

Electrolytic Clarification of Vegetable Washing Water

Fundamentals of the Electrolytic Process

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For the clarification of washing water from potato- and vegetable washing, the electro-chemical method proves superior to conventional sedimentation techniques because, after the necessary amount of electric energy has been expended, the wastewater is clear within a short time and requires a reduced basin surface for sedimentation. The present report describes the procedural principle of electrolysis, as well as its operational and performance parameters based on experimental studies during which standardized model washing water is subject to electrolytic clarification in a batch reactor.

Appropriate setting of the parameters allows the electrolytic clarification of vegetable washing water to be influenced: there is a direct connection between the electrolytic current and the process time required for electrolysis. The product of both parameters releases a defined quantity of electrode material for the precipitation of a certain pollutant load (Faraday's law). The amount of electrolytic current also depends on the set electrolytic voltage, the properties and the size of the electrolytic unit, and the conductivity of the liquid to be treated. High electrolytic tensions, which result in very short process times for clarification, cause the development of large quantities of gas so that the amount of electricity employed cannot entirely be converted into chemical precipitation material. Therefore, the cost of electric work increases disproportionately. At low tensions, electrolytic treatment is more cost-efficient. Longer process times result in improved clarification performance. For the reduction of the COD, however, which is present in a dissolved form, even significantly prolonged clarification periods do not provide substantial improvement. The electrode combination aluminium/chromium steel (Al/XSt) allowed for high current densities and led to the best clarification results with regard to COD reduction.

Keywords

Waste water clarification, electrolysis, processing parameter, washing of vegetables

Introduction

Wastewater from potato- and root vegetable washing mainly contains soil and plant residues [1]. Depending on the washing technique and the kind of vegetable, the amount of washing water may be up to twice as high as the quantity of the raw produce. In order to save fresh water, the vegetable washing water is recycled. The application of simple sieve techniques enables pollutant load particles with a diameter of up to 40 µm to be removed from the washing water [2]. Hydrocyclones reduce the lower separating limit to a par-

ticle size of up to 5 µm [3]. Pollutant load particles which - due to their density and diameter - do not settle at all or only after a longer period of time remain in the water either in a dispersed or dissolved form. Electrolytic water clarification enables turbid, polluted water to be processed into clear service water within a short time. Thus far, this method has been employed in industrial electroplating and varnish production plants, as well as in the metal industry. The application of this technique was also examined for agricultural wastewater (slurry) with high organic pollutant loads [4]. However, it failed to

establish itself. A project promoted by the Federal Ministry of Education, Science, Research, and Technology is now aimed at the application of this electro-chemical processing technique in the clarification of vegetable washing water, especially under the aspect of a further reduction in drinking water consumption during vegetable washing with the aid of clear, recycled service water. In the present report, the theoretical fundamentals of the electro-chemical method are expounded. Experimental studies during which standardized model washing water was clarified electrolytically at a batch scale describe the most important operational and performance parameters of electrolysis.

Theoretical Fundamentals of Electro-Chemical Water Clarification

Considerably simplified according to references [5, 6, 7], the procedural principle of electro-chemical water clarification can be described as follows (cf. **figure 1**): Direct current is applied between two electrodes or electrode bundles which are placed in wastewater or the liquid to be cleaned. This causes ions or charged particles to migrate in the electric field. Positively charged ions, i.e. ions with a lack of electrons, migrate to the negatively charged cathode in order to absorb electrons. Negatively charged particles, which have excess electrons, migrate to the positively charged anode in order to give off electrons there. Water with its charged colloidal dirt particles acts as an electrolyte, i.e. it conducts electricity to a varying extent depending on its charge density, the so-called conductivity. According to *Ohm's law*, the flowing current I is proportional to the applied voltage U and inversely proportional to the resistance R of the electrolyte (1):

$$I = \frac{U}{R} \quad \text{or} \quad U = I \cdot R \quad (1)$$

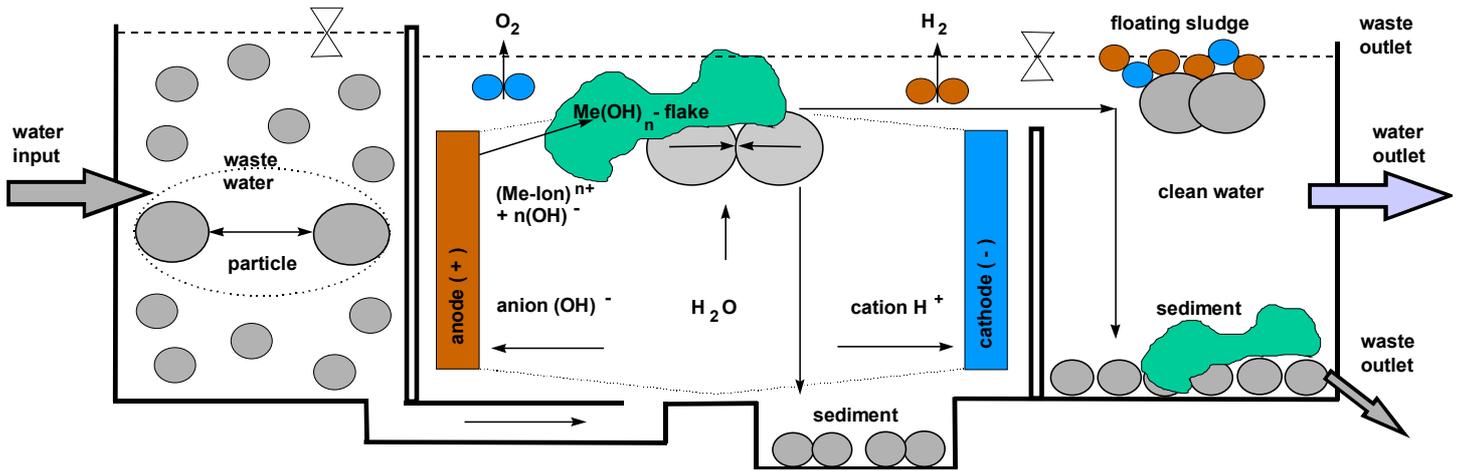


Figure 1: Principle of the electrolytic clarification process

In addition, tension depends on the geometry of the electrolytic cell, the distance d (cm) between the electrodes and the size of the electrode area A (cm²). If the electrolyte has the specific conductivity κ (Ohm⁻¹ cm⁻¹) and if one writes $I/A = i$ for current density, *Ohm's law* can be expressed as follows (2):

$$U = \frac{I \cdot d}{A \cdot \kappa} \quad \text{or} \quad U = \frac{i \cdot d}{\kappa} \quad (2)$$

Additional connections between current and tension (limiting diffusion current density, decomposition voltage, overvoltage) are described in reference [6].

The ions of the electrodes are part of the current flow. They migrate from the electrode if the anodes consist of non-inert material. This substance conversion during electrolytic processes is described by *Faraday's law* [6] (3):

$$\frac{dm}{dt} = \frac{M}{z \cdot F} I \cdot \gamma \quad (3)$$

dm / dt	substance conversion in g/s
M	molar weight in g
z	electrovalence of the ion or electron equivalents to be converted
F	Faraday constant [96 487 As], corresponding to the quantity of electricity which can precipitate, dissolve, or convert (oxidize or reduce) an equivalent of a substance
I	current in A
γ	current exploitation factor in %

This equation can be transformed as follows (4):

$$m = \frac{M}{z \cdot F} I \cdot t \cdot \gamma = \frac{M}{z} C_H I \cdot t \cdot \gamma = C \cdot I \cdot t \cdot \gamma \quad (4)$$

m	converted material mass in mg
t	electrolytic process time in s
C	electro-chemical equivalent in mg/As

Examples of electro-chemical equivalents

C_H	electro-chemical equivalent of hydrogen (= 0.010363 mg/As)
C_{Al}	electro-chemical equivalent of aluminium (= 0.09321 mg/As)
C_{Fe}	electro-chemical equivalent of iron (= 0.19303 mg/As)

The quantity of substance converted during the electrolytic process time in the form of migrating ions is therefore dependent upon the material of the anode, the amount of the flowing current, the electrolytic process time, and other factors.

The constantly, forced release and absorption of electrons as a result of the current flow leads to numerous redox reactions. The positively charged metal ions which leave the anode, e.g. trivalent iron or aluminium ions, thus aggregate (partly dependent on the pH) with the dissociated, negatively charged hydroxide ions of the water to uncharged hydroxo-metal complexes, which form large flocks.

At the same time, the applied electric field disturbs the electrostatic balance of the watery dirt dispersion. The generally negatively charged colloidal particles are discharged, and after their electrostatic repulsive forces have been neutralized or *Van der Waal's* attractive forces have set in, they aggregate with each other and the metal hydroxo-complexes to form flocculent, voluminous aggregates [8]. Due to their enlarged diameter, the agglomerates of dirt particles and metal hydroxides settle within a short time (*Stoke's law*). As compared with natural sedimentation without electrolytic treatment, they therefore require a reduced sedimentation basin surface [3].

After the flocks have settled, the electrochemically treated water is clear, i.e. largely free of particular, colloiddally dispersed components. According to references [9, 7], dissolved components are reduced in the treated water.

Studies on the Electro-Chemical Clarification of Vegetable Washing Water

Based on the theoretical fundamentals, it was to be examined whether vegetable washing water can in principle be clarified electrolytically, where the cut-off limits are, and to what extent the parameters electrolytic tension, current, and time influence the substance conversion described according to *Faraday's law* or make a contribution towards the clarification of defined vegetable washing water. Additionally, it was to be determined which electrode materials are most suitable for the electro-chemical clarification of vegetable washing water, what amount of electric work is required, and how strong the resulting clarification effect is.

Material and Methods

The experiments were conducted with standardized model washing water in a discontinually working small batch reactor.

Model Washing Water

One litre of model washing water was made using 1.7 g of quartz powder (Sigrano Type SP13) (99.4% silicon oxide (Si O₂), 99.9% ds, specific density 2.65 g/cm³, particle diameter 3 to 40 μm), 1.0 g of dry carrot powder, and 1 l of tap water. Due to its composition, the model washing water had an initial average turbidity of 1,000 formazine units (TE/F) and a chemical oxygen demand (COD) of ca. 1,000 mg O₂/l.

The quartz powder SP13 was primarily responsible for the turbidity of the model washing water. With 9 mg O₂/l, its COD value was negligibly small.

After drying, the grated carrots processed into dry carrot powder had an average dry substance content of 10% with regard to fresh weight. 1 g of dry carrot powder had

a COD of approximately 1,000 mg O₂/l with a range of variation from 850 to 1,200 mg O₂/l.

The dry carrot powder had a disproportionately small turbidity effect.

Electrolysis Batch Reactor

The small batch reactor consisted of a glass container with a capacity of 100 ml. Pairs of electrodes with different material composition (uni-polar electrode arrangement) were placed in the reactor space. The distance between the electrodes was set at 3 mm. The electrode form and -structure chosen were electrode plates with a smooth surface and a size of 30 x 30 mm. Aluminium (Al), iron (drawing sheet with a small carbon content (Fe)), highly alloyed chromium steel (X20Cr13 (XSt)), and graphite (Gr) were used as electrode materials.

While aluminium and iron count among the soluble electrodes, chromium steel and graphite belong to the quasi-inert electrodes. For this reason, the latter were not employed as anodes. The electrodes in the small reactor were connected to controllable electricity generators, which supplied load-independent direct current.

Measuring Method

The standardized model washing water was treated electrolytically in the reactor using defined electrolytic tensions (3.5 V, 5 V, 7.5 V, 10 V, 12.5V, 15 V, 20 V, and 25 V) and the electrode combinations aluminium/aluminium (Al/Al), aluminium/chromium steel (Al/XSt), aluminium/iron (Al/Fe), aluminium/graphite (Al/Gr), iron/aluminium (Fe/Al), iron/chromium steel (Fe/XSt), iron/iron (Fe/Fe), and iron/graphite (Fe/Gr). The first-mentioned electrode was always employed as the anode and the second-mentioned electrode as the cathode.

The amount of current, which resulted from the set voltage, was registered, and the time until clarification (electrolytic process time) was measured with a stopwatch. The clarification process was considered complete when the turbidity meter showed the liquid to have a turbidity of ca. 50 formazine units (TE/F) or when (during visual measurement) the white embossment of the glass container was legible through the electrolytically clarified liquid. Afterwards, the electrolytic process was stopped.

At 5 V and 15 V of electrolytic tension, the model washing water was additionally subject to electrolytic treatment lasting twice the amount of time it took for the clarification of the model washing water. During the electrolytic process, the electrolytically generated dirt particle/metal

hydroxide flocks were in constant motion. After the electricity supply had been stopped, the flocks precipitated. The time until the definite precipitation of the flocks was defined as post-clarification time. For post-clarification, the sample was poured from the reactor into a post-clarification container. The turbidity which developed after a post-clarification time of 20 min was measured with the turbidity meter (Hi 93703 Turbidity Meter, HANNA Instruments company, Kehl am Rhein (measuring cell 10 ml)).

After each electro-chemical treatment, the COD reduction (potassium dichromate or COD-Lange test) of the differently treated model washing water was measured, and alterations of the pH value and conductivity were registered.

Measurement Results

The connection between current density (= amount of electricity in relation to the electrode area) and the process time during the electrolytic clarification of model washing water at increasing electrolytic tensions and with different electrode combinations is shown in **figure 2**. Since the amount of current is one of the factors which determine the electrolytic substance conversion according to *Faraday's law*, the current or current density were given instead of the varied electrolytic tension. The electrolytic process time which led to the set clarification effect of ≤ 50 TE/F is correlated with current density, which resulted from the increasing electrolytic tensions and different electrode combinations.

This allows a potential connection to be

established: as current density and electrolytic tension increase, the electrolytic process time for the clarification of the model washing water diminishes. This applies to all tested electrode combinations. The time required for the clarification of model washing water with aluminium anodes was shorter than the time needed with iron anodes. As of a current density of 200 A/m², complete clarification of the model washing water was already achieved after a process time of 10 minutes.

Figure 3 shows the amount of electric work required for the clarification of model washing water at increasing tensions and with different electrode combinations. As electrolytic tension grows, the amount of electric work to be expended for the electro-chemical clarification of the model vegetable washing water, which can be seen as an indicator of the cost of electro-chemical clarification, increases significantly. At electrolytic tensions below 10 V, all electrode combinations require 1.5 to 2 kWh/m³ and thus a similar amount of electric work for the clarification of the model washing water. At higher tensions, the electric work needed by the variants with iron anodes is nearly twice as high as compared with the electrode combinations with aluminium anodes. At an electrolytic tension of 25 V, for example, the clarification of the same model washing water with Al-anodes and Fe-anodes requires ca. 5 kWh/m³ and ca. 9 kWh/m³ respectively.

Due to strong deposit formation at the graphite cathodes, which resulted in diminishing current densities, the electrode combinations Al/Gr and Fe/Gr were included in the measurements only to a limited extent.

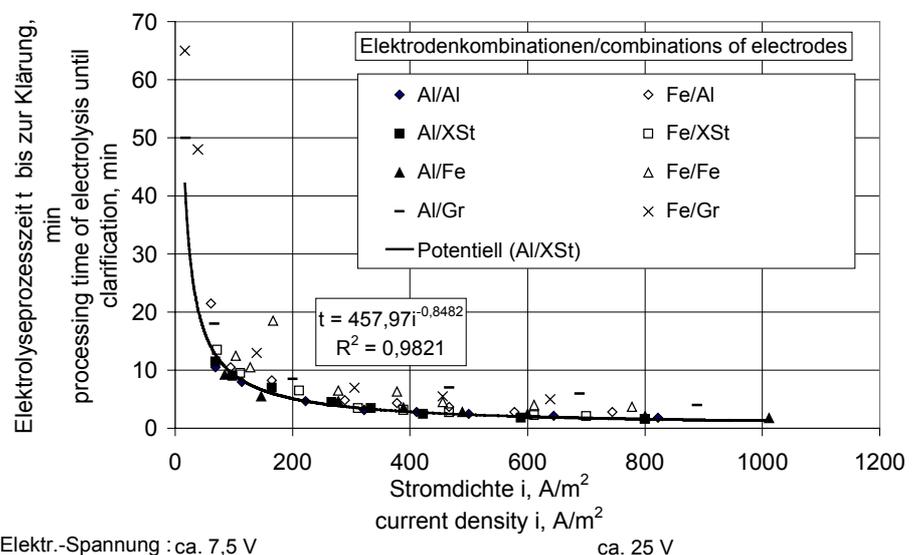


Figure 2: Connection between current density and electrolytic process time for the clarification of model washing water to 50 TE/F with different electrode combinations

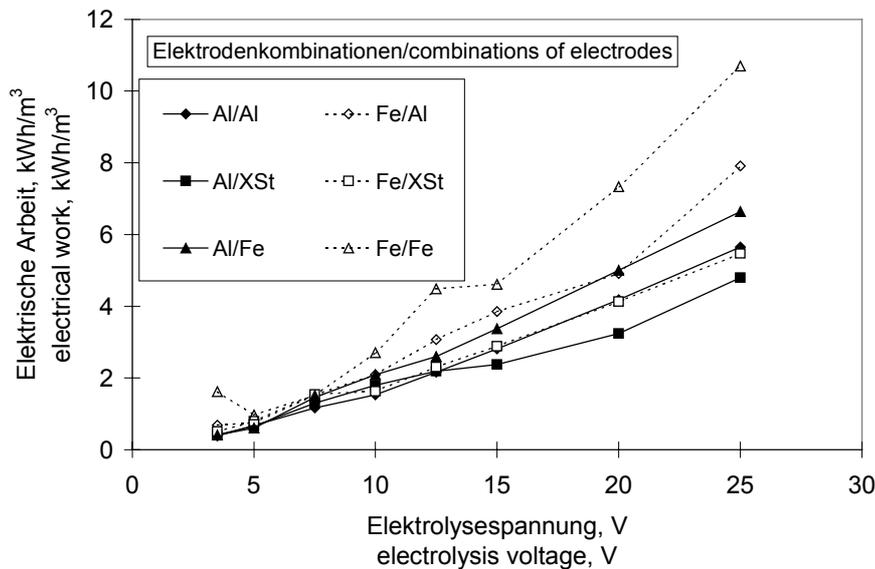


Figure 3: Connection between electrolytic tension and electric work until the clarification of model washing water with different electrode combinations

The COD values measured in the model washing water after electrolysis, which had been achieved with different tensions and electrode combinations, are shown in **figure 4**. For reasons of clarity, only 5 V, 12.5 V, and 25 V of electrolytic tension are plotted. The initial COD value amounted to 1,126 mg O₂/l.

The COD values determined in these experiments are generally inconclusive with a tendency towards better clarification at higher tensions.

In relation to the initial COD, an average COD reduction of 50% was reached. The overall difference in the COD reduction achieved by all electrode combinations and electrolytic tensions was small. After electrolysis, the lowest COD values were reached with aluminium/chromium steel (ca. 557 mg O₂/l) and iron/iron electrodes (ca. 553 mg O₂/l). The highest values were recorded for aluminium/aluminium electrodes (ca. 614 mg O₂/l). After 24 h of natural sedimentation, only a slightly higher COD value (671 mg O₂/l; COD reduction 40%) was reached than in the model washing water clarified with different electrode combinations.

The turbidity of the model washing water after electrolysis carried out with different electrode combinations is shown in **figure 5**. The values in formazine units after a post-clarification time of 20 minutes relate to an electrolytic tension of 12.5 V. For comparison, the turbidity values of the model washing water measured after 20 minutes and 24 hours of natural sedimentation are given as well.

The acceleration of the clarification process due to electro-chemical treatment was clearly shown. While the turbidity of model washing water with an initial turbidity of approximately 1,000 TE/F dimi-

nished to 832 TE/F after 20 minutes of natural sedimentation, the water was almost completely clarified after electro-chemical treatment and 20 minutes of post-clarification time, reaching an average of 40 TE/F. After 24 hours of natural sedimentation, the final turbidity values of the model washing water reached ca. 100 TE/F.

The electrode combinations with aluminium anodes provided better clarification results with regard to the final turbidity values (ca. 25 to 34 TE/F) than the electrode combinations with iron anodes (ca. 58 to 92 TE/F).

Only in iron anode combinations did higher electrolytic tensions exert a discernible effect on clarification.

Depending on the electrode combination used, the pH value of the model washing

water changed during electro-chemical treatment. During electrolytic treatment with iron anodes, the average pH value of the model washing water thus increased significantly by 0.74 (Fe/Al), 1.1 (Fe/XSt), and 1.22 (Fe/Fe). In model washing water clarified with aluminium anodes, the pH value exhibited a far smaller increase of 0.28 pH units for Al/XSt, 0.46 for Al/Al, and 0.43 for Al/Fe.

Electro-chemical treatment generally caused the conductivity of the model washing water to diminish by ca. 10-20% of the initial value. In some cases, however, conductivity later reverted to its original value.

The water clarified with the Fe/Fe electrode combination retained a reddish overall coloration after clarification. Furthermore, iron-containing deposits settled on the container walls and on the surfaces of submerged bodies within a relatively short time (ca. 30 min).

As electrolytic tension increased, the development of oxygen- and hydrogen gas grew considerably. This led to thick foam on the surface.

In order to exclude this effect of increased gas formation at higher electrolytic tensions, the electrolytic clarification of model washing water at low electrolytic tensions and doubled process times was examined through experiments. The model washing water was treated electro-chemically at electrolytic tensions of 5 and 15 V for single and double clarification periods with subsequent determination of COD reduction (**table 1**).

Both at 5 V and 15 V, doubling the electrolytic process time enabled the COD value in the model washing water to be reduced by a further 9% and 7% respectively. A comparison of the electric work

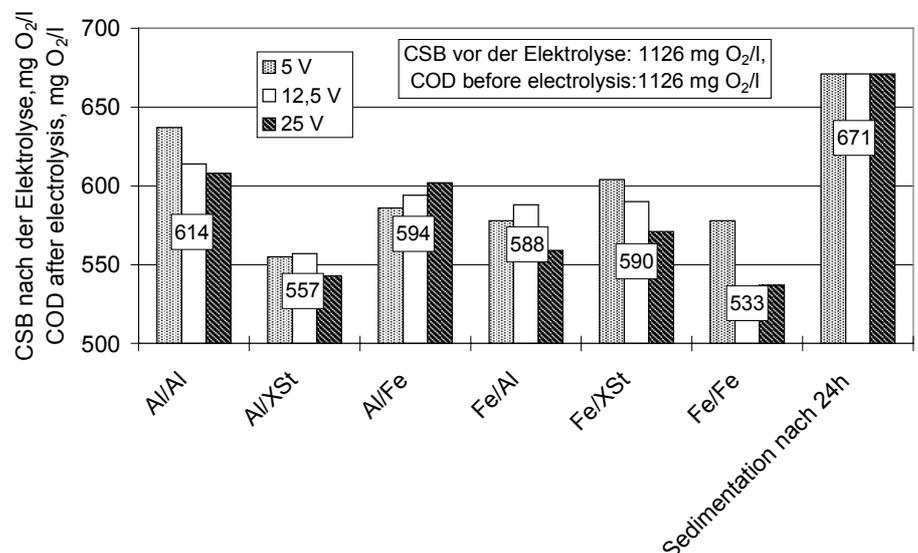


Figure 4: COD value of electrochemically treated model vegetable washing water after a post-clarification time of 20 minutes; determined for different electrode combinations and electrolytic tensions. The numerical value stands for the COD value reached with an electrolytic tension of 12.5 V.

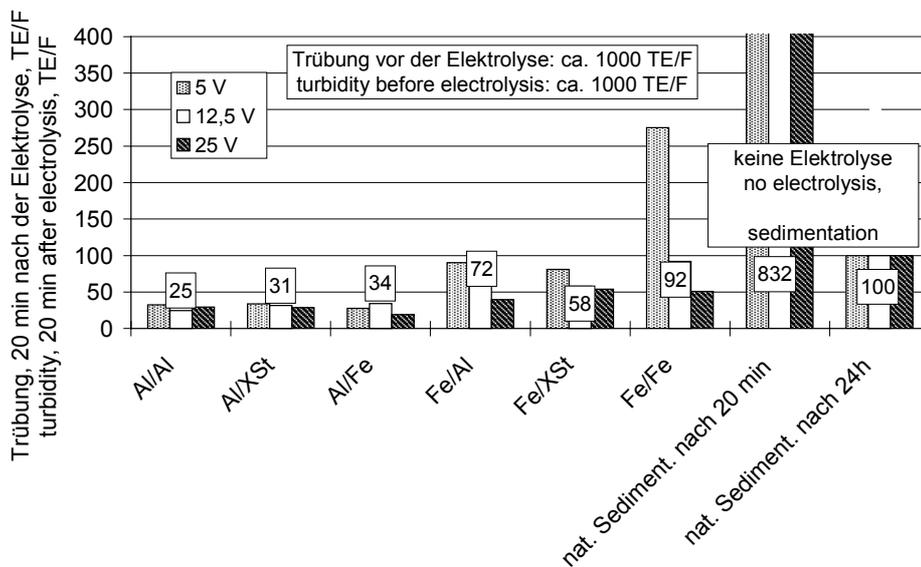


Figure 5: Turbidity values in formazine units of electro-chemically treated model vegetable washing water after a post-clarification time of 20 minutes; determined for different electrode combinations and electrolytic tensions

Table 1: Results of the electro-chemical treatment of model washing water at 5 V and 15 V after single and double electrolytic process time with aluminium/graphite electrodes; initial COD: 1,162 mg O₂/l

Tension (V)	Process time (min)	El. work for clarification (kWh/m ³)	COD after el. treatment (mg O ₂ /l)	COD-reduction (%)
5	12	0.80	673	42.1
5	24	1.60	569	51.0
15	4	2.90	633	45.5
15	8	5.80	557	52.0

required for the clarification of the model washing water shows that at 5 V and 24 min 1.60 kWh/m³ had to be expended to achieve a COD reduction of 51%. At 15 V and 4 min, however, 2.90 kWh/m³ are necessary for a COD reduction of 45.5%. The significantly (5.5%) higher COD reduction at low electrolytic tensions and longer electrolytic process times is thus reached with approximately 50% of the electric work required for the electrolytic clarification of the model washing water at high tensions and shortened process times.

Discussion and Conclusions

The presented experiments have shown that the electrolytic technique can be used for the clarification of vegetable washing water.

As compared with conventional filter- and sedimentation methods, the advantage of electrolysis resides in the accelerated clarification time. The surface requirements of sedimentation basins diminish. In the described experiments, electrolytic treatment allowed defined model washing water with a turbidity of ca. 1,000 TE/F

and a COD value of ca. 1,000 mg O₂/l to be optically clarified to a turbidity of ca. 30-50 TE/F and COD values of 550 to 600 mg O₂/l within an average of 30 to 40 minutes (including both process time and post-clarification time), depending on the combination of the electrode materials and energy expenditure. At the same time, an increasing pH value was recorded.

After electrolytic treatment, approximately 50% of the COD remained in the clarified water. The reduction of the COD value in the electrolytically treated model washing water was thus about 10% higher than in the model washing water which was clarified through natural sedimentation within 24 h. These results are partly caused by the characteristics of the model washing water used. In addition to quartz powder with a density of 2.65 g/cm³, it contained a high percentage of molecularly dissolved substances originating from the carrot. The results of natural sedimentation allow the conclusion to be drawn that 60% of the organic material was dissolved in water while a further 40% was present in a coarse-colloidal, i.e. settleable form. Electrolysis enabled an additional 10% of the colloidal dirt par-

ticles to be removed. The legally required input limit for wastewater from fruit- and vegetable processing with a COD of 110 mg O₂/l [10], however, would not be met. The literature also confirms that the electrolytic technique is particularly suitable for the elimination of colloidal dirt particles from wastewater: according to these results, the electrolytic clarification of wastewater with high BOD₅- or COD values due to soluble compounds causes difficulties [11] or very high expenditures [12]. Such water shows the limits of the electrolytic clarification process.

Another publication discusses the question of whether and to what extent the composition of vegetable- and potato washing water influences the clarification efficacy of electrolysis [13].

The clarification of the model washing water can be achieved with different electrolytic process parameters: a similar clarification effect with regard to COD reduction and turbidity was also reached with low current densities or electrolytic tensions and longer electrolytic process times, as well as with higher current densities/electrolytic tensions and shorter process times.

Growing electrolytic tension, however, led to increasing gas formation during the electrolytic process. In addition, a significant increase in electric work was recorded.

With regard to COD reduction, lower electrolytic tensions and prolonged process times resulted in an improved clarification effect while requiring less electric work.

These results match well with the theoretical fundamentals. The clarification of the model washing water is primarily dependent upon current and process time as electrolytic process parameters. According to *Faraday's law*, the quantity of electricity, i.e. the product of current and time during the electrolytic process, is one of the factors that determine the quantity of ions which migrate from the electrode area and lead to the formation of metal hydroxides. These metal hydroxide complexes adsorb the colloidal substances which are present in the water.

The experiments conducted with different tensions and varying electrode combinations enabled the potential connection between the clarification time and the current or the current density $t = i^{-1}$ required for the clarification of the defined model washing water to be proven with a high determinateness of $B = 0.98$ for $t = i^{-0.85}$ (cf. equation 4 and figure 2). According to these results, approximately the same

amount of electricity is required in order to cause the quantity of dirt which is constantly present in the model washing water to precipitate.

For a closer examination of the question of whether the clarification effect during the electrolytic treatment of model washing water is mainly dependent upon the process parameters current and time, the product of the electrolytic current and -time of the experimental results shown in Figure 2 was calculated taking *Faraday's law* into account and related to the electrolytically treated model washing water quantity. The value measured in As/cm^3 was accordingly equated with a specific quantity of electricity converted into metal hydroxides, which causes the clarification of the defined, specific amount of model washing water. This train of thought did not consider the electrochemical equivalent of the electrode materials and the current exploitation factor, which, in addition to current and time, are employed in *Faraday's law* for the calculation of *substance conversion*, i.e. the electrode material consumed.

It was shown that the specific quantity of electricity which flows during the electrolytic process, i.e. the amount of electricity required for the clarification of 1 ml or 1 cm^3 of model washing water increased slightly with electrolytic tension (figure 6). As electrolytic tension grew, iron anodes caused a more pronounced increase in the amount of electricity than aluminium anodes. At higher electrolytic tensions, however, increased electrolytic gas production was also registered. If the fact that part of the quantity of electricity employed at higher electrolytic tensions was converted into H_2 and O_2 gases or thermal energy is taken into account, this allows the conclusion to be drawn that at higher electrolytic tensions the current yield γ for the substance conversion required for the clarification of the model washing water diminished or that a larger specific amount of electricity became necessary for clarification.

Even though, in addition, the chemical equivalents C of aluminium ($C_{\text{Al}} = 0.09321 \text{ mg}/\text{As}$) and iron ($C_{\text{Fe}} = 0.19303 \text{ mg}/\text{As}$) differ significantly (i.e. almost twice as much iron as aluminium was converted or consumed for the clarification of the model washing water, using the same amount of electricity), no better clarification effect of the iron anodes could be detected. This indicates that, as compared with aluminium anodes, the electricity exploitation factor of iron anodes is smaller.

Further studies have shown that the amount of electricity expended for the clarification of a defined quantity of dirty water can be employed as a washing water-specific parameter, especially if the electrode materials are identical. Moreover, due to the potential connection between current and clarification time, the electricity requirements for the clarification of a specific kind of washing water in a batch experiment also apply to a flow plant [13].

Consequently, it is only a question of time and cost whether electrolytic clarification is supposed to be carried out in a very short time at high electrolytic tensions and with the resulting large amount of electric work/expenses or in slightly longer periods of time at low electrolytic tensions and low cost. After the evaluation of the results of all experiments, however, it is rather recommendable to carry out the electrolytic clarification of vegetable washing water at low electrolytic tensions and slightly longer process times because at higher tensions more energy is expended for the formation of gases and the raising of temperature. It was proven in the experiment (cf. table 1) that electrolytic clarification at low electrolytic tensions and prolonged process times also leads to lower electricity cost combined with a higher clarification effect (COD reduction). In addition to the expenses for electric work during electrolytic water purification, the cost of anode material consumption must be taken into account when calculating the fixed cost of electrolysis.

In practice, electrolytic wastewater purification plants also work with low electrolytic tensions and average process times

of about 30 minutes [9]: industrially available electrolytic plants for the clarification of wastewater from polymer production [14] and the corrugated cardboard- [7] or automotive industry [15], for example, use tensions of 6 to 8 volts and require electrolytic process times of 20 to 40 minutes. [4] achieved good clarification results with the electrolytic treatment of pig slurry diluted with water by keeping the distance between the electrodes small and providing a sufficient electrode area, which caused low current densities and tensions resulting in long electrolytic process times.

The material composition of the electrodes and their combination also played a significant role with regard to the clarification efficacy of electrolysis. In view of COD reduction and the lowest amount of electric work, the aluminium-chromium steel electrode combination provided the best results. Among other advantages, aluminium anodes achieved better elimination of turbidity than iron anodes. As compared with aluminium electrodes, the latter work with lower current densities and, consequently, longer electrolytic process times. In the water, they also caused a significantly greater pH value increase. Poor post-clarification behaviour, which can be attributed to post-electric (post-) flocculation and was not discussed in more detail here, as well as the remaining reddish turbidity of the clarified water, are undesirable as well. Graphite cathodes also proved to be rather unfavourable for use in electrolytic equipment because they were susceptible to increased deposit formation and a reduction in the required amount of electricity.

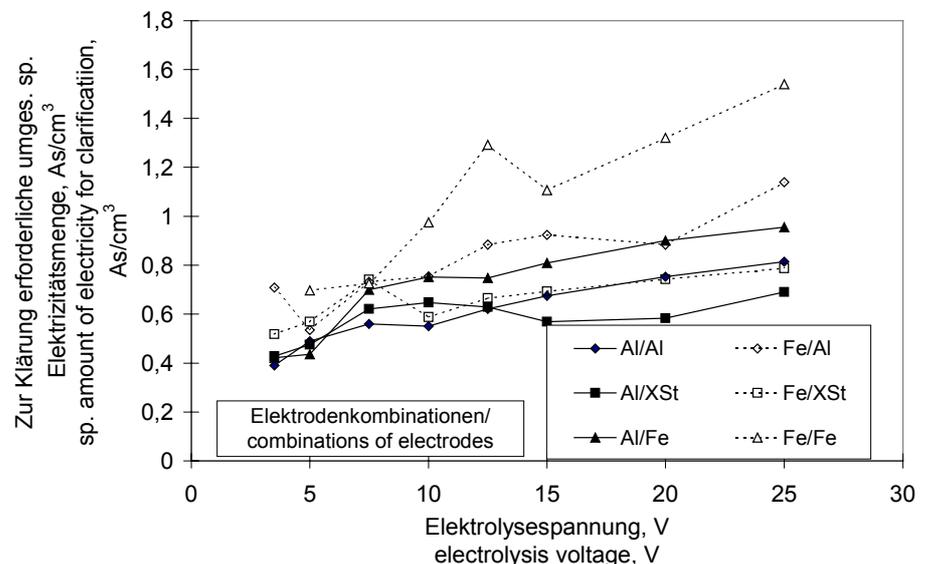


Figure 6: Connection between electrolytic tension and the specific electricity quantity required for the clarification of model washing water with different electrode combinations

Summary

The electrolytic technique lends itself to the complete removal of soil, clay, and other colloidal anorganic and organic particles from the washing water, i.e. those particles which are primarily responsible for the turbidity of vegetable washing water. As compared with natural sedimentation, the water to be clarified needs a reduced sedimentation area and is optically clear within a short period of time after the required expenditure of electric energy. However, electrolytically clarified vegetable washing water retains a residual percentage of components which mainly consists of *soluble* organic substances (COD value). Hence, the turbidity of the examined model washing water was reduced by 95 to 98%, while the COD value diminished by only 50%. In addition, the pH value of the treated water increases.

An appropriate choice of parameters allows the electrolytic clarification of vegetable washing water to be carried out within a short or longer period of time: there is a direct connection between electrolytic current and electrolytic process time. The product of both parameters releases a defined quantity of electrode material for the precipitation of a certain pollutant load. The entire process is very complex due to chemical and thermal processes running parallel. The amount of electrolytic current is also dependent upon the set electrolytic tension, the characteristics and the size of the electrolytic unit, and the conductivity of the liquid to be treated.

High electrolytic tensions which lead to very short process times for clarification cause the development of a large quantity of gas so that the expended amount of electricity cannot be completely converted into chemical precipitation material. This results in a disproportionately high increase in the expenses for electric work. Electrolytic treatment is more cost-efficient at low tensions. Prolonged process times provide improved clarification efficacy. However, even significantly longer clarification times do not lead to a considerable improvement with regard to the reduction of the dissolved COD.

The electrode combination aluminium/chromium steel (Al/XSt) allowed for high current densities and provided the best clarification results in view of COD reduction.

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