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Indicators of water consumption and the quantity of wastewater formed in selected branches of food industry

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The studies covered the branches: sugar industry, fruit-and-vegetable processing and potato processing plants. The analyses of water consumption and quantities of wastewater formed in 24 production plants were performed in the paper. A comparison of water and wastewater management in three branches showed that the highest water consumption is in fruit-and-vegetable processing. The data collected in the paper indicates the drop of water consumption in potato as well as fruit-and-vegetable industry. The values obtained for sugar industry indicate that it is the least diversified branch.

Keywords: water, wastewater/sewage, indicators, food industry.

INTRODUCTION

Due to its entry into the European Union, Poland had to undertake several tasks associated with the adaptation to legislative requirements of the Community. This also concerns management of water resources. In Poland, rational management of water should have special significance because in comparison with other European countries, fresh water resources per person are low (Table 1)[1–5]. In Poland, the main branches of economy utilizing fresh water resources include: chemical as well as farm and food industry. In the latter, particularly in the branch of fruit-and-vegetable processing, very high pressure is put on economic management of water since it is the medium utilized in very large quantities and the specifics of the production cause creation of large quantities of wastewater.

Table 1. Water resources and consumption. a-2007, b-2006, c-2004

Country	m^3 per 1 inhabitant	
	resources (2005)	consumption
Denmark	1101.7	126.0 c
Czech Republic	1288.1	191.4 a
Poland	1598.0	301.8 a
Belgium	1753.4	611.5 a
Germany	1861.8	430.8 c
Spain	2570.4	771.5 b
France	3354.6	516.7 b
Holland	5560.0	598.7 b

In the year 2008, water consumption in production of food items in Poland amounted to 101.6 hm^3. In the processing of fruits and vegetables (including potatoes) as well as in the process of sugar production, over 22% of water was drawn in this branch. The quantity of wastewater discharged by Polish processing of fruits and vegetables over the last five years underwent insignificant fluctuations and amounts annually to about 16 hm^3 (about 19% of food industry wastewater). Processing plants of the same branch can differ significantly with respect to the assortment of the products, this in turn affects water consumption and the quantity of wastewater formed. BAT[6] document states that 70 – 90% water drawn for the production in fruit-and-vegetable branch is discharged in the form of technological wastewater. According to the European[7] data, the quantity of wastewater formed during the production of fruit-and-vegetable preserves is tremendously diversified depending on the raw material processed and the product. The production of sugar, classified by Central Statistical Office of Poland (*GUS*) in the category of 15.83 (remaining food items), consumes over 40% of water and leaves 48% of wastewater among the processing of items of this group. In potato processing, constant drop in the quantity of wastewater formed from 2.5 to 1.8 hm^3 [2–5] has been observed over the past five years.

The purpose of the task was to determine the indicators of water consumption and the amount of wastewater formed in fruit-and-vegetable processing plants, in plants recasting potato and also in sugar factories.

MATERIAL AND METHODS

The studies covered the following branches: sugar industry, fruit-and-vegetable processing and potato processing plants (PPP) in the years 2005 – 2008. Twelve sugar factories with the total annual average quantity of raw material processed 4 921 172 Mg, total annual average of sugar production 739685 Mg, 5 plants of the potato industry of the total average annual production 55266 Mg, quantity of raw material processed 269415 Mg and 7 fruit-and-vegetable processing plants whose average annual sum of production amounted to 77543 Mg and the quantity of processed raw material 57279 Mg, were subjected to analysis. The sugar factories are characterized by the one-way production profile (1 main product – sugar), whereas fruit-and-vegetable processing plants and PPPs are the plants of diversified product range. In plants recasting fruits and vegetables, the products were: pastes, salads, pickles, jams, marmalades, plum jams, canned foods, compotes and frozen foods. The basic primary product produced in potato industry plants is potato starch. Also are a number of secondary and processed products such as modified starch, starch syrup, caramel, burnt sugar, glues and dextrin are produced in such plants. Due to the multi-directional character of the production in potato industry plants and also in fruit-and-vegetable industry plants, the principle should be assumed of giving indicators per unit of the processed raw material, whereas in the sugar industry, these indicators can be related both to the quantity of the raw material processed as well as the quantity of the finished product.

In this paper indicators of water consumption were defined as:

$$\text{The idicator of water consumed} = \frac{\text{guantity of wate consumed } (A_w)}{\text{Amount of production } (Z_2)}$$

$$\text{The indicator of wastewater generated} = \frac{\text{quantity of wastewater } (A_{ww})}{\text{amount of production } (Z_2)}$$

The notations used in this paper were defined by[8].

RESULTS AND DISCUSSION

Sugar branch

Water consumption in m^3/Mg of sugar in the plants under study amounted from 0.08 to 2.93, average of 1.52 m^3/Mg (Table 2). Converted into the quantity of the processed raw material, the indicators of Polish sugar factories range from 0.01 to 0.43 m^3/Mg, average 0.23 m^3/Mg. In the plants under study, the indicators of water consumption and wastewater generated with respect to the production unit show rather high diversification. The quantity of the wastewater formed during the production of sugar was from 0.0 to 3.22 m^3/Mg (Table 2).

In Polish plants, at the beginning of the nineties, average water consumption was at the level of 6.6 m^3/Mg of sugar[9]. According to literature[7], the general requirement of water was about 15 m^3/Mg of beetroot including requirement for fresh water 0.25 to 0.4 m^3/Mg of raw material or less. This depends on the degree of the modernization of the technologies applied. The indicators received are comparable with their European counterparts[7].

Another raw material used in the sugar industry around the world is sugarcane. The data gathered in 7 selected plants producing sugar from sugarcane showed that water consumption amounted to between 1.8 and 12, m^3 per ton of cane. The quantity of wastewaters generated during the production of sugar varied from 2.5 to 12.8 m^3 per ton of cane. It depends on the technology used in plants, availability of water to the factory, the efficiency of water management policy within the factor[10].

The actions recommended by the analyzed enterprises aimed at improving water and wastewater economy, such as: closure of flume, cooling and barometric water circulation; utilization of condensate from juice thickening process and water from dehydration of pulp, re-utilization of biologically treated wastewater, collection of beetroot preliminarily cleaned on the planter's field, reducing the water drawn for technological purposes by using the biologically treated wastewater, utilization of the sludge formed in the factory's wastewater treatment plant (by directing it to oxygen-free treatment section) and the biodegradation of the biogas formed (combustion in torch) enabled in some factories to considerably limit the drawing of water and the discharge of wastewater. In the factories FS4, FS5 and FS11, utilization of the mentioned solutions enabled total elimination of the wastewater dump (Table 2) and reduction of the quantity of the water used in the production process. The effect of introducing modernization into the sugar factory FS3 is the reduction of water used and quantity of wastewater formed (Fig. 1). A similar comparison conducted for the total value over 4 years shows that the quantity of wastewater generated increases in this branch (Fig. 2). Such a situation could be the result of the extinguishing of the production and liquidation of the sugar factory (FS5), and also the introduction of the liming-saturation lime dehydration method along with the drying up of the pulp. In the paper[11] authors suggest other simple but effective rules in water minimization e.g. reuse of steam condensate in boiler house or other process operations, good housekeeping

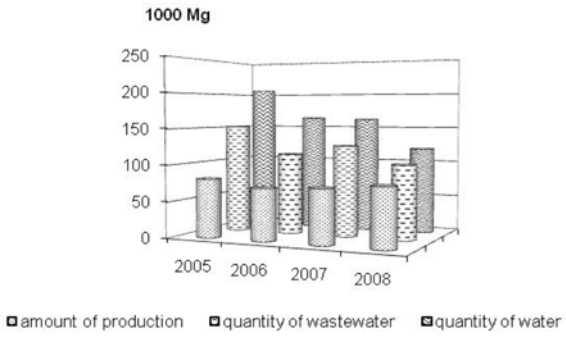

Figure 1. Amount of production, quantity of wastewater and quantity of water drawn in the factory FS3 in the individual years

Table 2. Average annual quantity of raw material processed, amount of production, quantity of water drawn and wastewater generated along with their indicators with respect to the amount of production

Factory (Plant) symbol	Quantity of raw material Z_1 [Mg]	Amount of production Z_2 [Mg]	Quantity of water A_w [m^3]	Quantity of waste-water A_{ww} [m^3]	Indicator of water consumed A_w/Z_1 [m^3/Mg]	Indicator of water consumed A_w/Z_2 [m^3/Mg]	Indicator of wastewater generated A_{ww}/Z_2 [m^3/Mg]
FS3	522697	77146	162605	122870	0.24	2.11	1.59
FS4	403140	61023	44925	0.00	0.00	0.74	0.00
FS5	345717	52166	4058	0.00	0.00	0.08	0.00
FS6	380222	55642	36277	118124	0.31	0.65	2.12
FS7	510964	75669	219540	243604	0.48	2.90	3.22
FS8	393530	59975	125652	173014	0.44	2.10	2.88
FS9	605041	83421	244091	221417	0.37	2.93	2.65
FS10	306648	46516	52500	17500	0.06	1.13	0.38
FS11	322027	47899	79500	0.00	0.00	1.66	0.00
FS12	381432	64917	42066	140418	0.37	0.65	2.16
FS13	301007	47372	14059	114901	0.38	0.30	2.43
FS14	448747	67939	98031	45423	0.10	1.44	0.67
Sum/ average	4921172	739685	1123304	1197271	0.24	1.52	1.62

and regular maintenance (diminished costs on the one hand and prevention of unnecessary water losses on the other), mixing of wastewater with fresh water in order to equilibrate contaminant concentration and temperature.

Potato industry

Not only the potato starch but also feed protein, glues, modified starch, caramel, burnt sugar and others are presently produced in potato processing plants. The processing plants analyzed differed considerably with respect to the production structure. In these plants, the share of potato starch in the total production was from 43 to 96%. The quantity of the water used in the processing of 1 Mg of potatoes in the plants studied, ranged from 2.43 to 17.52, averaging 4.59 m^3. The highest indicator of water consumption occurred in the plant of the lowest share of potato starch in the total production, analogically the indicators concerning the quantity of wastewater generated (Table 3). The document[9] containing the data from the nineties states that Polish potato processing plants consume 92 m^3 of water per 1 Mg of starch produced, whereas in other countries from 6 to 46 m^3/Mg of starch. According to 7, for the processing 1 Mg of potatoes, 0.7 – 1.5 m^3 of water is required, and the amount of wastewater is 2m^3/Mg of potatoes. Dutch data concerning the requirement of water for the production of starch give the quantity from 6 to 46m^3/Mg[12]. To compare this data with the indicators of the said plants, water consumption was calculated for the total mass of the products produced and it lies within the limits from 8.64 to 35.17 m^3/Mg.

The plants studied showed the directions of possible changes in water-wastewater management to limit the influence on the environment by: reducing the load of contamination in sewages by incorporating the system for the recovery of protein constituting high-value feed for farm animals, the introduction of the closed flume water circulation and supplementing flume water from the washer overflow, contracting potato variety of the increased starch content.

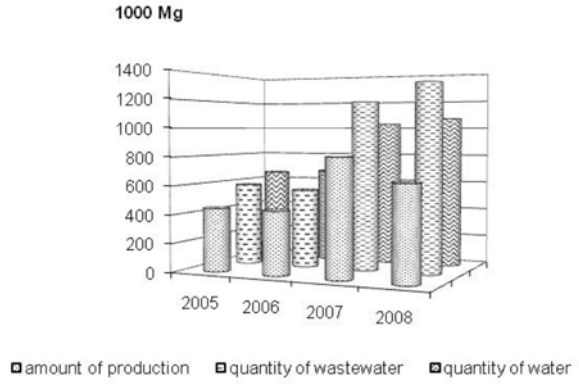

Figure 2. Total amount of production, quantity of wastewater and quantity of water drawn in the analyzed factories in the individual years

Water-wastewater management of industrial potato processing plants is moving in the much desired direction. With only few changing quantities of the processed raw material, the requirement for water decreases, which finds confirmation in the decreasing values of water consumption indicator – Fig. 3.

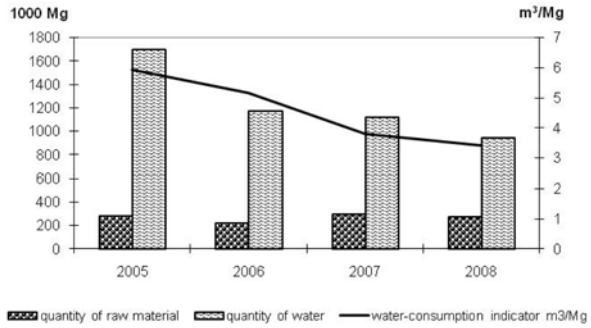

Figure 3. Total quantity of processed raw material, quantity of water drawn and water- consumption indicator in the potato industry

Fruit-and-vegetable processing

In the plants under study, the mean annual consumption of water varied from 5.0 to 61.3 m^3/Mg of raw material (Table 4). In the plant FF5, basic production constitutes the preserves and vegetable pickles, which determines the high indicator of water consumption and significant quantities of wastewater generated. The plants FF3 and FF4 are modern processing plants of a wide range of production in which closed technological water systems have been incorporated. The plant FF7 specializes in the production of fruit and vegetable frozen foods.

The variety of the ways of processing the products (preservation, pasteurization, freezing, pickling) causes large diversifications in the quantity of water consumed and wastewater formed. According to the European data, preservation of fruits and vegetables requires the consumption of 2.5 – 6.0 m^3 of water per 1 Mg of product. The quantity of wastewater generated in the processing of vegetables depends mainly on the raw material processed. The quantity of the wastewater formed ranges from a few to some dozens of m^3 (38 m^3 – spinach, 89 m^3 - cauli-

Table 3. From the years 2005 – 2008, average annual quantity of raw material processed, amount of production, quantity of water drawn and wastewater generated, and indicators

Factory (Plant) Symbol	Quantity of raw material Z_1 [Mg]	Amount of produc-tion Z_2 [Mg]	Share of starch in pro-duction [%]	Quantity of water A_w [m^3]	Quantity of waste-water A_{ww} [m^3]	Indicator of water consumed A_w/Z_1 [m^3/Mg]	Indicator of wastewater generated A_{ww}/Z_1 [m^3/Mg]
FP1	37588	7465	96	154683	152214	4.12	4.05
FP2	75600	15010	70	184050	237000	2.43	3.13
FP3	50577	10487	87	333500	337750	6.59	6.68
FP4	89868	18904	95	287588	274710	3.20	3.06
FP5	15782	3401	43	276500	244750	17.52	15.51
Sum/ average	269415	55266	80	1236320	1246424	4.59	4.63

flower). The production of frozen food requires from 5 to 8 m^3 of water per 1 Mg of product[7]. However, according to[12], water consumption for the production of frozen foods in Great Britain may reach up to 40 m^3 per 1 Mg of product.

The characteristics of 16 production plants[13] showed that average unit value of water consumption (m^3/Mg of raw material) ranges from 8.2 to 74.8 depending on the variety. The authors also noted the influence of cubage (volume) of the processing factory on the size of this indicator. Other data[13 – 15], also shows high diversification in water consumption depending on the type of the production ranging from 6 - 12 m^3 (for production of frozen foods and pastes) to 40 m^3 in production of thickened fruit juices and 5.75 m^3 /Mg of plum jam. Analysis of water consumption on technological lines of vegetable processing showed the possibility of decreasing consumption while processing mushrooms (by about 34%), green peas and green beans (about 55%)[14]. The results obtained (Table 4) correspond with the literature data[9, 13, 14].

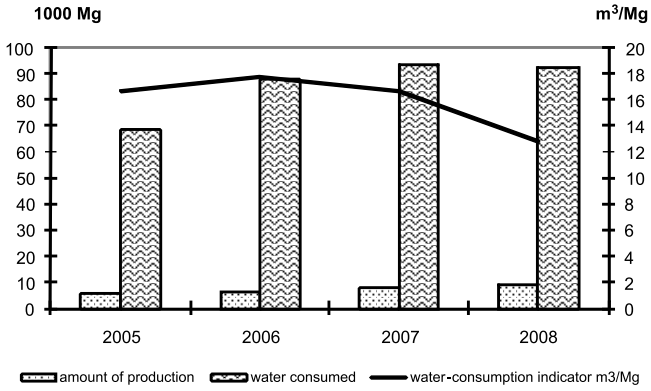

Figure 4. Total amount of production, quantity of water drawn and water-consumption indicator in selected fruit-and-vegetable processing plants

The fruit-and-vegetable branch is characterized by large diversification in water- consumption indicators (Table 4). However, as is concluded from Fig. 4, in spite of the large consumption of water, this indicator is decreasing. This situation is even more pleasing because it is accompanied by growth in the production of fruit-and-vegetable preserves.

Among the actions aimed at improving the water-wastewater economy in fruit-and-vegetable branch, the plants indicated: purchase of raw material preliminarily cleaned at the planters', utilizing water for pasteurization and cooling in continuous circuits, installation of systems enabling water recovery from salty inundations.

Summing up

The ever increasing social awareness and development of legislation is forcing the enterprises to undertake actions aimed at limiting the influence of production on the environment. This is linked with reducing the consumption of environmental components and minimization of wastes generated. Rational utilization of the environment is the basis for constant and balanced development. Comparison of water-wastewater economy of the three branches showed that fruit-and-vegetable processing is the most water-consuming. Wide diversification of water-consumption indicators in this industry (5.0 – 61.3) depends on the technology applied, the raw material as well as the variety. The specifics of the fruit-and-vegetable branch rather require referring the standards and requirements to the individual processes or stages of the production than to the global values achieved by production plants.

In spite of generating large quantities of wastewater (globally), the sugar industry branch is more "balanced" with respect to the calculated indicators. This is linked with the development of the whole branch along with investments associated with environmental protection. Statistical data (GUS) concerning water and wastewater in potato processing shows a successive drop in the quantity of water drawn and wastewater generated, and the data obtained in this paper confirms this fact, since in consecutive years the drop has occurred in water-consumption indicator from 5.9 to 3.4 m^3/Mg of potatoes. The result of the analyses conducted showed a drop in the water-consumption indicators of the production in fruit-and-vegetable as well as potato processing.

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Factory (Plant) symbol	Quantity of raw material Z_1 [Mg]	Amount of production Z_2 [Mg]	Quantity of water A_w [m^3]	Quantity of wastewater A_{ww} [m^3]	Indicator of water consumed Aw/Z_2 [m^3/Mg]	Indicator of wastewater generated A_{ww}/Z_2 [m^3/Mg]
FF1	5288	12934	36598	22497	6.9	4.3
FF2	7295	14941	129732	100135	17.8	13.7
FF3	4894	12322	39000	29000	8.0	5.9
FF4	3470	4923	17492	10447	5.0	3.0
FF5	1679	1506	103015	38810	61.3	23.1
FF6	26250	22500	408250	307925	15.6	11.1
FF7	8403	8418	140407	–	16.7	–
Sum/average	57279	77543	874495	508813	15.3	8.9

*no data

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