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The effectiveness of biodrying waste treatment in full scale reactor

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Abstract: The differences between the composting, stabilization and drying processes were discussed. The law criteria for mechanical-biological treatment plant were presented. The purpose of the article was to assess the effectiveness of biodrying MSW (municipal solid waste) in a full scale reactor taking into account the degree of biological decomposition of organic matter and its suitability for RDF (refuse derived fuel). Therefore the microbial activity was measured as the O_2/96 h uptake. CO_2/96 h production and the respiration activity AT4 for untreated and biodried waste were compared. The decomposition of organic matter was measured by loss on ignition (LOI) and total organic carbon (TOC). The product after the biodrying process was assessed according to the EURITS and PN-EN 15359 criteria for the quality of RDF (residual derived fuel). The result 8.48 MJ/kg of calorific value shows that bio- dried waste is ranked below the EURITS minimum level and can be classified as fifth class by PN-EN 15359 requirements. The amount of chlorine, mercury and lead fulfil the EURITS criteria. The microbial activity after processing in the biodrying reactor expressed as oxygen uptake exceeded the permissible level of 10 mg O_2/g d.m. in the time range ten months. The regulatory parameters TOC < 20% d.m. and LOI < 35% d.m. criteria were not met.

Keywords: mechanical-biological treatment (MBT), municipal solid waste, respiration activity, RDF, waste landfilling

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1 Introduction

Mechanical-biological treatment plants consist of mechanical and biological parts. The mechanical part is an automated mechanical sorting stage which usually removes the recyclable elements from a mixed waste stream. The ''biological'' part refers to either: composting, anaerobic digestion or biodrying. The types of aerobic biological process in waste management are classified as: composting, biostabilization and biodrying [1]. Heat generation is a common characteristic feature of the biological processes which is a result of microbial metabolism and the decomposition of the complex substances into simpler ones [2]. The decomposition of the organic matter is the main goal of the biological methods for waste management. The composting and biostabilization processes leads to the degradation of the easily degradable organic matter (OM) in order to reach a stabilized and humidified material (compost or stabilat) [3]. The differences in the biological methods of composting, stabilization and biodrying are not only in the operational variables but also in the final destination of the outputs. The final product of the stabilization can be treated as a stable and non- biologically active material that can be landfilled with minimum environmental impact [4-14]. In the biodrying reactor only a part of the easy biodegradable fraction is being decomposed in order to save the calorific value as the production of input to the refuse derived fuel RDF is the main target.

Biodrying is a variation of aerobic decomposition, fully described by Velis [15]. The term ''biodrying'' was used for the first time by Jewell [16] whilst investigating the drying of dairy manure. The term means: the bioconversion activity in the reactor for waste treatment, or the physiobiochemical process performed in the reactor, or the MBT plant including a biodrying reactor [15]. The results of the investigations show that the optimal temperature for the biodrying process is 45 °C, while in the composting and the stabilization the temperature can rise up to 70 °C [3, 14].

In a biodrying system, the waste material undergoes a period of rapid heating through the action of aerobic microbes. During this process the heat generated by the microbes results in the rapid drying of the waste. Biodrying technology is often undertaken to produce a refuse-derived fuel (RDF). After the biodrying process the waste has a low moisture content and an enhanced calorific value are is not completely biologically stable, but can be used as a source of refuse derived fuel (RDF) [16]. These RDFs should be used immediately without storage [4]. Hence biodried waste with a higher calorific value shall undergo further processing in the thermal methods [17]. The requirements of European Union for Responsible Incineration and Treatment of Special Waste (EURITS) for RDF are set as calorific value minimum 15 MJ/kg, maximum amount of elements: 0.5% of chlorine, 2.0 mg/kg d.m. of mercury, 200 mg/kg d.m. of lead [18]. Standard PN EN 15359 describes criteria by grading into five classes taking into account calorific value, chlorine and mercury [19].

The MBT method does not fullly destroythe biodegradable waste, but if conducted properly it can obtain the degree of decomposition of biodegradable matter to reach the parameters specified in the Regulation of the Minister of the Environment [20, 21]. The provisions of the regulation are consistent with the provisions of the European Union Directive 1999/31/WE and the European Council Regulation 2008/980/WE [22, 23]. In pursuance of the mentioned law regulation regarding the stabilat designed for safe landfilling, after the biological step one of the following criteria should be filled,:

- The loss of ignition (LOI) of the stabilat should be less than 35% related to the dry mass, and the amount of total carbon organic content (TOC) should be less than 20% in the dry mass, or
- The indicator ΔS of the LOI difference (see equation 1) based on comparing the waste before and after the biological treatment should be greater than 40% d.m, or
- Respiration Activity AT_4 should be less than 10 mg O_2/g d.m.

The indicator can be calculated according to the formula:

$$\Delta s = \frac{SPo - SPs\dfrac{100 - SPo}{100 - SPs}}{SPo} \cdot 100 \qquad (1)$$

where: SP_o is the LOI of raw waste, before stabilization; SP_s is the LOI of product after stabilization

The main aim of this work is to analyse the effectiveness of biodrying MSW process in the full scale reactor taking into account the degree of biological decomposition of the organic matter and its fuel properties. The criteria of LOI, TOC, AT_4, O_2/96 h, CO_2/96 h, calorific value, chlorine, mercury and lead are verified based on the results obtained during the 10 months experimental cycle.

2 Materials and methods

The municipal solid waste collected from a 155.000-citizen community was the material to be examined in the full-scale biodrying reactor. The described research work consisted of comparing the characteristics of the waste before and after the processing of the waste in the reactor. The MBT technology concept was designed in accordance with the law regulations implemented by the Minister of the Environment [20] and refers to the biological processing of the unsorted 0-80 mm fraction of municipal solid waste preceded by a mechanical step. The studied MBT plant includes in the biological stage a rectangular-shaped, galvanized steel reactor equipped with a module for active aeration connected with a stove and a bio-filter for removing plant odours. The scheme of the technology is presented in figure 1.

In the ~150 m^3 reactor the 0-80 mm fraction of the MSW undergoes a drying process for a minimum of 7 days. The supply ventilator (air flow 4500 m^3/h) and the exhaust ventilator (moisture removal 3000 m^3/h) work continuously, while the stove works periodically in specific winter conditions. After the biodrying, the process waste is transported to a rotary drum to separate the dried 20-80 mm fraction from the stabilized 0-20 mm fraction. According to the technology concept, the 20-80 mm fraction (code 19 12 10 – which means the combustible waste or the refuse derived fuel RDF) should be treated by the thermal methods.

The reactor works in periodic option and treats 50-60 Mg of waste at once. Taking into account regulatory requirements PN-EN 15442:2011[23] it was taken twenty of 5 kgs primary samples of the municipal solid waste. The composition of the raw 0-80 mm MSW was investigated.

For the purpose of our study the feedstock directed into bio-reactor was screened in a ∅10 mm sieve and then the oversized fraction was manually separated into categories: glass, green waste, minerals, paper, multimaterial, plastic, ceramic, foil, metals, textiles and weighed according to the Polish Standard PN-Z-15006:1993P [25]. Investigations of the humidity were conducted by the loss of the mass of the dried waste at 105 °C [26]. The mass of the dried samples of the waste was approximately 1000 g. The measurement of the loss on ignition was determined in a muffle furnace

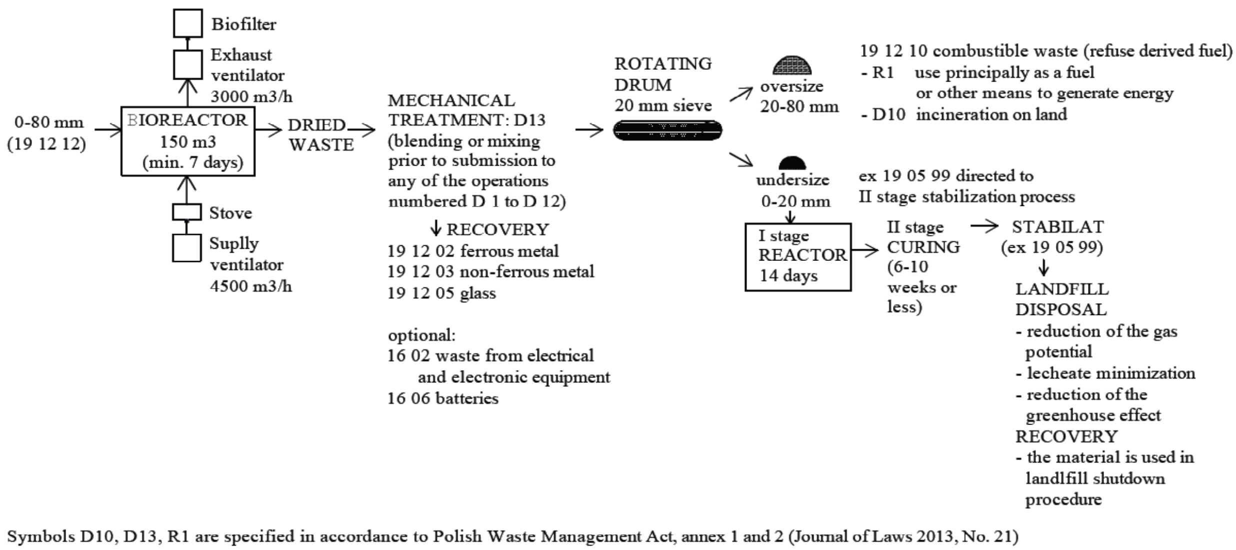

Figure 1: The scheme of the biological stage in an MBT plant.

at 550 °C for 6 hours using 5 g samples according to the Polish Standard PN – EN 15169 [27]. The TOC was measured according to the PN-EN 13137:2002 procedure (in English) [28]. The calorific value and heat of combustion were measured in accordance with the PN-93/Z-15008 and ISO 1928 procedures [29, 30]. The determination was made on 1 g mass samples placed in a bomb calorimeter in the form of compressed pellet. Ignition of the sample was made using a 0.1 mm diameter kanthal wire embedded into a pellet. The calorific value was calculated by a computer program controlling the operation of the calorimeter. The amount of mercury was determined by PN-EN 12457, chlorine by PN-EN 15408 and lead by ISO 11885 [31-33].

The amount of oxygen consumed and carbon dioxide produced by the microorganisms can be determined by the methods: static (without a continuous supply of air during the assay- in this study AT_4) and dynamic (with a continuous supply of air- the O_2/96 h parameter) [34, 35]. The respiratory activity AT_4 was examined in the ''Sapromat'' equipment according to the accredited laboratory procedure described by OENORM S 2027-4 [36].

The AT_4 presents the microbiological oxygen consumption over 4 days and determines the ability of the waste for further biological decomposition [37].

The biological stability was determined in the laboratory by dynamic aerobic tests using a respirometer Oxymax ER-10, which allows measurement of the CO_2 production and the O_2 uptake. The respiration activity should be measured in an oxygen atmosphere for the 30 g minimum mass sample at a humidity of 40-50% [34]. By means of a respirometer, a number of measurements were taken at 5 minute intervals, recording the net increase or decrease in the concentration of the monitored gases. A 100 g sample of waste was used for measuring the biological activity of the untreated 0-80 mm fraction.

The studies were conducted once a month over 10 months, from July 2015 to April 2016, thus covering all the seasons. The effectiveness of the processing in a full-scale bio-reactor was analyzed during the year to evaluate the impact of the external temperature.

3 Results and Discussion

The composition of the raw 0-80 mm fraction of the waste directed to the bio-drying reactor in the different seasons is presented in table 1.

The average contamination with glass, minerals and ceramic is about 35%. The contribution of the green wastes registered in April, January and October were 20.81%, 15.23% and 13.85% respectively. As shown in Table 1 the composition of the waste did not differ significantly between the months. Detailed investigations of the <10 mm fraction show that is composed of 80.6% of sand and soil and 19.4% of residues (glass and stones). The percentage of the residues in the <10 mm fraction increased in October due to a higher contamination of ash and slag. The morphological composition of the MSW fraction undersized ∅ <80 mm from our study was compared with previous results of research biodrying process made on Polish MSW and reported by Dziedzic et. al. [38]. The reported waste contamination MSW by metals, minerals, inert fractions was 26.17% in total, while in our study it was about 35%. The share of paper and foil in our study was similar to results presented in the Dziedzic et al. work. The most significant difference in the studies was the amount of the green waste fraction, 16.63% compared to the 40.87% reported by Dziedzic et al. This result can be explained by more effective collection system of green waste in our region.

It was found that mixed municipal solid waste is generally heterogeneous, particularly derived from different areas, and about 500 g, 380 g, 270 g of alternative fuel can be produced per 1000 g waste in urban areas, single-family housing and rural areas accordingly [39, 40]. The share of combustible waste in our considered case is about 450 g.

On the other hand the research results show that a significant share of biodegradable fraction in the morphological composition of the alternative fuel (over 15%) increases the moisture content and hygroscopic properties [41]. This may cause a decrease in energy content of the matter from 22 to 15 MJ/kg and the increase the moisture in a fuel (till 30%) that disqualifies RDF as a source of energy.

Table 1: The composition of the 0-80 mm waste directed to the reactor in January, April and September.

Composition	January	April	October	Average±SD* age
glass	19.21	16.99	17.87	18.02±1.19
< 10 mm	15.32	15.29	16.48	15.70±0.68
green waste	15.23	20.81	13.85	16.63±3.69
minerals	13.09	9.73	19.24	14.02±4.82
paper	12.12	11.91	9.22	11.08±1.62
multimaterial	6.01	5.90	5.59	5.83±0.22
plastic	5.23	5.15	4.86	5.08±0.19
ceramic	4.97	5.22	4.62	4.94±0.30
foil	4.82	4.74	4.48	4.68±.018
metals	2.38	2.65	2.21	2.41±.022
textiles	1.64	1.61	1.58	1.61±0.03
TOTAL	100.00	100.00	100.00	-

*SD-standard deviation

The final product, after being sifted with a ∅20 mm sieve, was analyzed comparing to the criteria regarding the potential thermal methods of utilization and presented randomly for January (Table 2). The table presents results only from January because RDF parameters were monitored only in this month. The parameters of the 20-80 m dried fraction is presented in table 3 and compares with the criteria given by the EURITS (European Union for Responsible Incineration and Treatment of Special Waste) [http://www.incineration.info/home] and Polish Standards PN-EN 15359 [18, 19].

Comparing the results of 20-80 fraction with the EURITS and PN-EN 15539 criteria for RDF (table 2), after bio-drying the calorific value is too low, so its use as an RDF is limited. According to the PN-EN 15539, the biodried 20-80 mm fraction can be classified as a fifth -class taking into account the requirements for the calorific value. Similar results have been obtained by Dziedzic et al. where the calorific value measured before waste processing, after 14 days of stabilization and 7 days of biodrying, were: 5971± 151 kJ/kg, 8659±283 kJ/kg, 8574±298 kJ/kg respectively. Alternatively, the high calorific value 9.38 MJ/kg had been achieved after 70 hours of biodrying treatment of MSW due to a satisfactory level of water content in the waste [42]. Shares of plastic and paper in their research results were similar to results obtained in our study. Share of green waste was 23.91%, while in our study was 16.63%. The significant difference was recorded for the fine fraction content which was double our study. Comparing the effectiveness in the drying process in the cited work it was better than in our study recorded at the level 8,48 MJ/kg. Potentially the effectiveness of biodrying

Table 2: The selected features of the biodried 20-80 mm fraction of waste measured in January vs. the EURITS criteria and the PN-EN 15359 standard for the RDF.

Parameter	Unit	Biodried 20-80 mm	EURITS* criteria	PN-EN 15359 by grading into classes				
				1	2	3	4	5
Calorific value	MJ/kg	8.48	15.00	≥25	≥20	≥15	≥10	≥3
Cl	%	0.36	0.50	≤0.2	≤0.6	≤1.0	≤1.5	≤3.0
Hg	mg/kg d.m	1.76	2.00	≤0.02	≤0.03	≤0.08	≤0.15	≤0.50
Pb	mg/kg d.m	35.3	200.00	not controlled				

* European Union for Responsible Incineration and Treatment of Special Waste

Table 3: The 10 months average biological activity of the untreated 0-80 mm fraction of the MSW before processing in the MBT plant.

Fraction	Accumulative 10 months average ±SD		Consumption O_2 /96 h 10 months average ±SD	Production CO_2 /96 h 10 months average ±SD
	O_2 uptake	CO_2 production		
[mm]	[mg/96 h]		[mg/g d.m.]	
raw 0-80	2870.89 ±210.11	3578.19 ±315.18	48.98 ±13.09	61.05 ±16.77

process was better in Hurka & Malinowski study due to the different processing conditions, for example their reactor capacity was much smaller (36 m^3) compared to our case (150 m^3).

The biodrying process affects the speciation of heavy metals in MSW and their subsequent release and partitioning during combustion [43]. The amounts of chlorides, lead and mercury fulfill the EURITS criteria but only the amount of chlorine allows qualification for third PN-EN class. Shao et al. investigated biodrying process in the laboratory scale for a synthetic feedstock consisting of 67% food waste, 14% papers, 16% plastic and 3% of other components [44]. The concentration of chlorine after biodrying process was 4 times higher than in our study because of higher percentage share of plastic in the waste. The concentration of lead in Shao et al. report was also higher comparing results in our study, more than double . Only the levels of mercury were similar.

The exemplification of the results obtained in the dynamic method (Oxymax unit) is given in table 3. In this table, the respirometric characteristic of the feedstock to the full–scale reactor is presented, being after the mechanical step. Results of oxygen uptake expressed as O_2/96 h parameters for untreated waste are similar to given by Tintner et al. [45] where median respiration activity index detected also during 96 h was examined at the level 45 mg O_2/g d.m

After the MSW treatment in a full-scale biodrying reactor over 7 days, the output product was separated using drum sieves into two fractions: 0-20 mm and 20-80 mm.

Studies conducted from July to April in the full-scale reactor were repeated 10 times to allowthe variability of the obtained results to be assessed. Tables 4 and 5 summarize the data obtained after the drying process of the particular fractions in the full-scale reactor. It was observed that a large differentiation of results occurred in individual months. This applies to the indicators for both the 0-20 mm and the 20-80 mm fractions.

Results show the highest values of the AT_4 fraction 0-20 mm after bio-drying (table 4): in September and January ; 18.4 mg O_2/g and 17 mg O_2/g respectively. Also in these months, the highest values of the AT_4 occurred after bio-drying for the 20-80 mm fraction (table 5). It confirms the fact that in these months the collected waste was with a high content of biodegradable OM and the 7 day duration of the biodrying process in the reactor was insufficient.

On the other hand, taking into account the average values of microbial activity calculated for the 10 months measured by O_2/96 h parameter it has been set 10.53 mg O_2/g d.m. for 0-20 mm fraction and 10.13 mg O_2/g d.m. for 20-80 mm fraction. This constituted about 80% decrease of microbial activity, similar to results reported by Tintner et al. and Grill et al. where respiration activity index determined during 96 h were decreased by 90% and 80% respectively [45, 46].

Moisture is known to be a critical parameter in microbial activity [47]. The biodrying processes were completed with 21.56% of moisture content detected in 20-80 mm fraction, and 18.07% in 0-20 mm fraction. During the biodrying process the drop of moisture at 50% content was obtained, similar results were reported by Zawadzka et al. [48].

The loss of ignition tested on the 20-80 mm fraction (table 5) was much higher than on the 0-20 mm fraction (table 4) as a result of variables in their composition. This confirmed the higher amount of biodegradable OM in the 20-80 mm fraction; in April it was about 93.10% d.m.

It should be noted that a high value of loss on ignition (LOI) does not always correspond to a high value of AT_4 (see Table 4 and 5). The LOI parameter of the 0-20 mm fraction seems more stable than the 20-80mm.

A lack of correlation between theAT_4 parameters and the LOI allows us to conclude, that in a particular month a varied fraction of biodegradable matter was included in the composition of the organic material. This was especially noticeable in February and April (table 5). The highest values of AT_4 were found in the 20-80 mm fractions in July, September and January.

Sidełko et al. investigated a 2-stage composting process of sewage sludge with the aim of comparing several parameters particularly useful for the assessment of compost stability [49]. They found high positive correlation at 0.887 between AT_4 and LOI. In start point of composting in first stage (6 weeks in piles under shelte) the value of LOI was equal 75% d.m. and at the end point (after curing for 2-3 months in boxes) the LOI decreased to about

Table 4: Characteristic of the 0-20 mm fraction after processing in the bio-reactor.

Parameter / Unit / Month	Humidity [%]	TOC [% d.m.]	LOI [% d.m.]	AT_4 [mg O_2 /g d.m]	O_2/96 h [mg O_2/g d.m]	CO_2/96 h [mg O_2 / g d.m]
July	12.60	8.51	24.10	8.50	9.80	11.05
August	25.00	13.60	22.20	7.43	9.14	10.80
September	28.60	12.60	25.60	18.40	22.58	24.08
October	18.40	9.25	18.60	7.46	10.02	13.08
November	18.40	9.25	18.60	7.46	10.02	13.08
December	16.90	10.50	19.60	6.86	7.80	8.40
January	22.00	15.70	27.80	17.00	19.06	20.50
February	8.90	18.10	26.60	1.00	3.80	4.51
March	18.80	11.90	33.20	8.99	9.05	10.05
April	11.10	13.10	40.40	1.72	4.01	4.80

Table 5: Characteristic of the 20-80 mm fraction after processing in the bio-reactor.

Parameter / Unit / Month	Humidity [%]	TOC [% d.m.]	LOI [% d.m.]	AT_4 [mg O_2 /g d.m]	O_2/96 h [mg O_2/g d.m]	CO_2/96 h [mg O_2 / g d.m]
July	16.60	13.50	21.00	14.30	18.03	22.06
August	22.20	15.10	19.60	4.42	6.90	8.04
September	34.80	15.40	34.70	13.40	16.8	19.52
October	26.40	10.00	29.20	1.00	1.20	4.69
November	24.80	11.60	20.80	10.90	14.04	17.00
December	22.60	21.10	41.40	1.00	2.50	4.50
January	18.40	18.70	36.80	14.00	16.70	18.51
February	20.10	34.20	77.80	9.61	10.09	12.28
March	10.80	16.10	39.10	9.77	12.13	14.21
April	18.90	14.00	93.10	1.97	2.91	4.89

65% d.m. The starting microbial activity assessed as AT_4 was detected above 25 mg O_2/g d.m. while the end result was detected below 5 mg O_2/g d.m. Based on those results the authors are going to create a mathematical model for assessment of the compost stability in short time, basing on the measurement only LOI after few hours.

In our study the average oxygen uptake in feedstock loaded into bio-reactor expressed as AT_4 was about 50 mg O_2/g d.m and in the final stage after processing in the bio-reactor this parameter ranged between 1-20 mg O_2/g d.m. Therefore, based on our study we cannot confirm the correlation between AT_4 and LOI (see table 4 and 5), which can be explained by vast difference in the nature of the waste.

The highest AT_4 parameter (static method) detected in the 20-80 mm fraction were confirmed by the highest parameters of oxygen uptake expressed by the O_2/96 h (dynamic method).

4 Conclusions

The biodrying processes were completed with 21.56% of moisture content in the 20-80 mm fraction and 18.07% in the 0-20 mm fraction.

The calorific value of the 20-80 mm biodried fraction of the waste is much lower than the EURITS criteria and the PN-EN 15359 standard for an RDF so its use as an RDF is limited. However, the amounts of chlorides, mercury and lead do not exceed the limits prescribed by EURITS. According to the PN EN 15359 requirements, the biodried 20-80 mm fraction is classified by the calorific value and the quantity of mercury to the last fifth-class. Therefore biodried waste can be transformed into a fuel thereby notably reducing the amount of MSW to be sent to a landfill.

An evaluation of the work of a bio-drying full-scale reactor was made by comparing the LOI, AT_4 and TOC values with the criteria given for MBT plants [20]. The respiration activity of the 0-20 mm fraction after biodrying was higher than the limited level of 10 mg O_2/g d.m in September and January. However, the quantity of the LOI and TOC were lower than that limited in law requirements, it means: less than 35% d.m. and less than 20% d.m. respectively. Summarizing, the MBT process for the 0-20 mm fraction, the stabilat expected for landfilling may be accepted taking into account the existing current law criteria. For the 20-80 mm fraction after the biological stage the levels of AT_4 were exceeded in July, September and January but the quantity of the LOI and TOC fulfilled the requirements in these months. It allows us to make the conclusion that the investigated 20-80 mm fraction had been properly treated in the MBT installation.

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