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Selected wastewater parameters from the vegetable washing process

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Abstract. This article follows selected parameters in wastewater which arise from the washing process for root vegetables, which is one of those problems which are current in terms of water usage. With a growing population, industrialisation, and urban development, there is also a growing demand for water resources. Industries which are dealing with the processing of agricultural products and food production in general significantly contribute to the growing consumption of water. Technology which is used for cleaning vegetables also significantly affect this growth in water consumption. Increasing demands on the quality of vegetables (eg. the cleanliness of vegetables at the point of sale), also leads to the necessity for more effective post-harvest cleaning, something which is carried out both with dry and wet methods. This article examines the cleaning process for selected root vegetables, particularly carrots and potatoes, by determining selected properties of the output process water in an assessed technological line. This line is specific with regard to its methods for cleaning carrots and potatoes. Following the investigation, the line was assessed as being satisfactory with respect to the quality of the input and output water. The monitored parameters of the process water (eg. concentrations of selected elements in the process water and concentrations of selected inorganic anions in the process water, mainly Na and Pb) from cleaning carrots and potatoes were considered as being satisfactory for recirculation into the cleaning process and therefore a reduction was achieved in overall water consumption.

Key words: food industry, technological line, vegetables, washing vegetables, wastewater

INTRODUCTION

Water is defined as an essential component of the environment. Without it life cannot exist. Given the irreplaceable nature of water, the wastewater treatment process is one of the most important conditions for sustainable development. As with energy saving (Vaculík et al, 2013), due to ongoing and further expected climate-related changes, it can be assumed that water management and water treatment will increasingly be an issue that will be have to be addressed (Alsiņa et al, 2016; Borys & Küüt, 2016). Vegetables are an important part of our diet (Dubrovskis & Plume, 2015). A proportion of the production reaches consumers in a fresh state, and a proportion of it is processed into other products.

Fig. 1 shows the general scheme involved in the product handling process, from its harvesting in the field to its distribution, either for direct consumption or further processing. Input and output variables such as consumed energy are assigned to each operations sequence (Kern, 2006). Table 1 shows the parameters for selected areas of the lines.

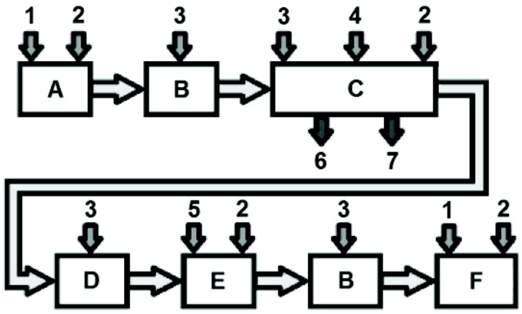

Figure 1. General scheme showing the technological line for cleaning vegetables. Explanatory notes: A – product transportation from the field, B – weight measuring, C – post-harvest treatment, D – storage, E – loading, F – transportation to the customer, 1 – fuel, 2 – human activity, 3 – electrical energy, 4 – water, 5 – power (forklifts), 6 – polluted water, 7 – organic waste.

Post-harvest treatment most often occurs in three stages. Step one involves cleaning the vegetables, where the aim is to remove organic and inorganic substances from their surfaces. This process is generally carried out under dry conditions or using water. Under dry conditions, coarse impurities, stems and such like are removed from the product. This is followed by washing, in particular for root vegetables and cucumber, which removes the remaining surface dirt.

Table 1. The parameters for selected areas of the lines.

The performance of facility				
De-stoning Machine (ton hr^{-1})	Soaking Reservoir (ton hr^{-1})	Machine for remove leaves (ton hr^{-1})	Brush Polisher (ton hr^{-1})	Interoperation Container (m^3)
20	5-30	15	8-20	19
The overall performance of the process line (ton day^{-1})				
Potatoes				312
Carrots				60

Depending upon the type of vegetable being processed and the degree of contamination, the following four types of washing equipment are most frequently used: (i) soak-wash equipment: the product is soaked in this equipment, which releases the deposited impurities. The product is then usually moved by conveyor from the soak-wash equipment to the primary washing equipment; (ii) shower washing equipment: washing is carried out using strong water pressure (0.8–1.2 MPa) from the shower component in the tunnel equipment. Nozzles are positioned above and below the conveyor which contains the product. An alternative is a mesh rotating grate. A shower device is often positioned above the conveyor, and the device removes soaked-off impurities from the product; (iii) drum washing equipment: the principle of this form of washing equipment is a partially submerged perforated rotating drum. The product is cleaned via mutual friction between the products and the drum's surface. The product can also be rinsed thanks to the immersion of the drum in water; (iv) brush washing equipment: the main mechanisms of this type of washing equipment involves rotating shafts which are fitted with brushes of different levels of hardness according to the product being washed. This is the most common type of washing equipment.

During post-harvest treatment, the second step is quality sorting. The aim is to remove pieces that do not meet quality requirements in terms of their appearance, colour, or other defects. Sorting takes place on inspection belts which carry the product at a speed of between 20 to 40 cm s^{-1} and also ensure that the product is rotated. Workers remove unsuitable vegetables. Vegetables can also be sorted using optical sorting equipment. In most cases, a desk is placed behind such sorting equipment with additional staff available to provide assistance.

The third step in post-harvest treatment is size sorting. Three structural systems are used for the purpose of sorting, these being rotary slit sorters, longitudinal slit sorters, and sorters equipped, with a system of screens with unequally-sized holes being employed.

A large quantity of water is used during the post-harvest treatment of vegetables, on whose cleanliness ever greater demands are being placed during the sale of such vegetables (Simons & Sanquansri, 1997). Both from an economic and ecological perspective, it is desirable to decrease the amount of water being used. One method could be the repeated use of the water, but the water must contain the corresponding parameters. This article deals with this problem (Goliáš, 2014; Pao et al, 2012).

MATERIAL AND METHODS

An analysis of wastewater from the line for the post-harvest treatment of potatoes and carrots was carried out at a company which is located in the Central Bohemian Region of the Czech Republic (concerning an important and representative agricultural company). The company's activities consist mainly of the cultivation and post-harvest treatment of vegetables (mainly involving carrots and potatoes).

Water which is intended for washing vegetables in a drum washer is pumped from a tank with a volume of 30m^3 (the water is provided via a water pipeline). The tank is drained three times during the day. The daily water consumption for both lines (ie. the line for potato processing and the line for carrot processing) is therefore approximately 90m^3 of water (the average efficiency rates for this line is between ten and fifteen tons of vegetables an hour). The water temperature is about 10°C. After passing through the lines, the water contains mainly impurities in the form of dirt, sand, and organic vegetable residues such as carrot chips, stems, etc. Using gravity, the polluted water flows to a sedimentation tank, Nos 1 or 2 (see Fig. 2). Only one of the two tanks is always used. During this time the unused tank is cleaned of any deposits. The use of tanks Nos 1 and 2 alternates in monthly intervals, and approximately 330m^3 of impurities settle in the tank during this time. From these outer tanks, in which the water remains for approximately four days, the water overflows through the outflow into the intermediate tank, No 3. These sedimentation tanks are not able to separate undissolved substances as efficiently and at the required levels of quality so that the water can be returned to the line. The water from the middle tank is therefore pumped out using three sludge pumps so that it reaches the recipient in accordance with Decree No 401/2015 Coll (Nařízení vlády č. 401/2015 Sb, 2015).

Samples of wastewater were taken over the course of three months. Measurements were carried out, with Sample A being taken in November 2015, Sample B in December 2015, and Sample C in January 2016.

Three sampling points were chosen (see Fig. 2), on the inflow to the sedimentation tanks (1), and to the overflow between the tanks (2), with the last sampling point being at the pumps at which water is removed from the tank and delivered to the recipient (3). The samples were removed at each collection point during a precisely-defined period of time while all of the water was drained from the line (the majority of the polluted water arrives at this time), during the process of draining the water from the pre-soak tub, and the third during normal outflow from the lines. A mixed sample was created from these three samples through their being mixed together. Three composite samples divided according to collection points were therefore obtained in one day.

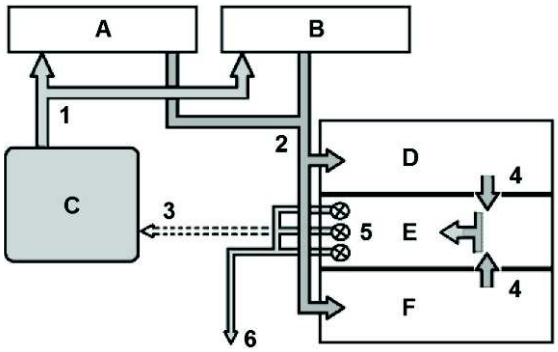

Figure 2. Block diagram showing the flow of water during the waste management of the monitored line. Explanatory notes: A – technological line for processing carrots, B – technological line for processing potatoes, C – reservoir with pure water, D – settling tank No 1, E – settling tank No 3, F – settling tank number 2, 1 – clean water, 2 – polluted water, 3 – pipelines from the settling tank to reservoir, 4 – water overflow, 5 – water pumps, 7 – brook.

Those components which are present in a given sample can be divided into undissolved and dissolved substances according to their physical properties. All of the substances are obtained by the sum of these two values. In terms of wastewater treatment, these values serve as indicators for the basic chemical composition of the water (the COD and BOD and microbiological quality were all determined within the context of another research project). Gravimetric determination is used to determine these values.

The gravimetric determination of all substances (TS)

A sample of wastewater that is properly homogenised is first evaporated and is then dried at 105 °C to a constant weight (dry matter). The process of annealing dry matter at

550 °C is carried out in order to determine the organic and inorganic proportions in the sample. The difference in the weight of the dry matter and annealed dry matter is labelled as the annealing loss. The annealing loss is the amount of substances in dry matter that volatilise or burn at temperatures of up to 550 °C (organic substances - organic TS). Minerals are largely resistant up to this temperature (inorganic substances - inorganic TS).

The gravimetric determination of dissolved substances (TDS)

Dissolved substances are labelled as having passed through the filtration device with an average pore size of 0.45 μm. The acquired filtrate is dried and annealed in the same way as for the determination process for all substances. The values of all organic and inorganic dissolved substances are obtained (TDS, organic DS, and inorganic DS).

The gravimetric determination of undissolved substances (TSS)

Undissolved substances which are contained in a sample are trapped on glass fibres in the filter. The acquired substances are dried and annealed in the same way as for the process which covers the determination for all substances. The values for all organic and inorganic undissolved substances are obtained (TSS, organic SS, and inorganic SS) (Horáková, 2003).

In addition to dissolved substances, an element analysis was conducted of the collected samples of wastewater.

The solution was filtered through 0.45μm Nylon disk filters (Cronus, UK) prior to analysis. The contents of the selected elements (elements which were monitored by decree - Vyhláška č. 252/2004 Sb and Council Directive 98/83/EC (As, B, Be, Ca, Cd, Cr, Cu, Fe, Mg, Mn, Na, Ni, Pb, Sb, Al)) were determined by means of ICP-OES (DUO iCap 7000, Thermo Scientific) under standard analytical conditions. The quality of the analysis was controlled using blanks and the standard reference materials (Ash et al, 2016). Moreover, after filtration through a 0.45 μm nylon membrane filter, concentrations of mayor inorganic anions (F, Cl, NO_2, NO_3, $(SO_4)_2$ and pH) in the washing water were determined by means of ion-exchange chromatography with suppressed conductivity. An anion chromatograph ICS 1600 was used (Dionex, USA), equipped with an IonPac AS11-HC guard (Dionex, USA), and analytical columns. The eluent composition was 1–37.5 mM KOH with a gradient of 1–50 mins; and the flow rate was set to 1 mL min^{-1}. In order to suppress eluent conductivity, an ASRS 300–4 mm suppressor (Dionex, USA) and a Carbonate Removal Device 200 (Dionex, USA) were used (Mercl et al, 2016).

RESULTS AND DISCUSSION

Table 3 shows the measured values for all substances, including dissolved substances and undissolved substances (Table 2 shows the measured values for the process water parameters).

These substances are further subdivided into organic and inorganic. It is mainly the A-3, B-3, and C-3 values which are important, as they characterise the water at the outlet, ie. water which is potentially intended for repeated use. When compared to the values indicated for tanks Nos 1 and 2, the cleaning ability of sedimentation tanks can be evaluated. Each sample (A-1, A-2 to C-3) is mixed. This means that the sample contains water of ten subscriptions.

Table 2. The parameters for process water

Concentrations of selected elements in the process water				
Al (mg l^{-1})	**As** (mg l^{-1})	**B** (mg l^{-1})	**Be** (mg l^{-1})	**Ca** (mg l^{-1})
0.02	0.00	0.01	0.00	0.01
Cd (mg l^{-1})	**Cr** (mg l^{-1})	**Cu** (mg l^{-1})	**Fe** (mg l^{-1})	**Mg** (mg l^{-1})
0.00	0.00	0.00	0.01	0.00
Mn (mg l^{-1})	**Na** (mg l^{-1})	**Ni** (mg l^{-1})	**Pb** (mg l^{-1})	**Sb** (mg l^{-1})
0.02	80.00	0.01	0.01	0.00
Concentrations of selected inorganic anions in process water				
F (mg l^{-1})	**Cl** (mg l^{-1})	**NO_{2^-}** (mg l^{-1})	**NO_{3^-}** (mg l^{-1})	**$SO_4{}^{2-}$** (mg l^{-1})
0.37	57.24	0.03	0.18	205.45

Table 3 shows that the sedimentation tanks primarily catch undissolved substances. At the inlet for the tank, the concentration of all undissolved substances ranges between 0.19–9.63g l^{-1}, while at the outlet the range varies between 0.05–0.52g l^{-1}.

Table 3. Measured values using gravimetric methods

Sample	**TS** (g l^{-1})	**TDS** (g l^{-1})	**TSS** (g l^{-1})	**VS** (g l^{-1})	**org.DS** (g l^{-1})	**org.SS** (g l^{-1})	**inorg.TS** (g l^{-1})	**inorg.DS** (g l^{-1})	**inorg.SS** (g l^{-1})
A-1	5.96	1.53	4.43	0.8	0.32	0.48	5.16	1.21	3.95
A-2	2.13	1.49	0.64	0.45	0.29	0.16	1.68	1.20	0.48
A-3	1.42	1.37	0.05	0.27	0.24	0.03	1.15	1.13	0.02
B-1	1.70	1.51	0.19	0.42	0.32	0.10	1.28	1.19	0.09
B-2	1.52	1.44	0.08	0.28	0.27	0.01	1.24	1.17	0.07
B-3	1.77	1.42	0.35	0.31	0.24	0.07	1.46	1.18	0.28
C-1	11.28	1.65	9.63	1.57	0.33	1.24	9.71	1.32	8.39
C-2	2.04	1.71	0.33	0.39	0.38	0.01	1.65	1.33	0.32
C-3	1.88	1.36	0.52	0.39	0.28	0.11	1.49	1.08	0.41

Explanatory notes: TS – all substances, TDS – dissolved substances, TSS – undissolved substances, VS – organic all substances, org.DS – organic dissolved substances, org. SS – organic undissolved substances, inorg. TS – inorganic all substances, inorg. DS – inorganic dissolved substances, inorg. SS – inorganic undissolved substances.

In Sample B (December 2015), the lower volume of TS is probably caused by different soil moisture levels which closely correlate to the weather conditions. Consequently, some specific parameters which are presented in Tables 3, 4, and 5 exhibit significantly different values. We can also expect the amount of clay and soil organic matter, together with the soil moisture, to have a great deal of influence on the volume of TS if different study plots are to be investigated.

Table 4 shows the concentrations of selected elements in the wastewater. The limit values for individual elements were drawn from Decree No 252/2004 Coll (Vyhláška č. 252/2004 Sb, 2004), which determines the hygienic requirements for drinking water and hot water, and the frequency and scope of drinking water controls.

Table 4. Concentrations of selected elements in the wastewater

Sample	**Al** 396.152 {85} (Radial) (mg l^{-1})	**As** 189.042 {478} (Axial) (mg l^{-1})	**B** 208.959 {461} (Axial) (mg l^{-1})	**Be** 234.861 {143} (Axial) (mg l^{-1})	**Ca** 396.847 {85} (Radial) (mg l^{-1})
DL	0.0386	0.0068	0.0068	0.0068	0.0079
A-1	n.d.	n.d.	0.15	n.d.	> 100
A-2	0.06	n.d.	0.16	n.d.	> 100
A-3	n.d.	n.d.	0.15	n.d.	> 100
B-1	n.d.	n.d.	0.14	n.d.	> 100
B-2	n.d.	n.d.	0.14	n.d.	> 100
B-3	n.d.	n.d.	0.16	n.d.	> 100
C-1	n.d.	n.d.	0.01	n.d.	> 100
C-2	0.08	n.d.	0.01	n.d.	> 100
C-3	0.11	n.d.	0.01	n.d.	> 100
Limit values	0.20	0.01	1.00	0.0020	30.00

Sample	**Cd** 226.502 {449} (Axial) (mg l^{-1})	**Cr** 267.716 {126} (Axial) (mg l^{-1})	**Cu** 327.396 {103} (Axial) (mg l^{-1})	**Fe** 259.940 {130} (Radial) (mg l^{-1})	**Mg** 280.270 {120} (Radial) (mg l^{-1})
DL	0.0002	0.0007	0.0060	0.0184	0.0029
A-1	n.d.	0.00	0.01	0.08	43.17
A-2	n.d.	0.00	0.02	n.d.	44.49
A-3	n.d.	0.00	0.01	0.09	45.64
B-1	n.d.	0.00	0.01	0.05	43.85
B-2	n.d.	0.00	0.03	0.10	43.99
B-3	n.d.	0.00	0.02	n.d.	46.40
C-1	n.d.	n.d.	n.d.	n.d.	40.67
C-2	n.d.	n.d.	n.d.	0.18	42.06
C-3	n.d.	n.d.	n.d.	0.12	40.00
Limit values	0.0050	0.05	1.00	0.20	10.00

Sample	**Mn** 259.373 {130} (Axial) (mg l^{-1})	**Na** 589.592 {57} (Radial) (mg l^{-1})	**Ni** 221.647 {452} (Axial) (mg l^{-1})	**Pb** 220.353 {453} (Axial) (mg l^{-1})	**Sb** 231.147 {446} (Axial) (mg l^{-1})
DL	0.0001	0.0258	0.0004	0.0015	0.0082
A-1	0.02	34.94	0.00	n.d.	n.d.
A-2	0.05	34.12	0.01	n.d.	n.d.
A-3	0.05	34.04	0.00	n.d.	n.d.
B-1	0.01	31.13	0.00	0.00	n.d.
B-2	0.02	30.69	0.00	0.00	n.d.
B-3	0.03	31.96	0.00	n.d.	n.d.
C-1	0.01	32.72	0.00	n.d.	n.d.
C-2	0.00	34.69	n.d.	0.00	n.d.
C-3	0.00	33.06	0.00	0.00	n.d.
Limit values	0.05	200.00	0.02	0.01	0.0050

Explanatory notes: DL – detection limit (Vyhláška č. 252/2004 Sb, 2004), n.d. – under detection limit.

The concentration values of elements were again considered at the outflow from the sedimentation tanks, ie. A-3, B-3, and C-3. In this case, the only elements which do not meet the limit values for drinking water are calcium and magnesium. The increased levels of these substances serve to change the taste of the water and increase its hardness. Since these substances are not toxic in nature and have no significant effect on the water being used for rinsing vegetables, their removal from the wastewater is not necessary. Table 5 shows the concentrations of selected inorganic anions in wastewater. As a comparison, the limit values for drinking water are used (Vyhláška č. 252/2004 Sb, 2004).

Table 5. Concentrations of selected inorganic anions in wastewater

Sample	F^- (mg l^{-1})	Cl^- (mg l^{-1})	NO_2^- (mg l^{-1})	NO_3^- (mg l^{-1})	SO_4^{2-} (mg l^{-1})	pH (-)	Conductivity (μS cm^{-1})
DL	0.0005	0.0012	0.0023	0.0042	0.0031		
A-1	0.49	73.28	0.68	109.73	244.03	7.76	1353
A-2	0.46	78.26	32.55	57.47	251.36	7.37	1375
A-3	0.69	77.10	22.01	54.58	242.87	7.13	1382
B-1	0.54	75.18	5.22	44.06	249.93	7.78	1379
B-2	0.53	73.24	3.45	6.32	241.67	7.97	1361
B-3	0.51	73.75	6.94	9.01	244.69	7.73	1414
C-1	0.52	84.62	14.07	74.36	255.27	7.35	1395
C-2	0.67	79.82	0.03	0.31	238.19	7.37	1383
C-3	0.86	80.85	35.60	7.68	244.18	7.57	1393
Limit values	1.50	100.00	50.00	50.00	250.00	6.5-9.5	1250

Explanatory notes: DL – detection limit, Limit values for drinking water is used from Vyhláška č. 252/2004 Sb, 2004.

An increased concentration of nitrates was detected through an analysis of inorganic anions, and a greater conductivity value was determined through measurements. An increased conductivity value indirectly indicates that the contents of mineral substances to be found in the water are closely related to the higher volumes of calcium and magnesium. These increased values have a negative impact on the drinking water that is used; however, for the purposes of the post-harvest treatment of vegetables, these exceeded limit values are acceptable.

CONCLUSION

Sedimentation tanks reduced the content of substances in wastewater, in particular undissolved substances. However, for the reuse of this water in the line for the post-harvest treatment of vegetables, it would be suitable to include another level of wastewater purification (Council Directive 98/83/EC). The concentrations of some elements on the outlet from sedimentation tanks increased slightly. The limit values are also exceeded for nitrates and conductivity.

On the basis of the values measured, an additional water purification step was recommended so that the water can be reused. This was mainly a reduction in undissolved substances. In order to select a suitable device, the highest TS value was overestimated to 0.7g l^{-1}. A gravitational flow-through drum filter was recommended, which will be placed on the outlet from the sedimentation tanks. In this case, the water would be exchanged once a week for new water taken from the water pipe line.

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