Szent István University

Doctoral School of Management and Business Administration

# TECHNOLOGICAL AND SOCIAL ASPECTS OF URBANISATION, WATER POLLUTION AND WATER TREATMENT

Doctoral (PhD) thesis

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**The Doctoral School**

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## TABLE OF CONTENTS

# 1. HISTORY OF WORK, PURSUADE OBJECTIVES

One of the important spatial segments of environmental protection, the main topic of my work is sewage treatment. Looking at the European Union, our country is constantly trying to follow the international development of sewage treatment technologies. However, it cannot be ignored that the competitiveness of Hungary depends greatly on the support of this field of expertise. National and EU tenders are available, which can be reasonably justified by the professional disclosure of claims. Taking a general look at the process of sewage purification, it can be concluded that the development of a technology line considered fundamental was a long process. At first, they tried to remove the float content of the effluent with simple settlers. This is considered as the forerunner of the mechanical cleaning stage. Later technological developments have been introduced, which have already cleansed biological wastewater from bacteria using microorganisms. The active sludge cleaning technology has also appeared. Thanks to the upgrades, the technological background of the chemical purification stage has also been renewed. Nowadays, modern methods are available such as membrane technology purification and Monod kinetics for the degradation of biodegradable non-toxic materials and Andrews's kinetics for toxic substances.

The heavy metal content of sewage is an important factor, both ecological and human health risk. Even before the driving, the concentration of heavy metals is below the limit of contamination in the purified sewage, before being driven, the loads in the environment, in surface waters - metal-complex compounds - may cause them to become enriched. The content of purified sewage and incoming (surface water) heavy metal is added, crossing the contamination limits. For this reason, I intended to develop a cleaning technique to remove the heavy metal content so that it is difficult to reach concentrations above the threshold after driving to the recipient. It is important to support the efficiency of newly developed environmental technology processes through risk management studies. As a result, the environmental and human health aspects of the expected efficiency in the technology development can be demonstrated.

The linear economic nature of commonly used heavy metal reduction technologies (for example, artificial, physical-chemical adsorption charges) can be clearly demonstrated as the total energy and mass of the technology is known. However, economic issues are also a priority for new environmental technologies. It is important that all new and developed environmental technology processes are circularly economic. For this reason, it is not just a matter of focusing on new and efficient technological developments, but also for the computation of the Circular Economic Value (CEV) for material and energy streams. The development of CEV test methods is of utmost importance, since each new environmental ecological procedure covers different technical and operational conditions, so their circular economic value is different. In some cases, the Energy Sustainability (CEV) value can be given in the absence of knowledge of energy balance, based on material flows.

*Objectives of the Dissertation*

1. Emphasize the relationship between sewage and urbanization, in particular the environmental and human health risks of heavy metal content in residential (communal) wastewater. The heavy metal content of the daily (communal) and industrial wastewater produced daily, but at different levels but is typically high, therefore the continuous improvement of heavy metal removal methods is necessary. I considered heavy metal content as a very important issue because it could cause pollution / health problems in both the environmental elements and living organisms in large quantities.
2. I have set the goal of developing an alternative heavy metal removal method, which results in a high efficiency in reducing the heavy metal content of wastewaters and thus, in my opinion, significantly reduces the environmental and human risk of heavy metals. The aim of my method of development was to promote the heavy metal adsorption in a physical way, by utilizing a large specific surface of special spider web composts. I wanted to prove the results of my research, such as the success of my heavy metal adsorption method, ICP-MS instrumental analytical measurements.
3. I also had the objective to examine the new heavy metal concentration reduction method to be developed, that is to say, the adaptability of shaking to sewage treatment technology and, hence, its applicability to the treatment of household wastewaters.

4. My aim was also to demonstrate that by adsorption with the new method the heavy metal concentration of purified water can be kept at a low level that no longer poses a risk to the environment and human health.
5. I set the economic analysis of the shaking heavy metal adsorption technique to be developed, that is to examine the circularity of the technique and further clarify the CEV (circular economic) value calculation.

*Hypothesis of the Dissertation*

1. Due to the shaking heavy metal adsorption, heavy metal concentration of communal effluents can be greatly reduced.
2. The method developed by me can be integrated into the series of sewage treatment processes that are developing in parallel with urbanization trends.
3. Because of my research, it is possible to develop an applicable method, which can significantly reduce the environmental and human health risk of purified water due to the reduction of heavy metal concentrations.
4. It is possible to define a factory technological design that facilitates practical applicability.
5. It is possible to determine the circular economic nature of the technique, the circular economic value (CEV), and the further modification of the CEV value calculation formula.

# 2. MATERIALS AND METHODS

## 2.1 Methodology of heavy metal adsorption researches

I used pumice composts for the tests. The cabbage soup was compost sampling, a specially tailored domestic small plant site, in several cycles (a prismatic composting method is used for the production of compost in the plant at the plant). The distribution of grain size of compost samples was made using a series of screens for determining the particle size distribution of soils. 0.02 mm, 0.2 mm and 2 mm mesh screen was screened to screen the compost sample so that the resulting three fractions made possible the adsorption tests. For 2 mm particle size, shaking was performed, followed by filtering the samples. This particle size is suitable for performing heavy metal adsorption tests. In my studies, my intention was to determine the adsorption properties of heavy metal metal in compartments, so it was necessary to produce known heavy metal concentrations and known concentrations. My goal was that stock solutions not only have a single heavy metal content, but also contain various combinations of heavy metals (in combinations of two or three heavy metals). This was done because during my studies I was also interested in how the combined heavy metal content changes the adsorption of certain heavy metals relative to the individual single stock solutions. The concentrations of the prepared stock solutions were as follows: 250 mg/dm$^3$; 500 mg/dm$^3$; 750 mg/dm$^3$ and 1000 mg/dm$^3$. Each single and combined heavy metal containing stock solution was prepared at these four concentrations. Single, double and triple combinations of heavy metals were formed as follows: Cu; Mn; CD; Cu + Mn; Cd + Mn; Cd + Mn + Cu; Mn + Cd + Zn. In order to facilitate the adsorption of heavy metal, I have developed a technique whose method of adsorption is relatively short and can be carried out in a few steps. One of the cornerstones of my doctoral thesis is that I have developed a shaking technique that promotes the adsorption of heavy metals by shredding at a specific time and speed by means of a shaving machine. The primary task of the method to be elaborated was to reduce the adsorption time as soon as possible (but of course the duration should not be reduced to the detriment of adsorption). The essence of the elaborated method is that the planer creates a continuous mixing of the compost and stock solution in a horizontal plane, preventing settling. For the technique, I used plastic 40 cm3 centrifuge tubes that were adapted to the physical forces during the centrifugation. In the method development studies, I worked with different compost - heavy metal contaminated water ratios, but the highest adsorption efficiency was found in the proportion of 10 g of clay pumice compost and 30 $cm^3$ of heavy metal containing stock solution (in ratio 1:3). In my research, I have found that the highest efficiency can be achieved at 50 min shaking time and at 480 rpm. After shaking, the samples were filtered and detonated so that the organic content did not have a disturbing effect on the measurement of heavy metal content. The destruction was done with the Milestone 1200M Microwave Destroyer. I worked with a 5 $cm^3$ solution sample to which 5 $cm^3$ $HNO_3$ and 1 $cm^3$ $H_2O_2$ reagents were added. The duration of the disruption program was 24 min, followed by a water bath for a period of 30 minutes. The heavy metal content of broken and filtered samples was measured by ICP-MS. This instrumental analytical measurement was available at the Institute of Analytical Chemistry at the University of Vienna (*Universität Wien, Institut für Analytische Chemie*). The ICP-MS used for the measurement was Agilent 7500CE (*Agilent Technologies*, *Waldbronn*, *Germany*), in combination with an automatic sample dispenser.

## 2.2 Investigation of municipal wastewater treatment and industrial technological form

The elaborated heavy metal adsorption technology showed remarkable efficiency in laboratory conditions. In order to ensure that the heavy metal removal efficiency does not show significant difference in the case of an industrial design, it is important to emphasize the suitability of the technology in sewage treatment technology. I was looking for the answer at which point of the sewage technology line would be the best way to introduce the technique. All this is done with a prudent implementation of the service, therefore by emphasizing the following important aspects:

- Do not cause volatile wastewater in the technology line
- Technique should not burden the system with organic materials
- In the design of the plant, it is necessary to decide whether batch or continuous sewage loads are counted, since on this basis a part of the heavy metal bound on

the compost surface of the pumice block is washed in water-soluble form and transmitted to the system

• Do not cause overload in the sewage plant from an energetic point of view.

## 2.3 Management research and investigation of environmental risk

The measurement results were evaluated statistically using the "Past3" program package. The results obtained (heavy metal concentrations) were compared with the available limit values for pollutant concentration "B" available in statutory (VM Decree 10/2010 (VIII. 18.)), so that the efficiency of the developed adsorption technique became measurable. Among the limit values for environmental elements, I have chosen data series for surface water, as the new developed wastewater treatment (heavy metal adsorption) technique has favourable indirect effects on living waters and surface water. Surface water limit concentrations are given in Annexes 2 and 3 to the abovementioned VM. In the risk modelling, I applied the "Bayerisches Landesamt für Umwelt" (Source: Bayer E.K.M.), which examines the potential risk of pollutants at three levels:

1. Emission phase (*characterization of the potential hazard of the pollutant*)
2. Transmission phase (*characterization of the environment and mobility*)
3. Imission phase (*rating of susceptibility sensitivity and degree of effect*)

### 2.4 Economical research and calculation of Circular Economic Value (CEV)

One part of my doctoral work was the economic analysis of the elaborated heavy metal removal method, namely the calculation of circular economic values (CEVs). The new heavy metal removal technology developed in my adsorption research (CEVScen) has been compared to the currently used chemical heavy metal removal method (the latter being CEVBAU). The CEV% values available in the literature were modified for both BAU and the new CEV% $_{\text{Scen (mod)}}$ and CEV% $_{\text{BAU (mod)}}$. This was necessary because after the present phase of the research, the exact technical technological development (in working conditions) will be realized in practice. The revised CEV% values are determined for raw material streams and the circular economic value of BAU and Scen technology is already comparable with this result.

## 3. RESULTS AND DISCUSSIONS

### 3.1 Determination of optimal shaking time of heavy metal adsorption

To determine the ideal shaking time, I increased the time in several steps (5 min differences), and then I measured the amount of heavy metal adsorbed by compost mortar in order to determine the efficacy. The initial shaking time was 5 min, and I raised it for up to 70 minutes. Based on the shaking adsorption measurements, the 50 min shaking period was the most ideal for the efficiency of the technique (Figure 1). During the shake of 50 minutes, the efficiency was 98% and then did not rise.

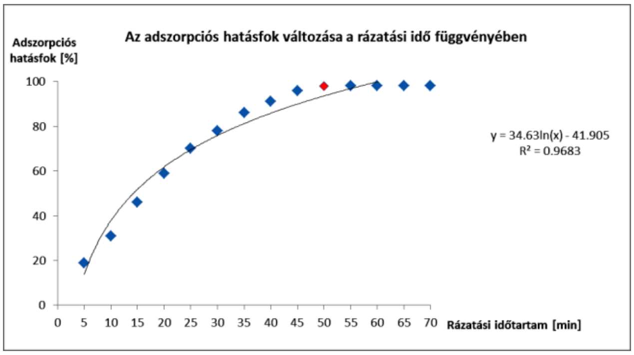


Figure 1. The optimal shaking time and adsorption capacity

### 3.2 Results of heavy metal adsorptions

*Single adsorption results of Mn, Cd and Cu*

After the adsorption of Mn from 500 mg/dm$^3$, 750 mg/dm$^3$ and 1000 mg/dm$^3$, the adsorption maximum did not show, so my assay results indicate that adsorption was effective at 98 to 99% in the measured concentration range. For Cd, it should be noted that isotope interference in this case is distributed between 111Cd and 112Cd. Adsorption efficiency for the original stock solution concentration of 250 mg/dm$^3$ was 97% lower than that of the higher concentrations. The two isotopes of Cu, 63Cu and 65Cu, similar to cadmium, were close to 50-50%, so it was expected that the adsorption efficiency would be similar. With concentration increasing, the efficiency remained as high as 98-99%. This means that the tests did not achieve the maximum adsorption. Mn. The results of the adsorption of Cd and Cu are shown in Figure 2.

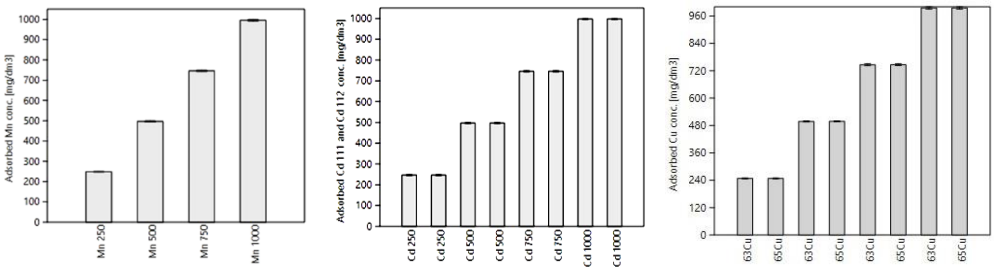


Figure 2. The adsorption of Mn, Cd and Cu

*Doubled adsorption results of Mn, Cd and Mn, Cu*

For solutions containing Cu and Mn combined heavy metal, the adsorption efficiency was 98-99%. Based on the data, it can be said that the two heavy metals did not inhibit the adsorption of each other despite the combination. So if both Cu and Mn, like heavy metal contamination, are in the wastewater at once, then both can adsorb at 98-99% efficiency. Based on the results of the measurements in the combination of Cd and Mn, it can be said that the adsorption efficiency of Cd was even more than 99% above the 1000 $mg/dm^3$ concentration versus Mn adsorption at 98% for all concentrations. There is no significant difference between the two adsorption efficiencies, but based on the results of the other combinations, Cd + Mn combines Cd somewhat reduces Mn adsorption. Figure 3 shows adsorption of double combination heavy metal containing stock solutions.

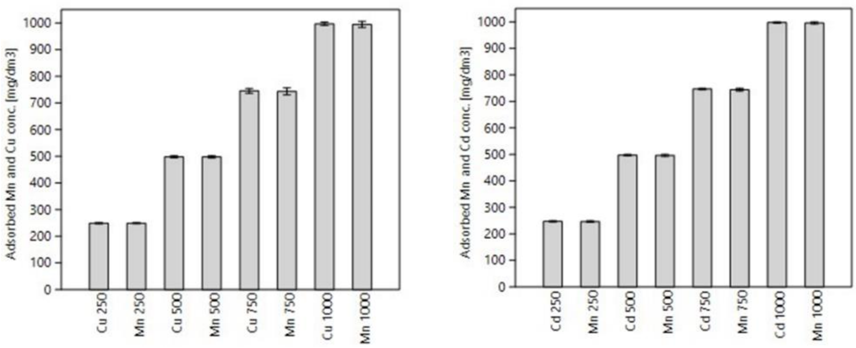


Figure 3. Cu+Mn és Cd+Mn adszorpciója

*Tripled adsorptions of Mn, Cd, Cu and Mn, Cd, Zn*

The adsorption of the triple heavy metal combination was investigated because there are more heavy metals at different concentrations in the waste water (at different concentrations), and the success of the adsorption is due to the higher number of heavy metal combinations. Cd was present in all three triple combinations because neither the single nor the double heavy metal content showed significant deviation at the adsorbed concentrations. However, the efficiency of adsorption of Cd was different from the one previously expected. The concentrations of Cd adsorbed on the surface of the dandelion were lower than the Mn and Cu values (there was no significant difference between the values). Compared with the adsorption efficiency of Cd in the double combination, the adsorbed concentration calculated from the same original heavy metal concentration values was lower for the triple combination. This is because Cd has different adsorption properties with simultaneous presence of several other heavy metals, and in this triple combination it has been combined with two heavy metals whose adsorption has not reached the adsorption maximum for either single or double combinations. Mn and Cd also featured in a second triple combination in which the third heavy metal was Zn. I wondered how both Mn and Cd show the adsorption tendency and efficiency when combined with a heavy metal not yet tested. As previously, 64Zn has similar adsorption properties as 63.65Cu. The adsorption results of triple combinations are shown on Figure 4.

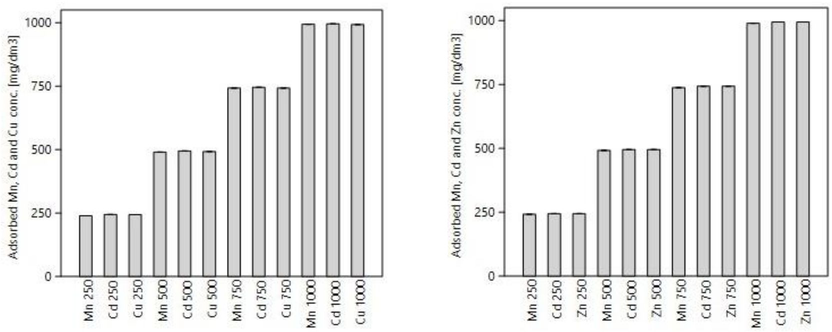


Figure 4. Tripled adsorption results of Mn, Cd, Cu and Mn, Cd, Zn

With regard to the adsorption results, it can be said that the evolved shaking technique was successful in both the single, double and triple combinations adsorption. The determination of the adsorption maximum in the heavy metal concentrations examined did not materialize, but I proved that (although it is possible to reach extremely high heavy metal concentrations in industrial effluents) it is able to adsorbate the compost heavy metals in the spores of sporadic 1000 $mg/dm^3$ heavy metals . The efficiency values ranged from 97-98-99%, and the efficiency decrease for each heavy metal did not mean any significant difference either.

## 3.3 The applicability of developed water treatment technology on settlement development issues

My results have shown, overall, that my method is suitable for reducing heavy metal pollution affecting some of the city's major problems, drinking water bases and surface water bodies. One of the possible practical uses is to connect an alternative route to the existing sewage technology line, which is daily linked to the main cleaning line and does not replace any of its segments. In the case of adsorption through the compartment of compartment mud, a high organic matter content may be present in further sewage water, which is typically in the form of water-soluble or water-miscible complex compounds. In order to avoid that the purified and incoming water does not cause eutrophication, organic matter accumulation and noxious oxygenation of living water in living waters, it is essential to reduce the amount of organic matter as well.

## 3.4 Results of risk management examinations

The pollution limit values for surface waters and their application are set out in Decree 10/2010. (VIII.18.) VM decree. The heavy metal removal technique I developed must also meet the requirement for heavy metal loading of surface waters and the human health risk of heavy metals. From this point of view, the efficiencies shown with my results and my analytical measurements (97-99%) can be considered as outstanding. The three key pillars of the Bavarian Simplified Risk Assessment Model, referred to in the 'Material and Methodology' section, define the risk classification, classification and environmental remediation techniques following a risk assessment for a particular pollutant. For this reason, it is important to refine the model and to modify it in smaller detail, taking into account the special features of the developed technique. Table 1 presents the Risk Assessment Model's written and elaborated amendments.

Table 1. Application of the Bayern Simplified Risk Assessment Model related to the developed technique (Source: Bajor E.K.M., with own modifications)

| *Soil and surface water bodies* | | ***Risk management classification*** |
|---|---|---|
| **Emission segment** | | |
| Fő tényezők | Az anyagok potenciális veszélyességének meghatározása (háttér szerinti besorolás): Közepes kockázati besorolás, a nehézfémek kettős jellege alapján (kis koncentrációban biogén elemek, magas koncentrációban szennyezőanyagok) | Started risk level: III. |
| Kockázat növelő tényezők | Nagy anyagmennyiség vagy helyi terhelés áll-e fent? Kockázat növekedés csak kiugróan magas (>1000 mg/dm$^3$) nehézfém koncentráció esetén jelentkezhet | II. |
| Kockázat csökkentő tényezők | Mobilitás mértéke: Nagyfokú mobilitás, jelentős szennyezőanyag transzport (oldott formában a talajvízzel, felszíni vizekkel). Kockázat csökkenése az oldódás, így a koncentráció mérséklődése miatt várható | III. |
| **Transmission segment** | | |
| Fő tényezők | Felszíni vízfolyások (mint befogadók) átlagos áramlási sebessége, az átlagos vízmélység, vízhőmérséklet, pH, elektromos vezetőképesség | III. |
| Kockázat növelő tényezők | Kedvezőtlen domborzati viszonyok (felszín erodáltságának mértéke, lefolyás gátoltsága) kérdése: Nem áll fent, mivel a szennyvíztisztító telepek sík területeken létesültek, így a kedvezőtlen domborzati viszonyok okozta problémák nem jelentkeznek a befogadóba vezetéskor | IV. |
| Kockázat csökkentő tényezők | A befogadó közeg szigeteltsége (amennyiben a talaj/talajvíz – felszíni víz rendszerétől elkülönítve tárolják az anyagot: A technika szempontjából nem releváns kérdés | IV. |
| **Imission segment** | | |
| Fő tényezők | A vízszennyeződés mértéke, illetve a vizsgálati eredmények esetleges hiánya: A kidolgozott technika esetében nem beszélhetünk vízszennyeződésről, mivel a kimagasló hatásfok miatt nem jelentkezik környezeti akkumulálódás. A rendelkezésre álló vizsgálati eredményekkel a kockázat csökkenését bizonyítottam | V. |
| Kockázat növelő tényezők | A környezeti hatásviselő közeg (korábbról) ismert károsodása: A szennyvíztisztító telepekről a befogadóba engedett tisztított víz számára olyan felszíni vízfolyást választanak, melynek károsodása nem ismert (hiszen előzetesen bevizsgált vízminőségi paraméterekkel rendelkezik) | IV. |

| | | |
|---|---|---|
| Kockázat csökkentő tényezők | Az áramló vízben a káros anyag szállításának mértéke: Mivel a technika hatásfoka nem 100%, így minimális koncentrációban tartalmaz nehézfémeket a befogadóba engedett tisztított szennyvíz (3. táblázat). A nehézfémek mobilitása magas, az akkumulálódás kérdése más felszíni vízfolyásokkal történő keveredést követően válik csak kérdéssé | IV. |

As can be seen in Table 1, the Bavarian Simplified Risk Assessment Model examines the environmental risk of pollutants in the environmental impact medium (groundwater surface water).

Table 2. Risk determination by Bayern Risk Model
(Source: Bayern E.K.M., with own modifications)

| **Expositional way of pollutions** | | |
|---|---|---|
| **Model classification** | **Risk level** | |
| >8 | I. | Very high |
| 5-7 | II. | High |
| 4-5 | III. | Medium |
| ***2-3*** | ***IV.*** | ***Low*** |
| 0-1 | V. | Very low |

The model works with risk estimation, so I find it necessary to link the technique with control measurements, which mean periodic monitoring of the water quality parameters of the receiving surface water stream through point and average samples. The Model also includes a classification system that gives the risk level of the groundwater surface exposure exposure based on the numerical values for each phase of the model. The evaluation based on the Bavarian Classification System is shown in Table 2.

Based on the classification of Table 2 and the analysis of the risk estimation model, it can be stated that the risk question of the developed technique is' IV. It is classified as a low risk class. Low risk classification can be advantageous in analysing the feasibility of a technique in pilotage conditions, as the primary task of the method is to reduce the risk exposure of environmental influences.

### 3.5 Calculation of the Circular Economic Value (CEV), determination of circular economic character of the developed technique

The first step was to determine the CEV value of the alternate scenario (the elaborated alternative heavy metal removal technique). By specifying the CEV equation, the input and output side can be determined for each material and energy.

$$CEV\% = 100 - \left( \frac{\left(\frac{Mp}{Mp + Ms} + \frac{Md}{Mr + Md}\right) + \left(\frac{Ef}{Ef + Es} + \frac{El}{Ec + El}\right)}{4} \right) x\ 100$$

Calculating the actual quantities of materials, according to the ratio of the amount of waste water to be cleaned in the heavy metal adsorption tests, the following numbered values were determined (CEVScen):

Quantities of the INPUT side:

- the amount of compost that is fed into the system is 1 kg
- the amount of waste water discharged to compost (heavy metal charged) is 3 $m^3$
- the amount of heavy metal (concentration) in the wastewater to be purified: 1000 $mg/dm^3$

Quantities of the OUTPUT side:

- the amount of purified (heavy metal discharged) waste water discharged from the system is 3 $m^3$
- the amount of "exhausted" spotted compote that is periodically removed is 1 kg
- the heavy metal concentration of the purified waste water is 30 $mg/dm^3$

Of the currently used heavy metal removal methods, I have labelled a heavy duty demineralizing system for the load-adsorbing agent as a BAU. The reason for my choice is that it works not only with the widely applied method but also with the highest efficiency of the available techniques, so it is comparable to the efficiency and the adsorption mechanism of the technology I have developed. The essence of the operation of the BAU system so chosen is that it can effectively remove the heavy metal content of dissolved or untreated sewage. The equipment contains a special catalytic filler that promotes or accelerates the oxidation processes required for the reaction of heavy metal ions and increases the amount of rainfall thus produced. The adsorption medium (filter material) saturated with heavy metal removal is regenerated by intensive counter-water washing. During the $CEV_{BAU}$ determination required for calculating ΔCEV, I examined the raw material and energy requirements of the selected primary process. For the input-output pages, the following data are available:

Mp: Primary raw material required to produce the product: That is, the amount of catalytic filler: 5 kg

Ms: Secondary raw material required to produce the product: So the amount of waste water to be cleaned to the system is 50 $m^3$

Md: Non-recyclable amount of material at the end of the product life cycle: That is, the amount of catalytic filler which has to be trained and regenerated after filling: 5 kg

Mr: Recyclable amount of material at the end of the product life cycle: So the amount of recyclable materials after heavy metal discharge is 0 kg

For the developed technology, we define the cornerstones to determine whether the new development is economically and technologically more favourable than the generally accepted and used BAU technique. Since my doctoral thesis has focused on the development of technological theoretical and basic engineering, there has not been a prototype design and precise design. The calculation of the orientation tests and the CEV values for the flow of materials will help to plan the future practical technological design and to define further technical parameters. The CEV value for the BAU fluxes can also be specified. This is important because the new scenario developed by me can be compared with the selected BAU technique.

The total CEV% of BAU was 47.75%. This value also includes the weighing of the available energy currents for the BAU. If CEV% $_{BAU}$ is calculated without the energy balance, the modified value (CEV% $_{BAU\ (mod)}$) will be:

$$CEV\%_{BAU(mod)} = 100 - \left( \frac{\frac{5}{5+50} + \frac{5}{0+5}}{2} \right) x\ 100$$

The calculated value is CEV% $_{BAU\ (mod)}$ = 45.5%. Since the linearity of BAU is reflected by energy currents, the number obtained from the modified CEV% formula does not convey the total value of the roundabout. At the same time, only this modified CEV%

value can be compared to the technology I have developed since $CEV_{Scen}$ has not yet determined the energy values associated with the design.

Calculation of CEV% $_{SCEN}$ in accordance with CEV% BAU is based on a modified formula based on material flows so that the results obtained can be compared.

$$CEV\%_{Scen(mod)} = 100 - \left( \frac{\frac{1}{1+3} + \frac{0}{1+0}}{2} \right) x\ 100$$

Counting by the calculation of the above equation: CEV% $_{Scen\ (mod)}$ = 87.5%. By comparing the values, we can draw important conclusions. The difference between CEV% $_{BAU\ (mod)}$ = 45.5% and CEV% $_{Scen\ (mod)}$ = 87.5% is that the amount of material that can be recycled at the end of the life cycle of the product is the same as that of the primary raw material, since the pumice compost is completely recyclable, it is considered to be a natural primary raw material. The question of recyclability is important for circularity testing and helps you determine the energy balance (energy streams) later. Based on the two modified CEV% mod values, the modified ΔCEVmod formula can also be written.

$$\Delta CEV_{mod} = CEV_{Scen(mod)} - CEV_{BAU(mod)}$$
$$\Delta CEV_{mod} = 87{,}5 - 45{,}5$$

So the value obtained with the modified ΔCEV computation: $\Delta CEV_{mod}$ = 42.0%.

Based on the result, the total circular economic value (ΔCEV) cannot be examined on its own, but it can be concluded that there is a significant difference between the BAU method and the method I developed for material flows. The difference in BAU is also because the adsorption medium used for the technique is an artificial chemical, just like the precipitate that is generated as a waste in the system. However, in the new technique, it is possible to speak of a natural adsorption medium that can be produced at any composting site, which can be regenerated and not endangered at the end of the life cycle, but as an energetically usable product. This latter point is one of the essential differences between the two techniques. For the elaborated technique, the exploration of the energy utilization of compost worms that have reached the end of the life cycle and exhausted can be part of a further research program. However, it can be stated that its energy utilization has been explored in other fields of science, the results of which should be compared with the special circumstances of the method used here. These circumstances are as follows:

- Scattered sewage floods the system, so the caviar sprouts compost
- Due to wastewater discharging, the compost at the end of the life cycle of the system has a minimum (chemically bound) water content to be taken into account during energy utilization
- The system power currents and the CEV% $_{Scen}$ can only be given accurately if the tests are performed on dewatered compost

Once the technical design is clearly defined and a prototype is available, it is possible to determine the energy streams needed for optimum operation and the technical conditions for the operation of renewable energy. As a result, the circular economic value of the new heavy metal adsorption technique developed can be further improved.

## 4. NEW SCIENTIFIC RESULTS

**1. A new mushroom-based adsorption technique has been developed to reduce heavy metal content in contaminated waters. For this purpose, a unique new adsorption medium was used, with the use of the shaking method; the heavy metal content in the wastewater can be adsorbed with extremely high efficiency.**

I have demonstrated that the pumice compost has adequate adsorption capacity to adsorb soils with a significant amount of heavy metal content even 1000 $mg/dm^3$. It has been found that the pumice compost is suitable for compost adsorption medium. My aim was to develop, in the literature, a new technique that is favourable to adsorption as it increases the percentage of adsorption and reduces the duration of adsorption. The conditions for the implementation of the technique were given in my examinations: this was the shaking time, the shaking speed, the ratio of the shake of compartment and heavy metal stock to shake, and I determined the additional tasks to be performed to control the success of adsorption (destruction, instrumental analytical measurement).

Adsorption with shaking technique is considered a new scientific result, because thanks to precise elaboration and settings, it greatly improves the capacity of the adsorption medium and reduces the adsorption time. To improve the adsorption capacity, due to continuous shaking, the heavy metal content of the liquid sample is constantly in contact with the entire surface of the adsorption medium (dumbbell compost), so adsorption will not narrow to a certain degree of surface but will be uniformly dispersed on the adsorption surface.

**2. I demonstrated the different adsorption tendencies in the combination of certain heavy metals (Cd, Mn, Zn, Cu), which made it clear that the new adsorption technology (adsorbing with fungi) is also characterized by the combination benefits of other adsorption methods also increase the efficiency of the binding.**

I have proved the fact that different heavy metals affect each other's adsorption ability simultaneously (GERNER, GRÖßL, 2014; BAGHER et al., 2017). For the use of combined heavy metal stock solutions, the behaviour of the individual heavy metals (the efficiency of adsorption) is influenced by the combination of heavy metals. The adsorption of certain heavy metals is different for single and combined contents. This may be due to larger ions displacing smaller ones, so their adsorption may in many cases be insignificant. At the same time, in the case of the triple heavy metal combination, with the literature data (WANG et al., 2013), the relative adsorption of heavy metals did not show any significant difference. By this, I determined that in case of 1000 mg /$dm^3$ heavy metal concentrations, adsorption would not be affected if three heavy metals were present at the same time in the solution. The degree of adsorption depends on the adsorption medium.

**3. From the management and social point of view it can be stated that due to the extremely high efficiency of the mushroom compost adsorption process, the human health and environmental risks caused by heavy metals can be effectively mitigated (low risk class). I have also proved my results by risk management analysis.**

The Bayern Simplified Risk Assessment Model used in my environmental risk management studies; I have demonstrated that from the environmental risk point of view, the low-risk class includes the elaborated heavy metal adsorption technique. I also proved that, according to the hypothesis, the adsorption efficiency achieved with the use of the technology does not present a relevant environmental risk. The human health risk of heavy metals is known, but the degree of risk depends largely on the environmental concentration of heavy metals. With my method, I managed to achieve a 97-99% adsorption efficiency, and in parallel, I demonstrated my ability to reduce the human health risk of heavy metals. My method cannot only be used in the sewage treatment line (with the creation of an alternative cleaning line), but also because of the heavy metal concentration of the purified sewage will be lower than the statutory limit. As the low heavy metal concentration decreases the environmental enrichment of the heavy metal content of purified sewage, the human health risk is expected to be lower.

**4. I have determined the Circular Economic Value of this process of development (CEV) and developed a new (modified) economic value calculation, which shows that the new procedure has a remarkably positive effect on increasing the maintenance of the material circulation.**

I have compared the new heavy metal removal techniques developed and analysed with the tests with the circular economic characteristics of the generally used (and accepted) BAU technique. In doing so, I determined the circular economic value of the new technique. As for the flow of materials, I determined the basic conditions of the operation of the technique and I demonstrated the circular economic nature of the technique.

I have put forward suggestions for further steps in the circular economic study of the new technology, an important part of which is the definition of energy flows, supporting the novelty of the new technology in economic development. In addition, I have put forward proposals for the further development of the CEV (circular economic value) formula, in which changes to the energy streams are also displayed.

# 5. FINDINGS AND PROPOSALS

With my test results, I proved that heavy metal adsorption on the surface of clay pits on compost surfaces is a viable method for reducing heavy metal content. At the same time, the maximum adsorption was not yet possible in the heavy metal concentrations I have been studying so far. Based on this, I conclude that the maximum adsorption will occur at concentrations greater than 1000 mg/dm$^3$. Not only the heavy metal concentration was calculated during the adsorption, but also the single solution of heavy metals as well as the two and triple combinations of heavy metals. In the case of stock solutions containing combined heavy metal, adsorption was different from the single-content solutions because the adsorption capacity of each heavy metal also depends on what other heavy metals are present in the solution. That is, in case of more than one heavy metal coin, adsorption is determined by the relative behaviour of the heavy metals. From the numerical results of the measurements, it can be concluded that certain heavy metals adsorption occurs sooner, so the adsorption of other heavy metals in solution is already limited.

Regarding the different adsorption of certain heavy metals, it is worth comparing my results and WANG et al. (2013). While my research shows that the adsorption of individual heavy metals is different for single and combined stock solutions, WANG et al. (2013) showed that the distribution of individual heavy metals during adsorption is insignificant. My research has shown that the distribution of the adsorption rates of heavy metals depends on the adsorption medium. The specialty material used in my work as a cobweb compost specialty material, such as heavy metals, strongly influences the degree of adsorption. MOHEE and SOOBHANY (2014) also address the adsorption properties of heavy metals. It is mentioned that heavy metals generally possess good adsorption properties, in particular Mn, Cu, Cd and Zn. If I compare this to my research results, I can state that I have proved the group of heavy metals with a particularly good adsorption property mentioned by MOHEE and SOOBHANY (2014) because of the high efficiency adsorption in the concentration range I examined. My heavy metal choices are supported by QUAN et al. (2007), which also demonstrated the high ratio and good adsorption properties of Mn, Cu, Cd and Zn in the environmental samples I examined. This part of my research shows a new heavy metal removal technique that can be successfully applied to sewage treatment in practical, operational conditions. The developed method is the shaking technique that helps the adsorption of heavy metals on the surface of compacts on clay pits. However, like any new method, it can be further developed.

*Further analytical directions and options for heavy metal adsorption*

• Since the adsorption efficiency at the 1000 mg/dm$^3$ concentration was 97-98%, it is absolutely necessary to study at further concentration values, so I suggest to increase the concentration

• Increasing the concentration value should be done until it reaches the maximum adsorption point, until the adsorption efficiency is reduced

• The adsorption tests are also required for other heavy metals not yet studied, both in the concentration values so far and in the extended range

• If all the heavy metals have been subjected to adsorption tests, I suggest creating a database that provides adsorption data for each heavy metal and their combinations at each concentration value.

*Suggestions for the technical feasibility of technology in operational conditions*

My heavy metal adsorption method helps in sewage treatment. To this end, the implementation of the operational conditions follows, for which I outlined a possible solution. The exact determination of the location of heavy metal adsorption is also important because of the presence of organic substances in the system due to the spillage of the effluent from the compartments of the spider. I propose that further tests be carried out to determine the placement in the wastewater treatment process. This would answer the question of how to develop the method developed in the laboratory in order to work with high operational performance.

*Economic and related energy test proposals*

I propose that the CEV value for the whole system be determined by further modification of the circular economic value so far, that the basic condition for determining the total energy system of the process (input-output side) after the exact technical design is determined. I will later plan to conduct studies on the operation of the technology system with renewable energy sources so that it can be completely detached from the power grid (supply). In the present state, the operation with biogas seems to be an obvious solution as most domestic wastewater treatment plants have biogas production to solve (or at least cover the greater part of their power supply) of wastewater plants. As a far-reaching energy supply, there is also an opportunity based on the production of a sponge-bin compost as an adsorption medium. During the composting process, the heat energy required for the maturation phase is produced by the composting system itself by means of microorganisms. If the spotted compost is produced at a given wastewater treatment plant, it is possible to recycle the heat generated by the composting process to provide the energy supply of heavy metal removal technology. At the same time, by examining the possibility in economic terms, the value of the circular economic (CEV) of the developed technology can be further increased. As a further test proposal, I will also modify the calculation of the CEV value. I consider it necessary to supplement the CEV formula in a way that not only shows the proportion of conventional and renewable energy sources on the energy flow side, but also the traditional / renewable share of the potential energy waste arising from permanent operation. For example, the heavy metal cleaning protocol can be operated based on biogas-based power supply.

## 6. LIST OF PUBLICATIONS RELATED TO RESEARCH FIELD

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