

Removal of Nitrogen Compounds from Wastewater in SBR Reactors with Brenntaplus VP1

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ABSTRACT

The paper presents the efficiency of nitrogen removal from wastewater using Brenntaplus VP1 as an external carbon source. The study was conducted during the municipal wastewater treatment process in two independent activated sludge chambers of SBR type. One of the chambers contained glycerol as the source of easily available organic compounds. The study showed that the use of Brenntaplus VP1 as the external carbon source during wastewater treatment resulted in a higher efficiency of nitrogen removal than in the reactor without the external carbon source applied, resulting in low level of the COD value in the treated wastewater. There was a significant acceleration of the denitrification process as compared to the control reactor.

Keywords: Brenntaplus VP1, carbon source, denitrification, reactor SBR

INTRODUCTION

Removing nitrogen from sewage is one of the main goals of the wastewater treatment plant [Zhang Y. et al. 2016]. The denitrification process, i.e. reduction of oxidized nitrogen compounds, is carried out by heterotrophic microorganisms that use nitrate (NO₃) or nitrite (NO₂) as the terminal hydrogen acceptors in the absence of oxygen. During this process, intermediates such as NO, N₂O or gaseous N₂ are formed [Kaszubowska M. et al., 2011]. One of the main reasons for the unsatisfactory effects of nitrogen removal in treatment plants is the shortage of organic carbon compounds, which limits the course of denitrification. In such cases, it may be necessary to add external carbon sources to the system that is readily absorbed by microorganisms [Cherchi C et al., 2009; Liu F. et al., 2016; Dinçer K., Kargı F., 2000; Oleszkiewicz J.A et al., 2004; Shi Y. et al., 2017; Sun H et al., 2017].

At present, many wastewater treatment plants support denitrification using alternative carbon sources such as methanol, ethanol, acetic acid or glucose [Cherchi C et al., 2009; Elefsiniotis

P., Li D., 2006; Plüg B.D. et al., 2015; Zhang Y. et al., 2016; Smyk J., Ignatowicz K., 2017]. There are also certain preparations designed for sewage treatment plants including, among others, Brenntaplus VP1, which was developed to support the biological removal of biogenic compounds. According to the manufacturer, these preparations are not hazardous materials, are non-poisonous, inflammable, non-explosive, are not waste products, can be used throughout the entire year, remain stable during storage, are completely biodegradable, and have a high COD content at the level of 1,000,000 mgO₂/dm³. The additional advantage is that this type of mixture guarantees superior species diversity in the activated sludge, rather than using methanol or ethanol alone, and has a very short adaptation time [Brenntaplus VP1 – producer's website, Ignatowicz K. et al., 2015].

According to literature data, the preparation can be successfully used in the sewage flow treatment plants [Simson G., 2009; Kogut P. at al., 2014; Ignatowicz K. et al., 2015]. The study was carried out to examine how Brenntaplus VP1, used as an external carbon source for wastewater treatment, affects the efficiency of removing nitrogen forms from wastewater in SBRs.

METHODS

The study was conducted during the municipal wastewater treatment process in two independent SBR-activated sludge reactors. The active capacity was 10 dm³, 6.5 dm³ was the activated sludge provided by the sewage treatment plant in Białystok, while the remaining quantity originated from the raw mechanically treated wastewater (3.5 dm³) that was also obtained from the sewage treatment plant in Białystok.

A single cycle of the reactor lasted for 6 hours and included following phases: sewage supply (2 min), mixing (anaerobic) (60 min), aeration (3.5 h), sedimentation (1h), and decantation (0.5 h). During the aeration phase, the compressed air was fed through the diffuser placed at the bottom of the reactor; depending on the operating phase, the amount of air was from 0.1 to 3.0 mg O₂/dm³, concentration of the activated sludge 3.5 kg/m³, sludge index oscillated within 120–150 cm³/g, hydraulic load of the chamber was 1.4 m³/m³d, whereas the pollution load amounted to 0.2 kg COD/m³d. Brenntapplus VP1, as a source of easily available organic compounds, in an amount of 100 mg/dm³ (8–12 g carbon source/1gNO₃⁻) wastewater was added into one of the chambers in each cycle, twenty minutes after the sewage pouring. Table 1 shows the parameters of SBR operation.

The collected sewage samples were filtered immediately after the filtration. Each filtrate was subject to determination of the following items in accordance with the applicable methodology:

- ChZT_{Cr} – dichromate PN-ISO 15705:2005,
- BZT₅ – manometric applying OxiTop Standard system,
- N-NH₄ – spectrophotometry according to PN-ISO 7150-1:2002,

- N-NO₃ – spectrophotometry according to PN-82/C-04576/08,
- Nog. – spectrophotometry according to PN-EN ISO 6878:2006,
- Pog. – spectrophotometry according to PN-C-04576-00:1973P,
- P-PO₄ – spectrophotometry according to PN-EN ISO 6878:2006.

RESULTS AND DISCUSSION

Results of the R1 reactor effluent tests without the addition of an external carbon source were included in Table 1, while Table 2 shows results of the wastewater tests from R2 reactor with Brenntapplus VP1 as external carbon source. In Figure 1, the ratio of COD to total nitrogen at the individual control points was compared. According to the ATV guidelines, Henze, Spindor, Lomotovskiy and other authors, denitrification occurs without interruption if the COD/N ratio is from 4 to 10. The COD/N ratio in wastewater in both SBRs was insufficient for the denitrification process and was below the recommended range. The addition of Brenntapplus VP1 did little to improve this dependence and the COD/N ratio almost reached the required lower limit of the range.

Table 1. Parameters of SBR operation.

Activated sludge concentration	3.5 kg/m ³
Sludge index	120–150 cm ³ /g
Hydraulic load of chamber	1.4 m ³ /m ³ d
Load with impurities	0.2 – 0.3 kg COD/m ³ d
Decantation coefficient	0.3

Table 2. Data and test results of wastewater without an addition of an external carbon source

REACTOR R1 – without carbon source							
Parameters	1	2	3	4	5	6	7
	Raw wastewater	Poured wastewater (20 min) after 20 min	Denitrification (20 min) after 40 min	Denitrification (20 min) after 60 min	Nitrification (1.5 h) after 2.5 h	Nitrification (2 h) after 4.5 h	Decantation (0.5h) after 6 h
COD [mgO ₂ /dm ³]	530	268	262	259	254	243	35
BOD ₅ [mgO ₂ /dm ³]	230	125	120	120	115	98	6
Total nitrogen [mgN/dm ³]	118.0	84.0	68.7	55.2	48.1	24.3	14.4
Nitrate NO ₃ ⁻ [mgN/dm ³]	2.6	3.9	2.4	3.6	4.6	8.6	8.6
Ammonia NH ₄ ⁺ [mgN/dm ³]	51.1	58.2	55.3	41.6	33.5	9.7	1.8
Phosphorus PO ₄ [mgP/dm ³]	18.5	15.2	18	12.8	1.5	1.1	0.8
Phosphate PO ₄ [mgP/dm ³]	18.5	15.2	18.0	12.8	1.5	1.1	0.8

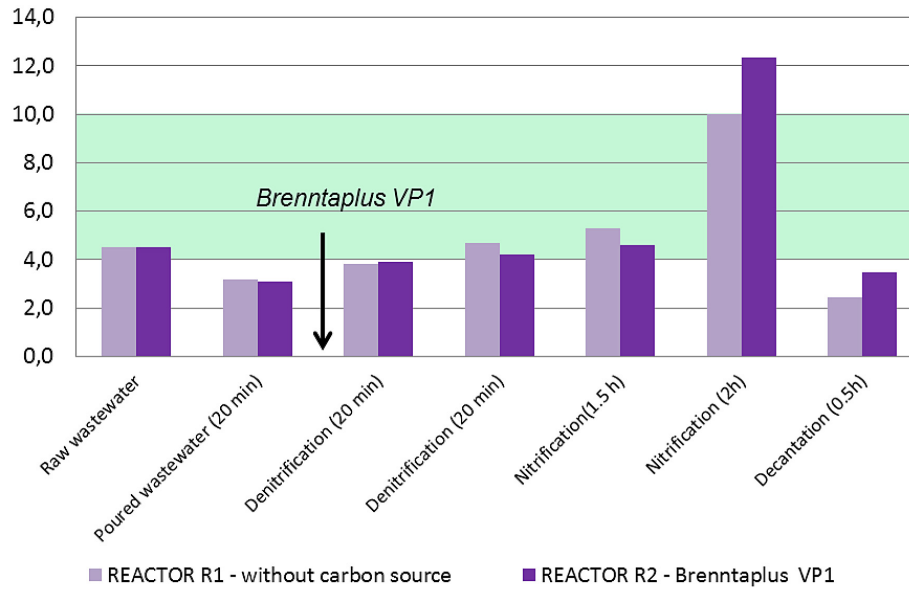


Figure 1. Concentrations the ratio of COD to nitrogen in control points.

Table 3. Data and test results of wastewater with addition of Brenntaplus VP1 as an external carbon source

REACTOR R2 – Brenntaplus VP1							
Parameters	Dosage of carbon source						
	1	2	3	4	5	6	7
	Raw wastewater	Poured wastewater (20 min) after 20 min	Denitrification (20 min) after 40 min	Denitrification (20 min) after 60 min	Nitrification (1.5 h) after 2.5 h	Nitrification (2 h) after 4.5 h	Decantation (0.5 h) after 6 h
COD [mgO ₂ /dm ³]	530	258	281	272	245	236	24
BOD ₅ [mgO ₂ /dm ³]	230	125	120	115	110	96	5
Total nitrogen [mgN/dm ³]	118.0	84.0	72.1	64.4	53.4	19.1	6.9
Nitrate NO ₃ ⁻ [mgN/dm ³]	2.6	4.4	2.1	2.4	12.7	11.3	5.4
Ammonia NH ₄ ⁺ [mgN/dm ³]	51.1	41.9	43.4	38.3	16.5	3.6	0.5
Phosphorus PO ₄ [mgP/dm ³]	18.5	15.2	16.9	17.6	3.1	0.8	0.8
Phosphates PO ₄ [mgP/dm ³]	18.5	15.2	16.9	17.6	3.1	0.8	0.8

Figures 2–4 illustrate the concentration of studied nitrogen forms after different stages of wastewater treatment.

Value of COD in raw wastewater amounted to 530 mgO₂/dm³, while BOD₅ 230 mgO₂/dm³. Concentration of the total nitrogen in raw sewage was 118 mgN/dm³, ammonia 51.5 mgN/dm³ and nitrate 2.6 mgN/dm³.

Twenty minutes after the reactors filling, decreases in COD and BOD₅ values were observed – the available carbon source was taken by denitrification bacteria. The value of COD in R1 reactor was 268.0 mgO₂/dm³, while the value of BOD₅ equalled 125.0 mgO₂/dm³. In the reactor R2, the following values of parameters were recorded: COD – 262.0 mgO₂/dm³, BOD₅ – 125 mgO₂/dm³. In both reactors, ammonia concentrations were the same, i.e. 84.0mgN/dm³. The content of ni-

trates in both reactors increased up to 3.9 mgN/dm³ in R1 and to 4.4 mgN/dm³ in R2. The increase in the ammonia concentration was also recorded in R1 to 58.2 mgN/dm³, whereas the decrease in R2 amounted to 41.9 mgN/dm³.

Afterwards, Brenntaplus VP1 preparation was added as the external carbon source into the R2 reactor and after 20 minutes of denitrification process, subsequent samples were collected. In R1 reactor, where the wastewater treatment process proceeded without the support of an external carbon source, a further slight decrease in COD (262 mgO₂/dm³) and BOD₅ (120 mgO₂/dm³) was noted. Introducing the carbon source in the form of Brenntaplus VP1 caused the increase in the COD value in R2 reactor by 23.0 mgO₂/dm³, up to 281.0 mgO₂/dm³. The BOD₅ value in R2 reactor decreased to 120 mgO₂/dm³. A decrease in the

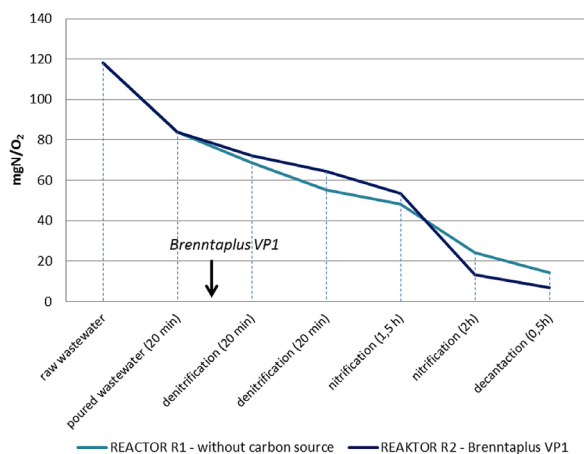


Figure 2. Concentrations of total nitrogen after individual phases of wastewater treatment

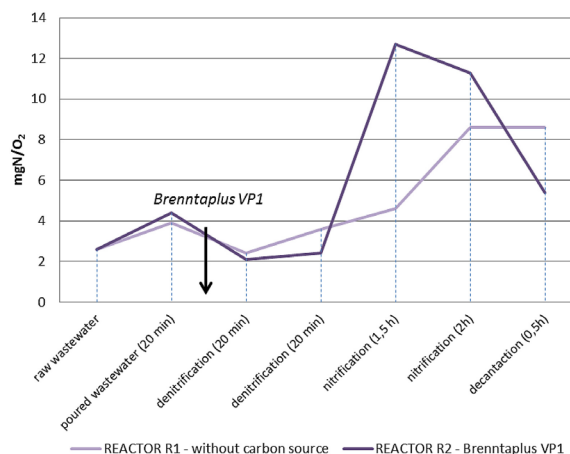


Figure 3. Concentrations of nitrate after individual phases of wastewater treatment

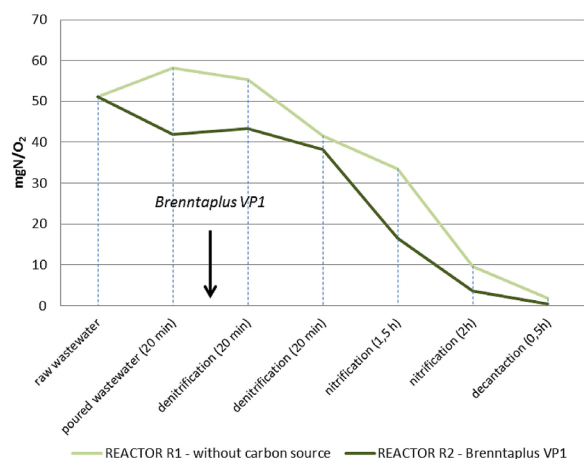


Figure 4. Concentrations of ammonia after individual phases of wastewater treatment

total nitrogen concentration in both reactors was recorded: in R1 – 68.7 mgN/dm³, while in R2 – 72.1 mgN/dm³. In the case of nitrate, there were also lower concentrations as compared to the previous control point. In R1 reactor, the nitrate content was 2.4 mgN/dm³, while in R2 reactor – 2.1 mgN/dm³. The concentration of ammonia slightly decreased in R1 to 55.3 mgN/dm³, whereas in R2 reactor, the adverse situation was recorded – there was an increase in ammonia up to 43.4 mgN/dm³; however, the concentration was still lower than in R1 reactor.

After subsequent 20 minutes of anaerobic wastewater treatment process, a further slight decrease in COD in reactor R1 was found (259 mgO₂/dm³). The value of BOD₅ remained unchanged (120 mgO₂/dm³). In the reactor with Brenntapulus VP1 addition, the COD decrease by 9 mgO₂/dm³ to the level of 272 mgO₂/dm³ was observed. The BOD₅ value decreased to 115 mgO₂/dm³.

The concentration of the total nitrogen decreased further, reaching 55.2 mgN/dm³ in R1 reactor. For R2 reactor with addition of Brenntapulus VP1, the total nitrogen concentration was higher than in R1 reactor and amounted to 64.4 mgN/dm³ translating into the difference of 9.2 mgN/dm³ total nitrogen between the reactors. In both reactors, an increase in the content of nitrates to 3.6 mgN/dm³ was recorded in R1 and 2.4 mgN/dm³ in R2. The ammonia level decreased in R1 to 41.6 mgN/dm³, while in R2 – to 38.3 mgN/dm³. The difference of the ammonia concentrations at that control point between the reactor without carbon source R1 and with molasses in R2 amounted to 3.3 mgN/dm³.

Other samples were collected after 1.5 hours of wastewater aeration. The value of COD in R1 reactor was 254 mgO₂/dm³, while BOD₅ – 115 mgO₂/dm³. In R2 reactor, the decrease of COD value by 27 mgO₂/dm³ to the level of 245 mgO₂/dm³ and the reduction of the BOD₅ value to 110 mgO₂/dm³ occurred. Moreover, total nitrogen concentration was lower in the reactor without carbon source, amounting to 48.1 mgN/dm³ in R1 reactor. In the case of R2 reactor, the concentration of the total nitrogen was 53.4 mgN/dm³. The difference between total nitrogen levels between R1 and R2 reactors was 5.3 mgN/dm³. The concentration of nitrates in R1 increased up to 4.6 mgN/dm³, which resulted from the inhibition of denitrification process due to the supply of oxygen into reactors. In R2 reactor, an increase in nitrates concentration was recorded as well, but these were higher values – even as high as 12.7 mgN/dm³. Such a high concentration was due to the intensive removal of ammonia nitrogen, which in the R2 reactor amounted only to 16.5 mgN/dm³ (decrease by 21.8 mgN/dm³). The

concentration of ammonia nitrogen in R1 reactor decreased to 33.5 mgN/dm³ (by 8.1 mgN/dm³).

Subsequent samples were collected after another 2 hours of wastewater aeration. The value of COD in R1 reactor was 243.0 mgO₂/dm³. In the reactor with Brenntapplus VP1, there was further intake of available organic compounds, which resulted in lower COD values (236.0 mgO₂/dm³) than in the reactor without carbon source addition. The BOD₅ value amounted to 98.0 mgO₂/dm³ in R1 reactor and to 96.0 mgO₂/dm³ in R2.

The concentration of the total nitrogen in R1 reactor was determined as 24.3 mgN/dm³. For R2 reactor, the concentration of total nitrogen was 19.1 mgN/dm³. The difference in the total nitrogen between both reactors amounted to 5.2 mgN/dm³. Nitrate concentration in R1 was decreased to 8.6 mgN/dm³, in R2 reactor a further removal of 1.4 mgN/dm³ was noted. A long duration of wastewater aeration resulted in a significant lowering the ammonia concentration in both reactors as compared to the previous control point. The difference in the ammonia content between R1 – reactor without carbon source – and R2 – with glycerin – was 6.1 mgN/dm³.

The value of COD in the treated wastewater from R1 reactor after decantation process amounted to 35.0mgO₂/dm³, while the value of BOD₅ was 6.0mgO₂/dm³. Despite the addition of the external carbon source, the COD value in the treated sewage with Brenntapplus VP1 addition amounted to 24.0 mgO₂/dm³, whereas BOD₅ – 5.0 mgO₂/dm³. These are lower numbers than in R1 reactor, where no additional carbon source was used. The concentration of the total nitrogen in the treated wastewater from R1 reactor amounted to 14.4 mgN/dm³, ammonia 1.8 mgN/dm³, and nitrates 8.6 mgN/dm³. Treatment of wastewater in R1 reactor caused the removal of total nitrogen in 87.8% and ammonia in 96.5%. In the case of the reactor with Brenntapplus VP1 addition, the concentration of the total nitrogen in the treat-

ed wastewater was 6.9 mgN/dm³, ammonia 0.5 mgN/dm³ and nitrate 5.4 mgN/dm³. Treating the sewage in R2 reactor resulted in the removal of total nitrogen in 94.2%, while ammonia was removed in 99%. The use of Brenntapplus VP1 in R2 reactor has resulted in a higher efficiency of the wastewater treatment process than in R1 reactor, where no external carbon source was applied. Despite the increase in the final nitrate concentration in R1 and R2 reactors, the reactor with external carbon source addition contained lower nitrate concentration by 3.2 mgN/dm³.

Pearson’s linear correlation was calculated to determine the correlation between the individual indicators. The Statistica 12 software was used to develop the results. The calculations included the analysis of Pearson’s correlation coefficients at p<0.05 to determine the degree of linear relationship between the raw sewage parameters and the reactor unit processes and COD fractions. The results are summarized in Table 4. According to calculated correlations, the strongest correlation values are between COD and BOD₅, COD and total nitrogen, BOD₅ and total nitrogen, total nitrogen and total phosphorus, total nitrogen and phosphates, total nitrogen and ammonia nitrogen, ammonia nitrogen and total phosphorus, ammonia nitrogen and phosphates, as well as total phosphorus and phosphates.

The denitrification rate along with the mean denitrification rate was determined twenty minutes after the addition of the carbon source (Figure 5). In the initial denitrification phase with the addition of an external carbon source in the form of Brenntapplus VP1, the removal of nitrogen compounds by 1.2 mgN·dm³/h was observed, as compared to the control reactor. For the mean denitrification rate in the reactor without the addition of carbon source, the speed was much lower and amounted to only 0.3 mgN·dm³/h, while the speed difference between the two reactors was 1.7 mgN·dm³/h.

Table 4. Pearson’s linear correlation coefficients

Parameters	Means	Std. Dev.	COD	BOD ₅	Total nitrogen	Nitrate	Ammonia	Total phosphorus	Phosphate
COD	264.071	139.690	1.00000	0.99466	0.88034	-0.41570	0.68944	0.66627	0.66452
BOD ₅	115.357	62.867	0.99466	1.00000	0.90662	-0.43949	0.73934	0.69469	0.69309
Total nitrogen	59.329	35.268	0.88034	0.90662	1.00000	-0.61858	0.87955	0.86438	0.86268
Nitrate	5.371	3.511	-0.41570	-0.43949	-0.61858	1.00000	-0.77977	-0.79810	-0.79836
Ammonia	31.893	21.066	0.68944	0.73934	0.87955	-0.77977	1.00000	0.90319	0.90274
Total phosphorus	10.129	8.053	0.66627	0.69469	0.86438	-0.79810	0.90319	1.00000	0.99998
Phosphate	10.057	7.984	0.66452	0.69309	0.86268	-0.79836	0.90274	0.99998	1.00000

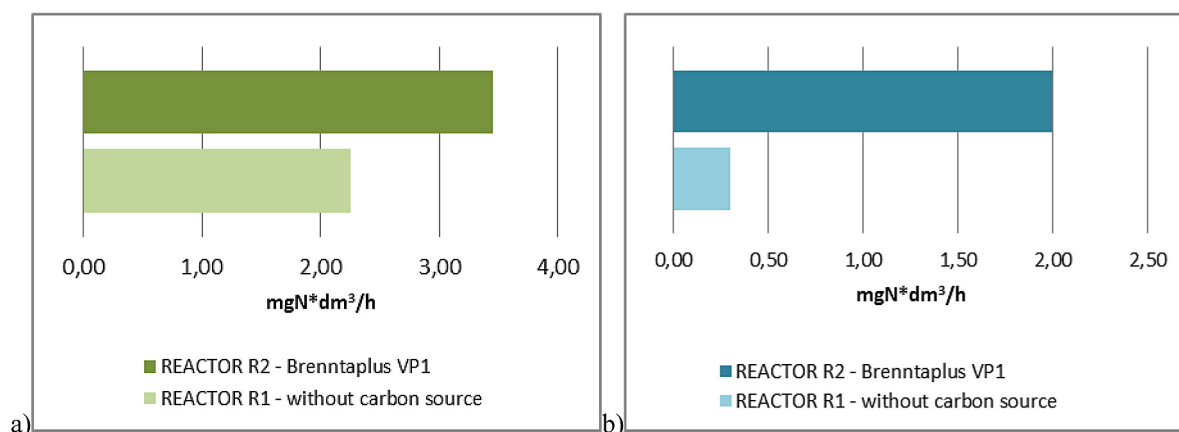


Figure 5. Denitrification rate a) twenty minutes after addition of the carbon source
b) average denitrification rate

CONCLUSION

1. The use of glycerin as an external source of carbon during wastewater treatment has resulted in a higher removal efficiency of nitrogen forms than in the reactor where no external carbon source has been applied along with low COD content in the purified wastewater.
2. Despite the increase in nitrate concentration in the sewage treated in both reactors, the use of molasses has resulted in a decrease in the concentration of nitrates in purified wastewater by $3.2 \text{ mgN}/\text{dm}^3$ as compared to reactor without supply the external carbon source.
3. Addition of Brenntapplus VP1 resulted in an accelerated denitrification by $1.7 \text{ mgN} \cdot \text{dm}^3$, as compared to the control reactor.

Acknowledgements

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