

PYROLYTICAL UTILIZATION OF WASTES FROM INSTALLATION FOR FISH PROCESSING PLANT WASTEWATER TREATMENT

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UTYLIZACJA ODPADÓW POWSTAJĄCYCH W PODCZYSZCZALNI ŚCIEKÓW Z ZAKŁADU PRZETWÓRSTWA RYB W PROCESIE PIROLIZY

Kompleksowy układ podczyszczania ścieków pochodzących z przetwórstwa ryb w Zakładzie SUPERFISH uwzględnia również zagospodarowanie odpadów powstających w czasie pracy tego układu. W artykule przedstawiono wyniki badań procesu pirolizy odpadów foliowych pochodzących z Zakładu z dodatkiem odwirowanego osadu i tłuszczów poflotacyjnych. Do zagospodarowania wtórnych odpadów pozostających po procesie pirolizy zastosowano proces cementacji. Otrzymane wyniki badań aproksymowano równaniami przy zastosowaniu metody punktu centralnego. Uzyskane równania poddano weryfikacji. Uzyskane wyniki pokazały, że piroliza jest skuteczna w neutralizacji badanych odpadów, natomiast wtórny odpad po procesie pirolizy poddany solidyfikacji nie stanowi zagrożenia dla środowiska.

Summary

Comprehensive installation for wastewater treatment coming from the fish processing in the SUPERFISH plant in Ustronie Morskie, Poland, includes utilization of wastes which arise during working of this installation. This paper presents results of research on pyrolysis process of PE waste coming from the plant with the addition of dewatered sediments as well as post-flotation fats. Cementation was applied for utilization of secondary waste left after the pyrolysis process. The results of examinations were approximated with equations applying the method of the central point. Next, the equations were verified. Results of the research showed that pyrolysis is effective in neutralization of examined waste, and secondary waste after the pyrolysis process after solidification is not dangerous for the environment.

INTRODUCTION

It would be possible to count water among renewable resources in the hydrological cycle. However presence of pollutants in surface and ground water may unmake this cycliness, which leads to degradation of water in the environment and deficit of water with suitable quality. And therefore it is important to treat wastewater „produced” in manufacturing processes before it gets to circulation in the environment [5, 6]. It turns out that in Poland, in spite of many transformations, the problem of wastewater treatment in still existing industrial plants has not been solved yet. 376.4 hm³ of wastewater yearly is not still treated and 850.1 hm³/year is treated only mechanically [1].

Wastewater from fish processing does not contain toxic substances, but it includes a huge load of organic substances. Fat and the big amount of suspensions content leads to blockage of sewer system. Fats and salinity may lead to deactivation of activated sludge in sewage treatment plant. In fishery wastewater putrefactive processes quickly occur which produce very onerous for the environment odors [3, 11]. So wastewater from the fish industry requires treatment (in the case of transferring it to open receivers) or at least pre-treatment (in the case it is transferred to the sewage system).

Fish processing plant SUPERFISH located at the Baltic Sea in Poland processes about 60 000 Mg of fish annually. SUPERFISH also “produces” wastewater. It amounts to about 24 m³ per hour [2].

Since 1998 a Division of Water-Sludge Technology and Waste Utilization of Koszalin University of Technology has co-operated with SUPERFISH plant to create installation for treatment of wastewater from fish processing. After many preliminary research installation presented in Figure 1 was designed and applied in SUPERFISH plant [2].

Examinations concerning two nodes of that installation are presented in this paper. Those nodes are: pyrolysis and solidification.

Research on those two processes consisted of four stages:

1. Research on the influence of the addition of waste coming from installation of wastewater treatment in SUPERFISH plant (dewatered post-sedimentation deposits and post-flotation fats) on running of pyrolysis process of PE waste from the plant.
2. Research on extraction of pollutants from secondary waste left after pyrolysis.
3. Research on compression strength of concrete blocks produced with addition of secondary waste from pyrolysis.
4. Research on extraction of pollutants from concrete blocks produced with addition of secondary waste from pyrolysis.

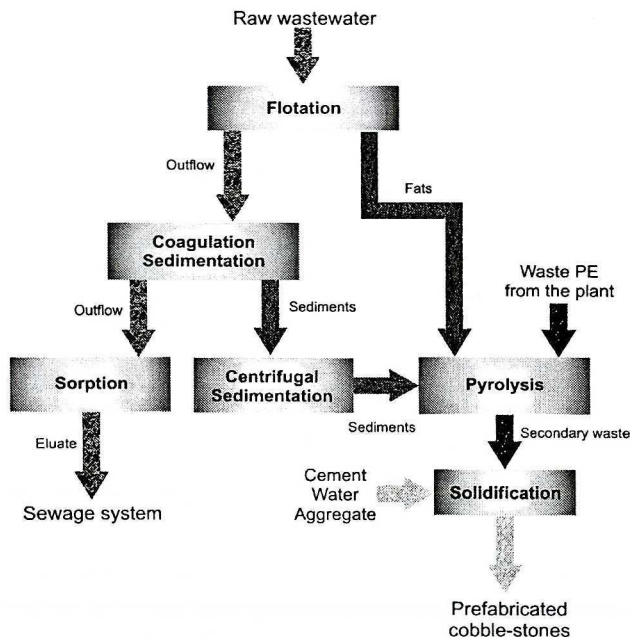


Fig. 1. Schema of wastewater from the SUPERFISH plant treatment installation

METHODOLOGY

Stage I

Pyrolysis was conducted in convective waste utilizer of WPS 350 type with the integrated burner [8], at the constant volume 350 dm³ and the fixed maximum temperature 595°C.

In the first series dewatered sediments were added to PE waste as a charge to the pyrolysis process. Amounts of sediments added were: 0, 10, 30 and 50 dm³ which is 0%, 2.86%, 8.57% and 14.29% of the WPS utilizer charge. In the second series post-flotation fats addition to pyrolysis of PE waste amounted to: 0, 10, 20, 30 and 100 dm³ which is 0%, 2.86%, 5.71%, 8.57%, 28.57% volume fraction of the WPS charge.

So the independent parameter of the first stage was volume fraction of waste from wastewater treatment installation in the charge to the WPS utilizer U_x [%].

Resulting parameters were: evaporation time t_o [h], time of achieving the maximum temperature t_{max} [h], working time without cooling t_p [h], amount of secondary waste in proportion comparison to the charge volume k_w [%].

Stage II

Secondary waste from pyrolysis process from stage I underwent extraction with demineralized water. The bed of secondary waste (0.5 m high and 0.05 m of diameter – total volume 0.981 dm³) was watered. The volume of demineralized water was equal to one-year atmospheric precipitation on the area where SUPERFISH plant is located (760 mm).

The independent parameter in this stage was volume fraction of waste from wastewater treatment installation in the charge to the WPS utilizer U_x [%].

Resulting parameters were: reaction pH, total suspension S [mg/dm³], dissolved substances D_s [mg/dm³], chemical oxygen demand COD [mg O₂/dm³], biochemical oxygen demand BOD [mg O₂/dm³], ether extract E_e [mg/dm³], zinc [mg Zn/dm³], chromium(VI) [mg Cr⁺⁶/dm³].

Stage III

Volume fraction of waste from wastewater treatment installation in the charge to the WPS utilizer U_x [%] and weight fraction of secondary waste from pyrolysis replacing aggregate in concrete mixture U_k [%] were independent parameters in this stage.

Compression strength of concrete cubes σ [MPa] was a resulting parameter in this stage.

Volume fraction of waste from wastewater treatment installation in the charge to the WPS utilizer $U_x = 8.57\%$ was constant in the first part of the 3rd stage. Weight fraction of aggregate replaced by the secondary waste U_k was changing from 0% to 10%. Percentage composition of concrete mixtures produced during the 3rd stage is given in Table 1.

Table 1. Percentage composition of concrete mixtures

Components	Wright fraction of aggregate replaced by secondary waste			
	0%	2%	4%	10%
Cement	14.64	14.64	14.64	14.64
Aggregate	78.57	77.00	75.49	71.32
Water	6.79	6.79	6.79	6.79
Secondary waste	0.00	1.57	3.08	7.25
Total	100.00	100.00	100.00	100.00

During the second part of the 3rd stage the weight fraction of aggregate replaced by the secondary waste $U_k = 2\%$ was constant. Volume fraction of waste from wastewater treatment installation in the charge to the WPS utilizer U_x was changing from 0% to 14.29% for sediments and from 0% to 28.57% for fats.

Individual components of concrete mixture after weighing were mixed in the right order. Next concrete mixture was poured into prepared forms and thickened. After one day cubes were taken out of the forms and stored according to Polish standards. After 7 days cubes underwent compression tests. Received results were calculated to compression strength after 28 days according to Polish standards.

Polish standards require strength not less than 20 MPa for pavement blocks (this value is expected to be kept during this research) and 50 MPa the road blocks.

Stage IV

During this stage concrete cubes with optimal addition of secondary waste from pyrolysis (this means maximum addition allowing to keep 20 MPa compression strength standard) were kept in water with modified reaction (pH = 4, pH = 7 and pH = 11). Each wall of cube had contact with water. After 10 days the following parameters were determined in water: reaction pH, total suspension T_s [mg/dm³], dissolved substances D_s [mg/dm³], chemical oxygen demand COD [mg O₂/dm³], biochemical oxygen demand BOD [mg O₂/dm³], ether extract E_e [mg/dm³], zinc [mg Zn/dm³], chromium(VI) [Cr⁺⁶/dm³].

RESULTS OF THE RESEARCH AND THEIR DISCUSSION

Stage I

Results of the research on the influence of addition of dewatered sediments and post-flotation fats on parameters of pyrolysis process in the WPS utilizer as well as on the amount of secondary waste left after pyrolysis, are shown in Table 2 and Figures 2 and 3.

Table 2. Results of the 1st stage

Independent par.		Resulting parameters			
Volume fraction of waste In the WPS charge:		evaporation time t_0 [h]	time of achieving max temp. t_{max} [h]	working time without cooling t_p [h]	amount of secondary waste k_w [%]
Sediments U_S [%]	0.00	0.60	10.00	11.00	1.41
	2.86	1.25	12.50	14.00	2.24
	8.57	4.50	15.00	18.50	3.43
	14.29	7.50	16.00	20.50	4.57
Fats U_F [%]	0.00	0.60	10.00	11.00	1.41
	2.86	1.10	11.00	12.50	1.86
	5.71	1.25	13.00	14.00	2.57
	8.57	1.50	14.00	15.00	3.14
	28.57	6.50	24.00	33.00	7.14

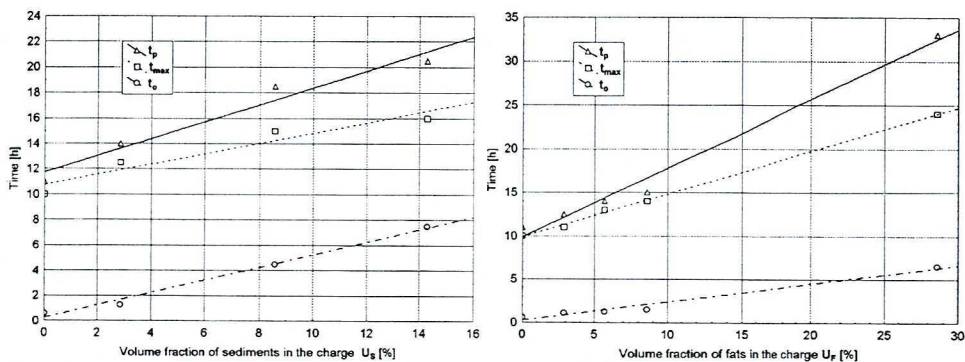


Fig. 2. Influence of volume fraction of sediments U_S and fats U_F in the charge on individual working times of the WPS utilizer

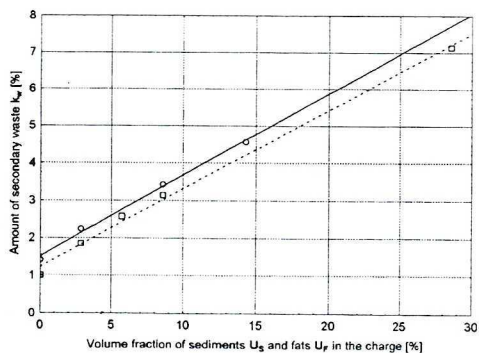


Fig. 3. Influence of volume fraction of sediments U_S and fats U_F in the charge on the amount of secondary waste k_w left after pyrolysis process

Graphs in figures 2 and 3 were approximated using following equations:

$$t_o(U_S) = 0,2458 + 0,5004 \cdot U_S \quad (1)$$

$$t_o(U_F) = 0,2506 + 0,2121 \cdot U_F \quad (2)$$

$$t_{\max}(U_S) = 10,7627 + 0,4064 \cdot U_S \quad (3)$$

$$t_{\max}(U_F) = 9,8854 + 0,4938 \cdot U_F \quad (4)$$

$$t_p(U_S) = 11,7288 + 0,6644 \cdot U_S \quad (5)$$

$$t_p(U_F) = 9,8694 + 0,7908 \cdot U_F \quad (6)$$

$$k_w(U_S) = 1,5136 + 0,2176 \cdot U_S \quad (7)$$

$$k_w(U_F) = 1,2284 + 0,2094 \cdot U_F \quad (8)$$

where:

t_o – evaporation time [h],

t_{\max} – time of achieving the maximum temperature [h],

t_p – working time without cooling [h],

k_w – amount of secondary waste in proportion comparison to the charge volume [%],

U_S – volume fraction of sediments in the charge to the WPS utilizer [%],

U_F – volume fraction of fats in the charge to the WPS utilizer [%].

Addition of both sediments as well as post-flotation fats had a definite influence on lengthening the evaporation time of water from the charge to the WPS utilizer. It is most probably caused by the content of water both in sediments as well as in the fats. Also water content in PE waste affected evaporation time. The longer evaporation time for sediments may be explained by considerably bigger mass of sediments in comparison to fats (when taking into consideration the same volume). So more water is charged into the utilizer with sediments than it is with fats addition. Also sediment contains a lot of $\text{Ca}(\text{OH})_2$, which during pyrolysis is lumping, making evaporation harder.

Addition of sediments and fats affected also lengthening of the working time of utilizer. First of all, longer time is needed for evaporation. Also more time is necessary for decomposition of added with sediments fats. Those substances also need higher temperatures of decomposition than waste PE. Also bigger mass and lumping of sediments may cause longer working time of WPS utilizer.

About 1.41% of initial charge volume of secondary waste is left after pyrolysis of waste PE only. It is not much, so pyrolysis of waste PE is an effective process. Addition of both sediments and post-flotation fats causes increase in the amount of secondary waste left after the process. Such increase is almost equal for both additives. So it may be assumed that sediments as well as fats contain similar amount of hardly decomposing substances in pyrolysis process and products of pyrolysis.

Stage II

Results of the research on the influence of addition of dewatered sediments to the pyrolysis process in the WPS utilizer on the amount of pollutants extracted from secondary waste, coming from the pyrolysis process, are shown in Table 3 and Figure 4.

Table 3. Influence of volume fraction of sediments in the charge to WPS utilizer U_s on extraction of pollutants from secondary waste

Parameter	Unit	Volume fraction of sediments U_s [%]			
		0.00	2.86	8.57	14.29
Reaction	–	9.2	10.62	11.4	12.06
T_s	mg/dm ³	86	452	1092	1411
D_s	mg/dm ³	227	449	742	952
BOD	mg O ₂ /dm ³	2	0	0	2
COD	mg O ₂ /dm ³	40	202	299	363
Ether extract	mg/dm ³	15	96	218	302
Zinc	mg Zn/dm ³	3.38	2.83	2.29	2.25
Chromium(VI)	mg Cr ⁺⁶ /dm ³	0.08	0.05	0.02	0.01

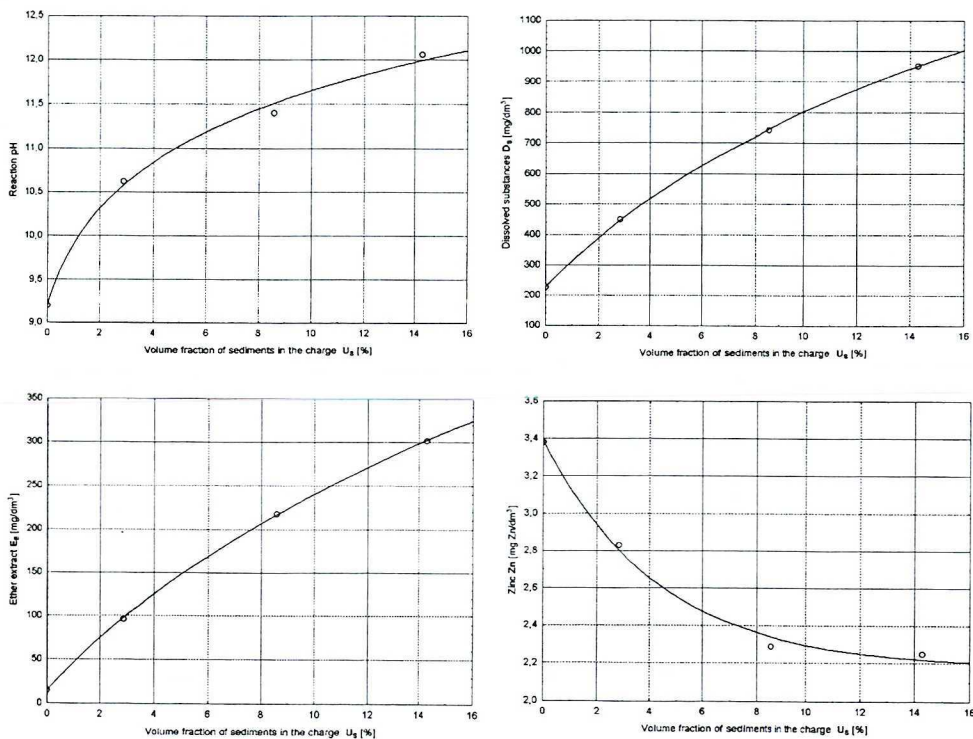


Fig. 4. Influences of volume fraction of sediments U_s in the charge on the value of reaction pH, ether extract E_e and content of zinc in the eluate from secondary waste

The influences of U_s value on the values of individual ultimate parameters were approximated by the following equations:

$$\text{pH}(U_s) = 9,1551 + 2,3939 \cdot \log(U_s + 1,0497) \quad (9)$$

$$T_s(U_s) = -2376,0 + 2858,7 \cdot \log(U_s + 7,1901) \quad (10)$$

$$D_s(U_s) = -1133,7 + 1558,26 \cdot \log(U_s + 7,4774) \quad (11)$$

$$\text{COD}(U_s) = 44,520 + 266,02 \cdot \log(U_s + 0,96398) \quad (12)$$

$$E_e(U_s) = -682,93 + 717,17 \cdot \log(U_s + 9,3863) \quad (13)$$

$$\text{Zn}(U_s) = 2,1755 + \exp(0,19392 - 0,23248 \cdot U_s) \quad (14)$$

$$\text{Cr}(U_s) = 0,003764 + \exp(-2,5725 - 0,17776 \cdot U_s) \quad (15)$$

where:

pH – reaction of eluate from secondary waste,

T_s – total suspension [mg/dm^3],

D_s – dissolved substances [mg/dm^3],

COD – chemical oxygen demand [$\text{mg O}_2/\text{dm}^3$],

E_e – ether extract [mg/dm^3],

Zn – zinc [$\text{mg Zn}/\text{dm}^3$], ether extract [mg/dm^3],

Cr – chromium(VI) [$\text{Cr}^{+6}/\text{dm}^3$],

U_s – volume fraction of sediments in the charge to the WPS utilizer [%],

The results of the research dealing with the influence of addition of post-flotation fats to the pyrolysis process in the WPS utilizer on the amount of pollutants extracted from secondary waste, coming from the pyrolysis process, are shown in Table 4 and Figure 5.

Table 4. Influence of volume fraction of fats in the charge to WPS utilizer U_F on extraction of pollutants from secondary waste

Parameter	Unit	Volume fraction of fats U_F [%]				
		0.00	2.86	5.71	8.57	28.57
Reaction	–	9.2	11.5	11.8	11.9	12.1
T_s	mg/dm^3	86	96	125	134	158
D_s	mg/dm^3	227	1386	2016	3054	5286
BOD	$\text{mg O}_2/\text{dm}^3$	2	1	1	1	2
COD	$\text{mg O}_2/\text{dm}^3$	40	55	90	109	180
Ether extract	mg/dm^3	15	38	62	103	218
Zinc	$\text{mg Zn}/\text{dm}^3$	3.38	2.56	2.06	1.89	1.37
Chromium(VI)	$\text{mg Cr}^{+6}/\text{dm}^3$	0.09	0.06	0.04	0.03	0.00

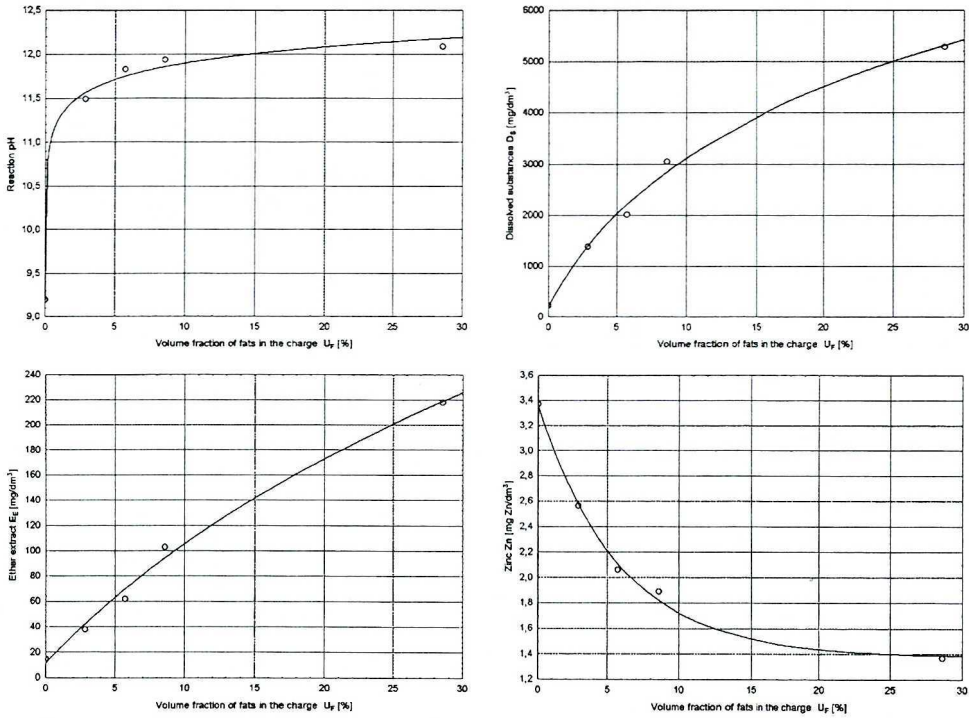


Fig. 5. Influences of volume fraction of fats U_S in the charge on the value of reaction pH, ether extract E_E and content of zinc in the eluate from secondary waste

The influences of U_F value on the values of individual ultimate parameters were approximated by the following equations:

$$pH(U_F) = 11,282 + 0,61487 \cdot \log(U_F + 0,00420) \quad (16)$$

$$T_S(U_F) = 53,622 + 71,541 \cdot \log(U_F + 2,633) \quad (17)$$

$$D_S(U_F) = -4446,3 + 6376,6 \cdot \log(U_F + 5,363) \quad (18)$$

$$COD(U_F) = -174,02 + 226,34 \cdot \log(U_F + 8,498) \quad (19)$$

$$E_E(U_F) = -723,54 + 555,53 \cdot \log(U_F + 20,988) \quad (20)$$

$$Zn(U_F) = 1,374 + \exp(0,68711 - 0,17416 \cdot U_F) \quad (21)$$

$$Cr(U_F) = -0,00176 + \exp(-2,3954 - 0,13091 \cdot U_F) \quad (22)$$

where:

pH – reaction of eluate from secondary waste,

T_S – total suspension [mg/dm³],

D_S – dissolved substances [mg/dm³],

COD – chemical oxygen demand [mg O₂/dm³],

E_E – ether extract [mg/dm³],

Zn – zinc [mg Zn/dm³],

Cr – chromium(VI) [Cr⁺⁶/dm³],

U_F – volume fraction of fats in the charge to the WPS utilizer [%],

The results of the research on basic parameters values in eluate from secondary waste from the pyrolysis process show that as the volume fraction of sediments and fats is growing most of the tested parameters of pollution are also growing.

A pH increase was noted which is obvious in the case of the addition of sediments. Post-sedimentation deposit mostly consists of $\text{Ca}(\text{OH})_2$ and CaCO_3 . Increase of its amount in the charge is causing increase of CaO amount (noticeable visually) in secondary waste. This also may cause increase of the total suspension value. In the case of fats addition pH increase in eluate may also be explained by $\text{Ca}(\text{OH})_2$ presence. Lime is being added to the flotation process. So part of dosed lime is flotating together with fats and than gets to the pyrolysis process.

Also along with the increase of volume fraction of sediments an ether extract increase was noted. This may also be caused by $\text{Ca}(\text{OH})_2$ content in the charge. Lime during the pyrolysis is lumping and fats contained in the sediments which are inside the lumps are not totally, thermally decomposed. Before extraction with water secondary waste required earlier grinding, so undecomposed fats were washed out to the eluate. Presence of fats in eluate influences also COD value.

In the case of fats addition, when there is no problem of lumping, noted values of ether extract are smaller than in the case of secondary waste from the pyrolysis process with addition of sediments, even in spite of the fact that the load of fats is much bigger. However, the part of fats is not totally decomposed due to temperature, which causes increase of the E_E value along with fats volume fraction in the charge to the pyrolysis. Increase of E_E value also causes increase of COD value.

Increase of the amount of dissolved substances in eluate from secondary waste from the pyrolysis process with addition of sediments may result for two reasons. First of all, as it was stated before, increase of the sediments amount in the charge to the pyrolysis process causes $\text{Ca}(\text{OH})_2$ amount increase in secondary waste. In the extraction process it gets through to eluate, causing increase of total suspension and dissolved substances. Also, fats and other organic substances present in the charge to the pyrolysis process are decomposed to soluble compounds under the influence of temperature. So during extraction those substances get through to the eluate. In the case of eluates from secondary waste from the pyrolysis process with the addition of fats, the amount of dissolved substances is considerably bigger. Increase of their amount may be caused by the processes described earlier. However, in this case thermal decomposition of fats has bigger influence on dissolved substances amount in the eluate.

Very low BOD values were determined in all tests, which may be explained by almost total decomposition of biodegradable compounds. So secondary waste is not biodegradable material and it may be neutralized in the cementation process.

Big concentrations of zinc were determined. A decreasing tendency was noticed together with the increase of volume fraction of sediments and fats in the charge to the pyrolysis process. The biggest concentration of zinc was determined in eluate from secondary waste left after pyrolysis of waste PE only. The above findings may suggest that to the content of zinc in eluate is caused by its presence in PE waste.

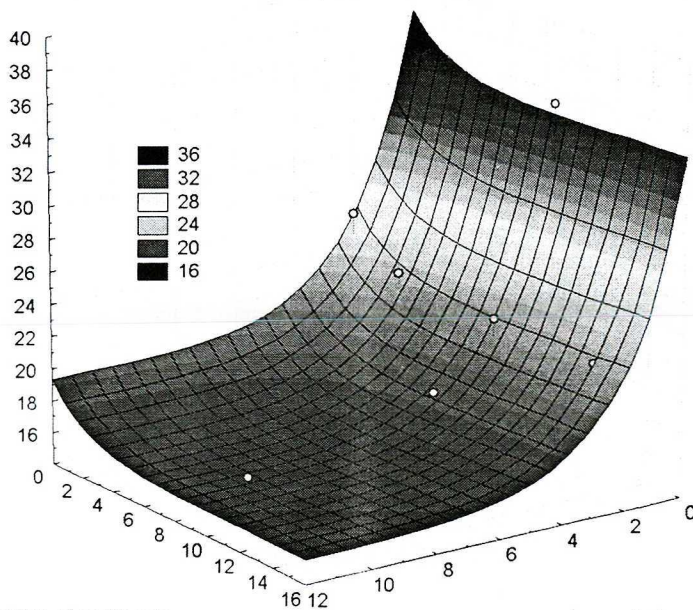
Stage III

The results of the research on the influence of addition of secondary waste from pyrolysis of dewatered sediments with PE waste to concrete on the compression strength of the concrete cubes are shown in Table 5 and Figure 6.

Table 5. Results of the research on the influence of the addition of secondary waste from the pyrolysis process U_k and volume fraction of sediments in the charge U_s on the compression strength σ of concrete cubes

Amount of secondary waste replacing aggregate U_k [%]	Volume fraction of sediments in the charge U_s [%]	Compression strength σ [MPa]
0	8.57	35.2
2		22.8
4		18.9
10		16.1
2	0	26.2
	2.86	23.5
	8.57	22.8
	14.29	22.3

Compression strength σ [MPa]



Volume fraction of sediments in the charge U_s [%]

Amount of secondary waste replacing aggregate U_k [%]

Fig. 6. Influence of the addition of secondary waste from the pyrolysis process U_k to concrete and sediments to the pyrolysis process U_s on the compression strength of concrete cubes

Approximation equation after the first and the second stage describing the influence of both independent parameters was gained using the method of central point [7, 9, 10]. It looks as follows:

$$\sigma(U_K, U_S) = 15,395 + \exp(2,9473 - 0,5084 \cdot U_K) + \exp(1,3638 - 0,4099 \cdot U_S) \quad (23)$$

where:

σ – compression strength of concrete cubes [MPa],

U_K – mass volume of secondary waste from the pyrolysis process replacing aggregate [%],

U_S – volume fraction of sediments in the charge to the WPS utilizer [%],

Results of the research on the influence of addition of secondary waste from pyrolysis of post-flotation fats with PE waste to concrete on the compression strength of the concrete cubes are shown in the Table 6 and Figure 7.

Table 6. Results of the research on the influence of the addition of secondary waste from the pyrolysis process U_K and volume fraction of fats in the charge U_F on the compression strength σ of concrete cubes

Amount of secondary waste replacing aggregate U_K [%]	Volume fraction of fats in the charge U_F [%]	Compression strength σ [MPa]
0	8,57	35,2
2		20,1
4		16,9
10		14,8
2		0
	2,86	22,4
	5,71	21,9
	8,57	20,1
	28,57	18,8

Approximation equation after the first and the second stage describing the influence of both independent parameters was gained using method of central point [7, 9, 10]. It looks as follows:

$$\sigma(U_K, U_F) = 13,490 + \exp(3,002 - 0,6667 \cdot U_K) + \exp(2,002 - 0,2517 \cdot U_F) \quad (24)$$

where:

σ – compression strength of concrete cubes [MPa],

U_K – mass volume of secondary waste from the pyrolysis process replacing aggregate [%],

U_F – volume fraction of fats in the charge to the WPS utilizer [%],

Compression strength σ [MPa]

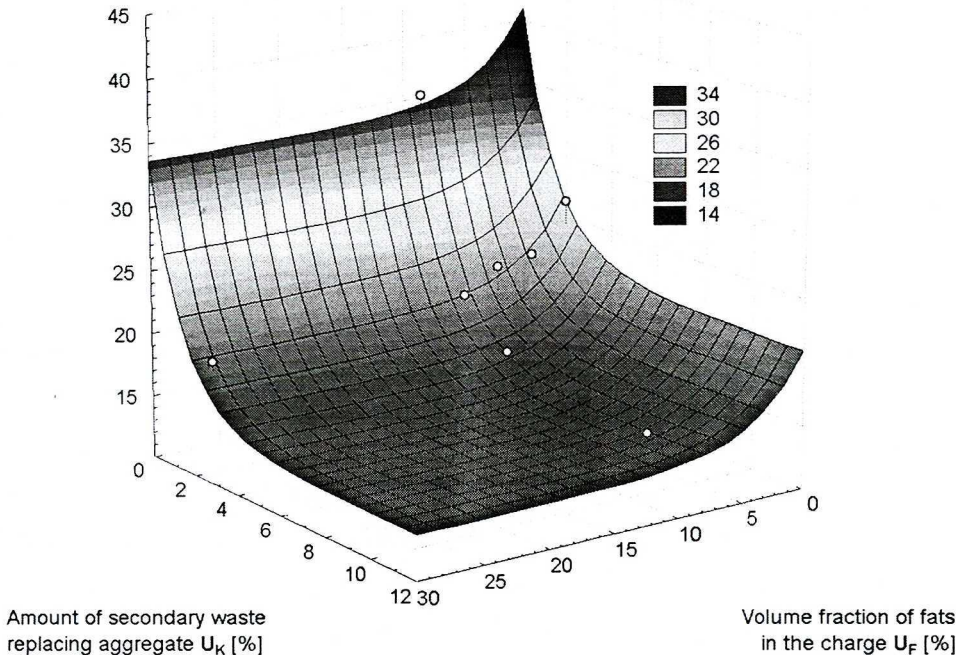


Fig. 7. Influence of the addition of secondary waste from the pyrolysis process U_k to concrete and fats to the pyrolysis process U_F on the compression strength of concrete cubes

The results gained in the stage of research show that increase of volume fraction of sediments and fats in the charge to the WPS utilizer as well as increase of secondary waste amount in the concrete cause decrease of compression strength of concrete cubes. However, much less significant influence has addition of fats or sediments to the charge. For example, an increase of volume fraction of sediments in the charge from 2.86% to 14.29% causes decrease of compression strength only by 1.2 MPa. In the case of fats it is similar – an increase of their volume fraction in the charge from 2.86% to 28.57% causes compression strength decrease by 3.6 MPa.

A decisive influence on the compression strength has the amount of secondary waste replacing aggregate. Each, even small, addition of secondary waste causes the considerable decrease of the compression strength of concrete cubes. From the two examined secondary wastes, the one obtained from pyrolysis of sediments and waste PE, since it contains a certain amount of $\text{Ca}(\text{OH})_2$, should be better addition to the concrete. Results of the tests confirm that fact. A limit value of compression strength 20 MPa is kept when adding 3% of secondary waste instead of aggregate (at 8.57% volume fraction of sediments in the charge). In the case of the secondary waste from pyrolysis of PE waste and post-flotation fats (at 8.57% volume fraction of fats in the charge to pyrolysis) the limit value is kept at 2% participation of secondary waste instead of aggregate.

In general, it may be stated that the secondary waste left after the pyrolysis process

of PE waste and sediments or fats have very adverse influence on the compression strength of concrete cubes created with their addition. Probably this is caused by their big dustiness, small thickness and mechanical resistance as well as large content of washable substances.

Stage IV

Results of the examination of water extracts from concrete cubes created from mixture where 3% of aggregate was replaced by the secondary waste left after pyrolytic neutralization of waste PE and 8.57% dewatered sediments are presented in Table 7.

Results of the examination of water extracts from concrete cubes created from mixture where 2% of aggregate was replaced by secondary waste left after pyrolytic neutralization of waste PE and 8.57% post-flotation fats are presented in Table 8.

Table 7. Results of examination of water extracts from concrete cubes created with optimal amount of secondary waste after pyrolysis of waste PE and sediments replacing aggregate

Parameter	Unit	Initial water pH		
		4	7	11
Reaction	–	11.97	11.85	11.98
T _S	mg/dm ³	26	18	18
D _S	mg/dm ³	369	354	398
BOD	mg O ₂ /dm ³	0	0	0
COD	mg O ₂ /dm ³	2	0	2
Ether extract	mg/dm ³	21	7	40
Zinc	mg Zn/dm ³	1.88	0.81	1.13
Chromium(VI)	mg Cr ⁺⁶ /dm ³	n.o.	n.o.	n.o.

Table 8. Results of examination of water extracts from concrete cubes created with optimal amount of secondary waste after pyrolysis of waste PE and fats replacing aggregate

Parameter	Unit	Initial water pH		
		4	7	11
Reaction	–	11.85	11.95	12.01
T _S	mg/dm ³	49	39	41
D _S	mg/dm ³	377	373	416
BOD	mg O ₂ /dm ³	1	1	1
COD	mg O ₂ /dm ³	2	2	1
Ether extract	mg/dm ³	41	35	38
Zinc	mg Zn/dm ³	0.62	0.41	0.59
Chromium(VI)	mg Cr ⁺⁶ /dm ³	n.o.	n.o.	n.o.

Values of pollution parameters in water extracts from concrete cubes created from concrete mixture with the participation of secondary waste from the process of pyrolysis are small. It means that the cementation prevents the process of washing out pollutants effectively. Only reaction value exceeds limit values due to CaO content – one of main ingredients of cement [4].

A certain amount of ether extract is caused by the methodology of cubes production. Using oil to protect forms from concrete sticking is necessary.

The extraction of pollutants is running more intensively in aggressive environments, particularly in the acid environment, in which washing out pollutants, especially metals is bigger.

VERIFICATION OF GAINED EQUATIONS

Equations characterizing individual parameters of the sequential nodes of the wastewater pre-treatment technology were verified in real conditions, during work of wastewater pre-treatment plant in the SUPERFISH fish processing plant. The verification consisted in execution of the seven series of tests under conditions of technology work at various values of independent parameters in suitable individual processes. The node of pyrolysis of waste PE and post-flotation fats and solidification of secondary waste following equations were subjected to the verification: working time without cooling t_p (6), amount of secondary waste in proportion comparison to the charge volume k_w (8), ether extract in eluate from secondary waste left after pyrolysis process E_e (20), zinc in eluate from secondary waste left after pyrolysis process Zn (21), compression strength of concrete cubes created with addition of secondary waste from the pyrolysis process σ (24).

The obtained results and values calculated using equations are compared in Tables 9, 10 and 11.

Differences between values obtained during tests and values calculated from the equations, presented in Tables 9, 10 and 11 are small, maximum 19%. They show that equations obtained during laboratory research of the process also produce results consistent with reality when different values of independent parameters are substituted (within the researched ranges).

CONCLUSION

A process of waste pyrolysis, which arises during working of the installation of wastewater treatment together with PE waste coming from the plant, allows to utilize (neutralize) effectively both groups of waste (sediments and fats). After pyrolysis process a few per cent of secondary waste is left, which should be neutralized. Solidification applied for that purpose is an effective solution.

Table 9. Comparison of tests results with calculations using analytical and empirical equations in the pyrolysis process (stage I)

Parameter	Unit	Independent parameter U_F	Equation	Test	Deviation of results
Working time t_p	h	8.59	16.66	15.20	8.8%
		4.01	13.04	13.50	3.4%
		10.20	17.94	14.90	16.9%
		5.88	14.52	15.10	3.8%
		16.50	22.92	23.20	1.2%
		2.40	11.77	11.29	4.1%
		21.00	26.48	32.10	17.5%
Amount of sec. waste k_w	%	8.59	3.03	2.95	2.6%
		4.01	2.07	2.14	3.3%
		10.20	3.36	3.2	4.8%
		5.88	2.46	2.65	7.2%
		16.50	4.68	4.58	2.1%
		2.40	1.73	1.98	12.6%
		21.00	5.63	6.95	19.0%

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Table 10. Comparison of tests results with calculations using analytical an empirical equations in the pyrolysis process (stage II)

Parameter	Unit	Independent parameter U_F	Equation	Test	Deviation of results
Ether extract E_E	mg/dm^3	8.59	93.63	92	1.7%
		4.01	53.04	55	3.6%
		10.20	106.42	103	3.2%
		5.88	70.45	72	2.2%
		16.50	150.81	138	8.5%
		2.40	36.98	36	2.7%
		21.00	178.16	182	2.1%
Zinc Zn	$\text{mg Zn}/\text{dm}^3$	8.59	1.82	1.87	2.7%
		4.01	2.36	2.34	0.8%
		10.20	1.71	1.75	2.3%
		5.88	2.09	2.03	2.9%
		16.50	1.49	1.38	7.4%
		2.40	2.68	3.05	12.1%
		21.00	1.43	1.52	5.9%

Table 11. Comparison of tests results with calculations using analytical an empirical equations in the solidification process (stage III)

Parameter	Unit	Independent parameters		Equation	Test	Deviation of results
		U_F	U_K			
Compression strength σ	MPa	8.59	1.0	24.67	24.3	1.5%
		4.01	3.0	18.91	17.6	6.9%
		10.20	4.0	15.46	15.2	1.7%
		5.88	6.0	15.54	15.6	0.4%
		16.50	7.0	13.8	14	1.4%
		2.40	9.0	17.59	17.5	0.5%
		21.00	10.0	13.55	12.7	6.3%

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