facilities:

- dump with stabilisation material tailing,
- tailing ponds with dross ashes mixture.

Coal combustion products that are hydraulically transported are stored with stabilisation material in the tailing pond with two cassettes of dross ash mixtures (cassette no. 1 is already closed) (**Figure 4**). Stabilisation material is a by-product of the desulphurisation of power plant technology and combustion processes [2].

Safety and operation oversight within the relevant legislation of tailing pond of EVO plant Vojany are needed because it is a water work. On the verge of PLA Latorica, on the left bank of the

Area of base	Cassette No. 1—47.2 ha
	Cassette No. 2—48.1 ha
Overall capacity of stock ash	Cassette No. 1—7,580,000 m^3
	Cassette No. 2—5,760,000 m^3
Dispozition capacity	Cassette No. 1—full
	Cassette No. 2—850.000 m^3

Table 7. Base parameters of tailing pond.

Figure 5. Place cassette no. 1 on pond in scale 1:10,000.

river Laborec, it was built in 1965 to store dross ash mixture and is located in the administrative area of village Drahňov and Vojany. It is bounded on all sides by high grass-covered embankments. Two separate approximately similar cassettes create the tailing pond (**Table 7**):

- cassette No. 1–29 ha (with dam 47.2 ha), (**Figure 5**) and
- cassette No. 2–27 ha.

Cassettes are separated by dividing dam, which originally had the function of the peripheral dam cassette No. 1. This means that the area to be addressed after the final shutdown of the pond is about 56 ha [3].

3. Experiments and methods of research

This chapter presents development of original remediation technologies for unconventional tailing pond dross ashes mixture disposal and results of the experiments in the research. This technology uses structured layers of land, soil and stabilisation material. The reason is to replace previous legislative solution by the overlapping of hydrofilm material and drainage system.

3.1. Experiments of containers

The experiment simulating any large-scale use of this new non-traditional, uncertified practice or technology was based on the verification of replacement waterproofing properties of the stabiliser. The purpose of verification of experiments was to assess the possibility of using a stable material due to its potential to prevent solidification of penetrating rain water into the lower layers of the pond, with the risk of another accident.

A mixture of grass varieties that are resistant to typical and local conditions is used for covering of the energy crop with the future consideration of using pond grown plants as biomass for co-incineration with coal in power plants. The cultivation of fast growing Swedish willow with respect to its root system was experimentally verified. Therefore it was used in this experiment and the subsoil thickness was of 500 mm.

The laboratory experiment was set up with the following procedure:

- the stabilisation material of thickness of 0, 50, 100, 150, 200, 250, 300, 350, 400, 450 and 500 mm, was kept in the bottom of a 2 × 11 container with a size of 1000 mm × 1000 mm × 1000 mm,
- the second layer reflects the subsoil profile of the rehabilitated land and was then deposited in the soil with subsoil thicknesses of 300 mm for grass and 500 mm for Swedish willow (**Table 8**),
- like the subsoil, even topsoil profile describes the reclaimed area, the last build up layer of topsoil with a thickness of 200 mm is uniformly used for all variants,
- a part of containers was located in areas with variable weather conditions (the first half) and the other part is placed under the local climate conditions (the second half) (**Figures 6** and **7**) [4].

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	Subsoil	Topsoil	Soil together
Grass	300 mm	200 mm	500 mm
Willow	500 mm	200 mm	700 mm

Table 8. Requirements for growing.

Figure 6. Containers in terms of controllable.

3.1.1. Stabilisation material: its analysis and usage

We provide an analysis report of hazardous substances contained in the stabilised in the following tables and **Figure 8** show the structured layers in individual containers, which appeared in the experiment. The used stabilisation material has pH 8.45 and a conductivity of 38.7 (**Tables 9** and **10**).

Every container was filled with layers of stabilisation material, subsoil and topsoil according to their draft. The first container was filled without a layer of stabiliser, as a control container—nothing else has been done. Afterwards, sufficiently compacted individual layers were filled to bring them closer to actual conditions [4].

3.1.2. Experimental method

The half of containers were located in areas under local climatic conditions and the second half of containers were placed in areas where weather conditions were controlled.

Figure 7. Containers under conditions consistent with local climate.

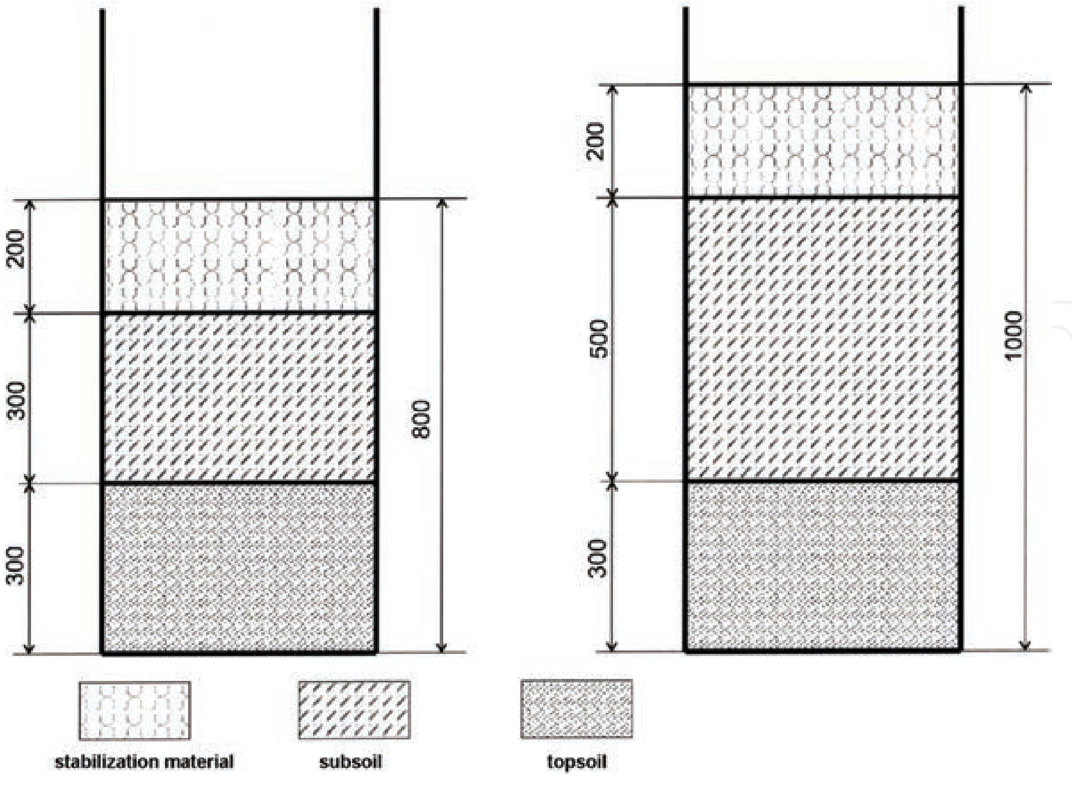

Figure 8. Diagram of the experimental variations of the experiment at 300 mm stabiliser.

	Indicator	Abbreviation	Value
1	Total organic carbon	TOC	**105,100**
2	Benzene, toluene, ethylbenzene and xylenes	BTEX	**<0.001**
3	Polychlorinated biphenyls, seven members	PCB	**<0.01**
4	Mineral oil (C10–C40)	NEL	**<1**
5	Polvcyclic aromatic hydrocarbons	PAH	**<0.05**

Table 9. Analysis of stabilisation material based on based on regulation of Ministry of Environment of SR No. 599/2005 Z.z.

	Indicator	Abbreviation	Value [mg]
1	Arsenic	As	**0.02**
2	Barium	Ba	**0.58**
3	Cadmium	Cd	**<0.003**
4	Total chromium	Cr	**0.03**
5	Copper	Cu	**0.03**
6	Mercury	Hg	**0.002**
7	Molybdenum	Mo	**0.05**
8	Nickel	Ni	**<0.02**
9	Lead	Pb	**0.05**
10	Antimony	Sb	**0.01**
11	Selenium	Se	**<0.01**
12	Zinc	Zn	**0.10**
13	Chlorides	cl^-	**31.7**
14	Fluorides	F^-	**2.2**
15	Sulphates	SO_4^{2-}	**1490**
16	Phenol index	FNI	**<0.3**
17	Dissolved organic carbon	DOC	**243**
18	Total solubles	CL	**3240**

Table 10. Analysis of water extract of stabilisation material based on regulation of Ministry of Environment of SR No. 599/2005 Z.z.

Reflecting the maximum monthly average for last 50 years indoor watering and simulation of precipitation in real outdoor was applied with water. Data on rainfall was used from the Slovak Hydrometeorological Institute, Regional Centre of Kosice from stations in Michalovce, Somotor and Milhostov ,which are the closest to the tailing pond.

Except for the rainy year 2010, when the monthly average rose to 85 mm/month, the long-term measurements of rainfall in the area show that the average monthly values range from 40 to 50 mm/month [4].

3.1.3. Results of experiment

According to different climatic conditions, the results of the experiment can be divided into two groups, with respect only to the quantity of water received:

3.1.3.1. Containers under conditions consistent with local climate–natural amount of rainwater

Rainfall was observed in containers on average 43 mm/month, which represents 1.43 mm of rainfall per day during the period January 2011–December 2011 (**Table 11**). The rainwater do not get through the layers, but in one container that contained stabilisation material, soil absorbed them.

Station	Month												Total	Average per month
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII		
Michalovce	40	6	30	17	30	92	180	27	51	16	1	77	567	47
Milhostov	28	4	31	14	46	112	166	11	41	14	1	58	525	44
Somotor	30	9	36	21	28	92	115	9	49	18	3	76	484	40
Average														**44**

Table 11. The rainfall [mm] of nearby stations in 2011.

3.1.3.2. Containers with controllable received amount of water (pouring)

The containers with variable conditions were simulated with extreme daily rainfall amounts of water, minimum 50 mm/day, that is to say, more than 7 times the maximum daily average precipitation. In May 2010, a long-term, extremely high quantity of rainwater were measured—the calculated average of monthly rainfall was 208 mm, it means that the average rainfall of the day is 6.9 mm (**Table 12**).

A part of the precipitation is absorbed by each layer in the container and seepage water accumulated the discharge outlet in the prepared containers and continuously measured.

Station	Year	Month	Rainfall [mm]
Michalovce	2011	VII	180
Milhostov	2010	V	219
Somotor	2010	V	226
Max. average			**208**

Table 12. Maximum of rainfall [mm] of nearby stations.

In order to determine the waterproofing ability of the individual layers for carrying out experiments, the maximum long-term nature of rainfall in the area of the tailing pond was taken as the basis of the daily rainfall amounts of water in the controlled.

In the following **Figures 9** and **10** are shown information depending on the amount of water tightness where the thickness of stabiliser and the subsoil are 300 and 500 mm, respectively.

Alternative use of 170 and 230 mm of stabilisation material, depending on the thickness of subsoil differences for willows and seed grass, resulted in implementation of laboratory experiments, leading to establish the maximum daily amount of rainwater at 100 mm in containers (70-times more than the average daily value). The root system of plants planted on the surface will gradually pump saturated water to the topsoil and subsoil.

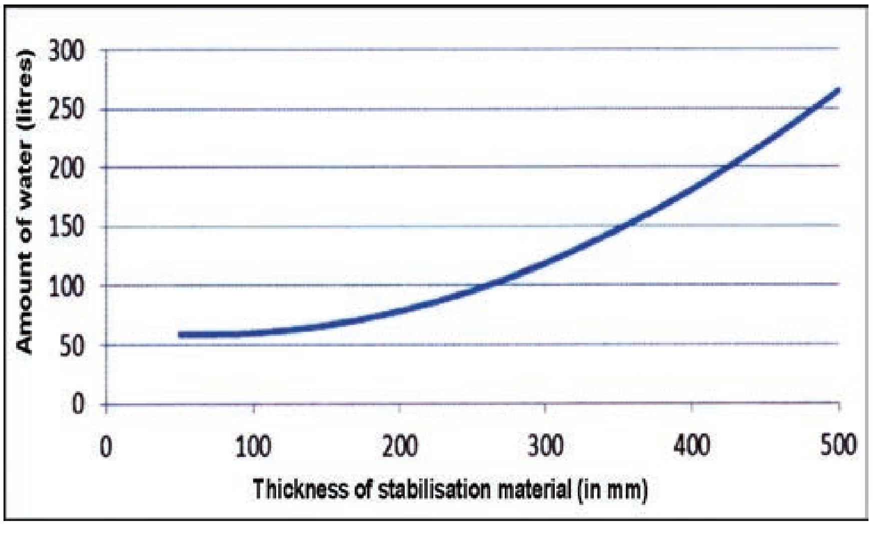

Figure 9. Dependence of the thickness of stabiliser and the amount of water tightness in thickness of the subsoil 300 mm.

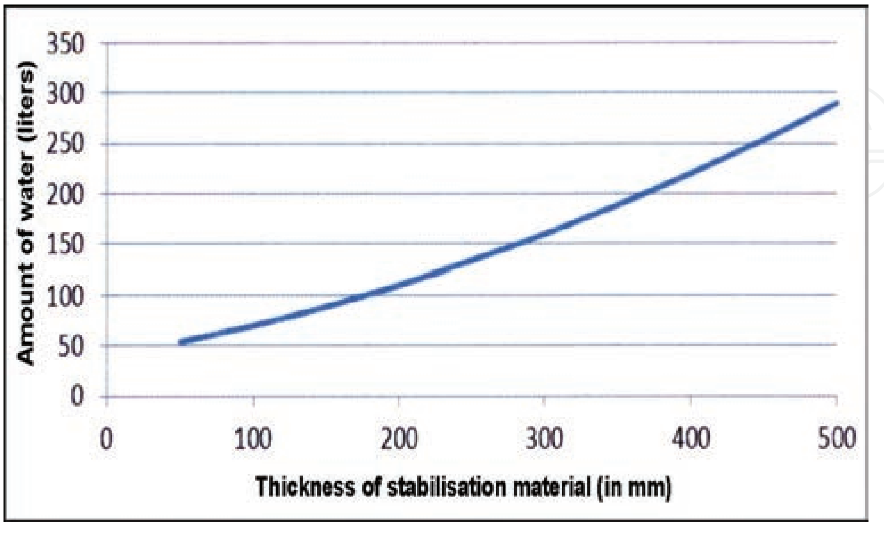

Figure 10. Dependence of the thickness of stabiliser and the amount of water tightness in thickness of the subsoil 500 mm.

3.2. Willow cultivation on tailings pond

3.2.1. Small plot trials on tailings pond

The second phase of experiment was to implement small plot trials on the surface of tailing where four large-sized parcels of 7 m × 20 m in a given structure have been built (**Tables 13** and **14**).

Parcel	Stabilisation material	Subsoil	Topsoil	Together
1st parcel	300 mm	500 mm	200 mm	1000 mm
2nd parcel	500 mm	500 mm	200 mm	1200 mm
3rd parcel	-	500 mm	200 mm	700 mm
4th parcel	-	500 mm	200 mm	700 mm

Table 13. Structure of parcels for willow.

Parcel	Stabilisation material	Subsoil	Topsoil	Together
1st parcel	300 mm	300 mm	200 mm	800 mm
2nd parcel	500 mm	300 mm	200 mm	1000 mm
3rd parcel	-	300 mm	200 mm	500 mm
4th parcel	-	300 mm	200 mm	500 mm

Table 14. Structure of parcels for grass.

The possibility cultivation of willow and grass cultivation in the closed tailing ponds in reality during the vegetation seasons are tested the proposed alternatives of the covering layer for the biological re-cultivation of the tailing ponds from the viewpoint of water permeability under natural conditions of atmospheric impacts (**Figures 11** and **12**). The results of experiment are

Figure 11. Experimental parcels on tailings pond.

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Figure 12. Grass mixtures rapid and prosoil.

supplemented with 7 years of practical knowledge about the cultivation of Swedish willow on the territory of 15 ha in the nearby town of Kežmarok.

The average root striking of plant slips after the willow planting in two research stations of the Slovak University of Agriculture in Nitra was in the range between 66.91–89.51% and 45.67–91.35%. The planting was implemented in 2011.

Under suitable conditions, it is possible to achieve a root striking of more than 90% according to Dawson statement (2007). High root striking percentage of slips is inevitable for the optimal structure of vegetation and for optimal crops [5]. The number of rooted pieces can be influenced by the planting way of slips during the founding of commercial plantations. Better root striking in the case of planting of slips horizontally to the soil surface in comparison with the classical planting vertically to the soil surface was identified by Lowthe-Thomas et al. This planting method at the same time can significantly reduce the cost of planting [6].

We have achieved an average root striking of 91.76% (**Table 15**) in our experiment. The conditions for willow cultivation (structured layers of the stabilized stabilised waste, subsoil layer and arable layer) were suitably prepared. We can conclude from this result that, it is feasible to produce biomass directly in the power plant or in the tailing ponds which is 2 km away from the plant.

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Plot	**% of rooted plants**
1.	88.72
2.	92.63
3.	91.14
4.	94.57
Average	**91.76**

Table 15. Number of rooted pieces of the Swedish willow in the experiment.

The optimal total quantity of precipitation in summer months should achieve 300 mm and during the total vegetation season it should achieve 550 mm [7]. Besides the extremely rainy year 2010, the measured values for the whole vegetation season were lower than 570 mm.

The precipitation data have been acquired from the three nearest monitoring stations to the tailing ponds (**Table 16**). The monitoring stations belong to relevant regional centre of the Slovak Hydro-Meteorological Institute.

Station	2009	2010	2011	2012	2013	2014	2015
Milhostov	585	892	526	496	529	567	556
Michalovce	636	929	567	635	578	625	593
Somotor	590	1030	486	481	522	520	537
Average	604	950	527	537	543	570	562

Table 16. The rainfall of nearby stations.

Swedish willow was planted in the spring of 2011. As most of the shoots were damaged, it was necessary to carry out planting of new shoots of Swedish willow in spring 2012. Rodents damaged willow root systems and most of them were completely destroyed by the spring of 2013. Subsequently the tree was replanted and fenced and rodent repellers were installed as well. Since the Swedish willow has been gradually replanted, various heights of tree shoots can be found on experimental fields. It is possible to achieve more than 90% of embeddedness of the Sweden tree shoots under appropriate conditions. High embeddedness of shoots is essential for achieving the optimal harvest. The method of planting Swedish willow cuttings might influence the number of in-rooted units. Worse embeddedness of shoots is monitored during planting cuttings vertically to the soil surface than planting the cuttings horizontally to the soil surface. We can conclude that conditions for growing Swedish willow were suitably prepared because in this experiment the average embeddedness of shoots was up to 92% (**Table 17**, **Figure 13**).

Approximately 580–600 mm of rainfall is the optimal precipitation value for the entire growing season. The willow can produce large amounts of biomass at this level. The rainiest year was 2010, as shown in **Table 13**, according to the atmospheric precipitation of individual

Season	Hight of willow
2012 – June	120 – 640 mm
2013 – April	1100 – 1750 mm
2014 – May	1900 – 2450 mm
2015 – April	2800 – 3200 mm

Table 17. Height of Swedish willow.

Figure 13. Swedish willow on 4th parcel.

periods. The total amount of rainfall was below the required level and did not exceed 550 mm in the next 3 years. As a result, Swedish willows have been drying out.

At Vojany thermal power plant through small plot trials continues the general process of experimental testing of the possibility of re-cultivating cinder/ash mixture tailings. The biomass yield of mowed grass is corresponding with the expected values which are increasing every year. It would be appropriate if the annual rainfall total was around 600 mm in terms of growing willow. We might conclude that total rainfall for the last period was below the long-term average. Because of lower-than-average precipitation during the year, the newly planted willow took a much lesser extent than initially expected.

3.2.2. Results of experiment

Upon analysing the individual components of experimental plots it was shown that at the edges of the experimental plots the formation of continual solidified layer of stabilisation material was not observed. The coherent layer of solidified stabilisation material was formatted in cuts, which was made closer to the centre of the plot. This situation could significantly affect the rainfall, whose intensity was at a time of experimentation very low. On the edges of the plots rainfalls withered quickly, more than the centre of the plots, in which the water was maintained for longer. In the edge stabilisation material was loose, but gradually towards the centre were produced visible larger chunks of hardened stabilisation material **Figure 14**.

From the plots were taken samples of manually cut root systems of Swedish willow (**Figure 15**). Selected root systems had different length, branching and direction depending on structured underlay of various plots. We can conclude, that in terms of length, the root system corresponds to the length of the part above the topsoil (mutually correlated). Another factor that cannot be ignored is, that the root system of Swedish willow did not crush the layer of stabilisation material in the vertical direction.

Figure 14. Solidified layer of stabilisation material.

Figure 15. Horizontal root system of Swedish willow above stabilisation material.

The experiments resulted in the application of new environmental recycling technology by new remediation technologies unconventional pond dross ashes mixture by using structured layers of stabilisation material, soil and land. Stabilisation material is the by-product of the desulphurisation process of power plant in combustion processes. The uniqueness new environmental recycling technology lies in the presented technology solutions, where a waste product of energy combustion processes will be used in another defused form.

During the growing season, the proposed real alternatives to the coating of bio-remediation of the pond in terms of water permeability under natural conditions and atmospheric effects were tested. It also verifies the best type of plants grown in the creation of sanitation, security conditions, with respect to the possibility of their further use as a co-incineration of biomass with coal in the same technology plant.

The final results showed that stabilisation layer prevented penetration of water into the lower layers of the tailing pond. The solution thus achieves a synergistic environmental-security effect [8].

3.3. Combustion of biomass

According to EU legislative from year 2008 EU is to provide 20% energy from renewable sources which is the energy sector goal for 2020 [8]. Co-incineration of biomass can be one of the ways to achieve this goal. Under the shared combustion of biomass and coal, there is a reduction, specifically, partial elimination of the environmental impact due to low content of nitrogen and sulphur in the biomass, resulting in a reduction of CO, NOx and SO_2, as well as reducing emissions of heavy metals [9].

One of the most promising methods for the provision of energy production in general is co-incineration of biomass energy willows and other biomass plant with coal in the near future and in the present [10]. It failed to apply in Slovakia and at global level, despite the availability, environmental and technological benefits announced by this system on a larger scale. Increased costs associated with the production and logistics of biomass assurance seems to be the biggest problem. Co-incineration of biomass with coal significantly increases the clean energy ratio. It is defined as the ratio of produced electricity to the total consumption of fossil energy. It is primarily reducing the greenhouse gas emissions from mining, transportation and combustion of coal when substituting a certain percentage of coal with biomass [11]. In practice, co-incineration of willow chips with wood wastes have been used in biomass power stations in Sweden. In the local energy supply, it plays an important role. Study of environmental impact of coal combustion from a power plant have been carried out in Poland and also in a number of countries [12].

The power plant Vojany started to implement them as well in collaboration with this author, in 2009 in line with the above trends. Project combustion of black coal with biomass in fluidised boilers was realised in the form of a scientific research complex. The research includes the provision of (growing) plant biomass in the pond area surrounding the facility gaining self-made slag-ash mixture. The first positive results in the reduction of emissions was produced by co-incineration of biomass, mainly wood chips mixed with black coal in a 4%

ratio by 40 kg per MWh produced, and operational savings associated with the consumption of limestone, creation and disposal of ash, water consumption and steam. The project's next phase was experimentally realised with the co-incineration of biomass with a value 7% and then 15%. The surroundings of the facility has good power potential of the fast-growing energy crops—willow was showed in research focused on the potential provision of biomass. In connection with this research specific purposeful cultivation of biomass was initiated in the large pond of about 56 ha that contained slag-ash mixture. One of most burdened areas in eastern Slovakia is the area of Vojany [13].

3.3.1. Co-incineration of wood chips with coal

In 2007, co-incineration of biomass in EVO boilers started. Forest biomass has been chosen for the first tests of wood chips. To achieve the same thermal input it was needed to deliver six cubic meters of biomass to the boiler, instead of one cubic of black coal, due to different heating value, calorific value and density of black coal and wood chips. It could not be replaced by any amount of coal with biomass because wood chips have a density of 0.3 t/m^3 and calorific value 10 MJ/kg and coal has a density of about 1 t/m^3 and heating value of 25 MJ/kg.

The added mixture of wood chips containing about 4% of the heat energy mix wood chips—coal, does not negatively affect dynamic characteristics of the power plant units—it was proved from calculations based on the time. It was also proved by tests in 2007 that it is possible to smoothly combust biomass (wood chip) in fluidised boilers in the power plant of Vojany. It turned out that wood chips have a positive impact on the boiler combustion mode, because of a higher proportion of volatile matter and a lower ignite temperature than coal. The resuls were a decrease in the concentration of carbon monoxide in the exhaust gas and more efficient combustion of irradiated fuel [14].

The launch of scientific-research activities aimed at complex solution for the issue of environmental energy-biomass combustion optimisation processes was initiated because of these partial positive results.

Replacement of a share of combusted black coal in thermal power EVO with biomass-based fuels was carried with priority to maximise the reduction of emissions especially carbon-sulphur oxides, by providing the required energy performance and therefore ultimately in increasing competitiveness improving economic indicators, manufacturing and energy-production companies.

The co-incineration of black semi-anthracite coal and wood biomass in fluidised FK5 boilers in the examined facility was performed as the experiment.

The wood chips ranged from 8.0 to 8.65 MJ/kg and the black coal average heating values in the experiment ranged from 25.4 to 28.1 MJ/kg. Graphically illustrated in **Figure 16** is the dependency of the heating value of wood chips on its moisture.

From different forms of concentrations of pollutants (the individual VOP) it is significant that:

- with increased performance there was a decrease in the concentration of carbon monoxide in co-incineration ratio of wood chips,

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- during testing, legislative allowed emission limits for SO_2 were preserved and there has been an increase in performance and in values and
- other values of VOP were as well below the individual emission limits.

At the same time the efficiency of boiler and co-incineration of coal and the biomass, are presented in **Table 18**.

The co-incineration of a mixture of wood chips and coal led indeed into a slight reduction in boiler efficiency, which is negligible compared to the achieved environmental-safety effects—it can be stated when taking into account the partially different characteristics specifically, quality of supplied and combusted coal and wood chips.

The implementation of the I phase in plant biomass co-incineration in the power plant Vojany at the block no. 6 began in July 2009 based on these tests, and partial results of experimentation.

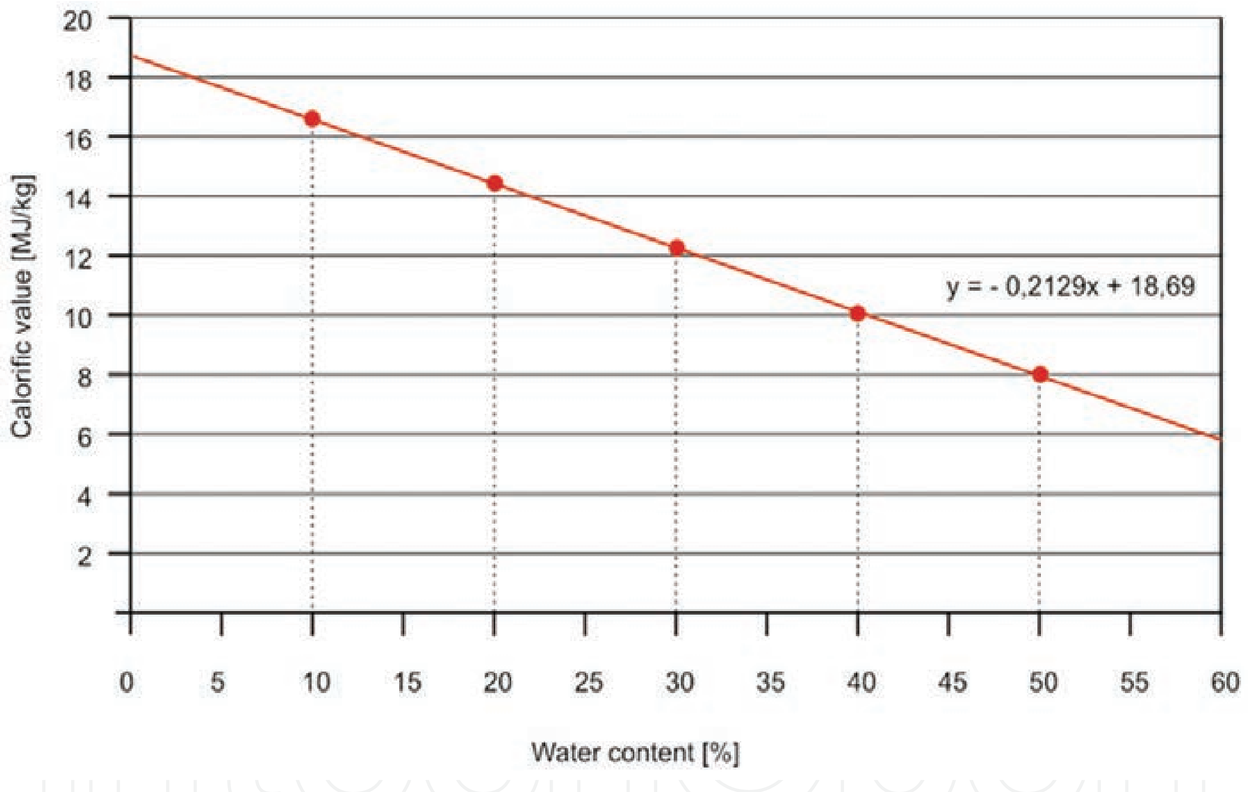

Figure 16. Dependency of the calorific value of wood chips on the water content.

Electrical performance	Black coal	Share of wood chip 1.91%	Share of wood chip 3.91%
[MW]	[%]	[%]	[%]
66	93.81	93.47	92.30
88	93.55	93.32	92.91
110	93.52	92.57	93.20

Table 18. The effectiveness of fluidised boiler K5 in Vojany.

A landfill with open capacity of 400 tons adjusted with transport (conveyor belts) and technology (crusher-sorter) biomass was built and customised to support experiments.

A rated power of conveyor belts was set to properly balance the mutual ratio and a mechanised system was used for wood chips, to transport them over conveyor belt and coal through the other one. The use of raw wood chip (hardwood and softwood) and its share was gradually increased to 5.3%.

Co-incineration of a better quality of the combusted wood chips with a higher calorific value than previously considered biomass was achieved with a share of 5.3%, not by increasing the weight. This means that projected calorific value changed from 9.5 MJ/kg to over 11 MJ/kg. This ratio has proved to be the best possible, to maintain the maximum dynamic properties of the boiler and in the execution of transporting the fuel mixture into the boiler. The implementation of II stage of biomass project co-incineration, which consisted of the construction of independent mechanised access to the boiler especially for biomass was determined in relation to the achieved results.

Table 19 shows that the combustion of 1 ton of biomass eliminated approximately one ton of carbon dioxide emissions and capacities of coal lines remained clear and the new path was used to transport higher volume of wood chips into the boiler (**Figure 17**).

3.3.2. Results of experiment

The production of biomass and co-incineration of coal in fluidised boilers, of thermal power stations SE, a.s. as well as other power plants is need in terms of environmental benefits. By burning coal and biomass is reflected in a significant reduction in emissions and production of solid waste.

The facility is obtaining its biomass currently from six local suppliers. EVO facility is a promising purchaser and will be their regular customer in the future as well because the surrounding wetlands around the facility provide good conditions for rapidly growing trees (poplar, willow). There is potential for increasing employment in the region for people with lower qualifications with the cultivation of biomass in the surrounding area of the plant or in the wetlands.

Year	Wood chip share [t]	CO_2 – eliminated [t]
2009	8,310	10,487
2010	21,443	27,061
2011	24,099	30,413
2012	26,917	33,969
2013	60,794	92,954
2014	48,752	84,899

Table 19. The amount of CO_2 saved by co-incineration of biomass.

Figure 17. Biomass—landfill and transport.

4. Summary

The research carried out in the tailing pond EVO Vojany showed that on the tailing pond can be planted Swedish willow, as a source of biomass, while the by-product (waste) of the desulphurisation of power plant technology, combustion processes, can be used as the stabilisation material, making it possible to be reused on reclaimed areas of tailing ponds.

Using biomass has a positive impact on the environment and it is environmentally adequate way of power generation. We developed our knowledge with this new technology with 7 years of experience in cooperation with the EVO. About 80 tons of wood chips are co-incinerated based on daily experiment based model. The European Union's commitment to continually increase the use of renewable energy of 20% by 2020—there are contributing implementations of research that results into practice.

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