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RECIPIENT POLLUTION CAUSED BY SMALL DOMESTIC WASTEWATER TREATMENT PLANTS WITH ACTIVATED SLUDGE

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Abstract: The study evaluates the impact of small domestic wastewater treatment plants (SDWWTP) working on the principle of the activation processon the water quality in small recipients. The water sampling was carried out above and below domestic wastewater treatment plant's outflow, from September 2014 to August 2015, regularly every month. All samples were collected and determined as per the applicable standards. Results were evaluated on the basis of current surface water legislation and compared with environmental quality standards (EQS) contained in Government Order No 23/2011 Coll., on Indicators and Values of Permissible Pollution of Surface Water and Wastewater, Mandatory Elements of the Permits for Discharge of Wastewater into Surface Water and into Sewerage Systems, and on Sensitive Areas. Water analysis in recipients under SDWWTP has shown high concentrations of total phosphorus and ammoniacal nitrogen. At the same time, reduced concentrations of dissolved oxygen were analysed below domestic wastewater treatment plant's outflow, where two SDWWTP has shown increased concentrations of Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD). Not working nitrification process is a consequence of high concentrations of ammoniacal nitrogen due to low concentrations of nitrite nitrogen and nitrate nitrogen.

Keywords: domestic wastewater treatment plant, activation process, water analysis, environmental quality standards, ammoniacal nitrogen, total phosphorus

1. INTRODUCTION

The use of water resources leads to the formation of wastewater, which, despite the treatment process, has poor quality, and at the same time the quality of both surface and underground water can be adversely affected (Kovář, 2008). Groundwater can be used, by means of a well, as drinking or service water. Here the chemistry of the water can be adjusted by the zeolitic tuffs (Pop et al., 2012).

Nowadays, we still can find administrative territories with no sewerage system leading to the central wastewater treatment plant. Because of that, most of new houses, which are built outside the sewerage network, usually solve the problem by building small domestic wastewater treatment plants (SDWWTP).

In Czech Republic, 63.443 buildings are connected to SDWWTP (1 July 2016) and more than 60 manufacturers of such treatment plants are registered (RSO, 2016)

Manufacturers offer various types of SDWWTP, with different technologies. Anaerobic types of treatment plants – mostly used in recreational centres where there is no permanent wastewater supply secured – are usually accompanied by another degree of wastewater treatment. The most commonly used is soil or sand filter. Without this additional treatment, an efficiency is about 70% while up to 85% efficiency can be achieved after its implementation. Much more widespread types of wastewater treatment plants are aerobic ones. Many modifications are also available here, such as treatment plants working on the principle of the activation process, biodiscs or biofilters (Šmídová, 2004; Blum et al., 2017).

Domestic wastewater treatment plants – activation type, is the most widely used method of biological wastewater treatment, as the activation system appears to be the best available technology in the field of wastewater disposal (LawDecree 23/2011). Activation is a method of biological way of wastewater treatment, which consists in creation of activated sludge in aeration tank. This sludge must be sufficiently oxygenated, because the activated sludge is made up of microorganisms that need oxygen for their lives. These microorganisms are the most important component of wastewater treatment plants. Activated sludge is composed of both single-cell and multi-cell microorganisms. Among multicellular organisms we include e.g. rotifers or nematodes. On the other hand, single-celled microorganisms are mainly protozoa and bacteria, which participate in the elimination of nutrients in processes of nitrification and denitrification (Lu, et al., 2014; Hashimoto et al., 2014).

The process of nitrification consists in the oxidation of ammoniacal nitrogen to nitrite nitrogen, which is then oxidized to nitric nitrogen, e.g. by *Nitrosomonas* and *Nitrobacter* bacteria (He et al., 2017). The process of denitrification is linked to the nitrification process. Otherwise, the treatment would never happen since the nitrogen compounds would remain in water, but in another form. In denitrification, nitric nitrogen is reduced to gaseous nitrogen, e.g. by the family of *Pseudomonas* bacteria (Zielinska et al., 2012; Zhou et al., 2014).

Oxidation takes place at the bottom of activation chamber where the aeration system is located – mostly fine bubble aeration is used, but coarse bubble aeration can be installed as well. These systems are sorted by the size of the holes in the aeration elements (Hlavínek, 2001).

The constantly increasing number of SDWWTP negatively affects the chemical composition of the water in the recipient (undissolved ammonia, total phosphorus), and subsequently affects organisms in it. As a result, both the number and the occurrence of those species that are sensitive to the pollution of the environment they live in, getting food in and reproduce in, decrease (Porrello et al., 2002).

The aim of this study is to find out how the selected small domestic wastewater treatment plants, operating on the principle of activation, affect the chemical and physical parameters of the water in the recipient where it flows in.

2. MATERIAL AND METHODS

The study monitored the impact of four SDWWTP - activation type, on water quality of three recipients. Two SDWWTP are in the Moravian-Silesian region, specifically in the village of Těrlicko (about 10 km from Havířov), further as A (in service from 2008) and B (in service from 2013) and another one in Ostrava-Radvanice, further as C. Third recipient is in Zlín region, in Prlov (about 15 km from Vsetín). This treatment plant is further referred to as D. All of these treatment plants usefine bubble aeration.

The water sampling was carried out from September 2014 to August 2015. The samples were taken monthly from all sampling points, from 1 m above and below the treatment plant's outflow. Water treatment plant C was the only exception – here only samples below the plant's outflow were collected. The sampling was carried on according to ISO 5667-6. All recipients were of the similar nature – they are forest streams with lower water content, faster stream, numerous obstacles such as stones and branches, with a depth of about 30 cm and a length of only a few hundred meters.

In the samples, following indicators were determined: pH, dissolved oxygen, Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), total phosphorus (P_{total}), nitrates NO_3^-, nitrites NO_2^-, concentration of ammoniacal nitrogen $N\text{-}NH_4^+$; suspended solids, dissolved solids, total solids, and the water temperature in the particular flows was measured as well.

After the selected indicators were determined, the results were evaluated and averaged according to Government Order No 23/2011 Coll., as amended in Government Order No 229/2007 Coll. on environmental quality standards (EQS) applicable to surface water (Table 1).

Table1. Selected surface water indicators contained in the EQS

Indicator	Limit (mg.L^{-1})
DissolvedO_2	>9
Biochemical O_2demand	3.8
Chemical O_2demand	26
P_{total}	0.15
$N\text{-}NH_4^+$	0.23
$N\text{-}NO_3^-$	5.4
pH	6-9
Suspended solids	750
Dissolved solids	20

3. RESULTS AND DISCUSSION

Analysis of water samples collected from the sampling point below the treatment plants showed high concentrations of total phosphorus and ammoniacal nitrogen. The environmental quality standards were thus exceeded in all cases of SDWWTP (Table 2).

During the twelve months of monitoring concentrations of total phosphorus significantly fluctuated at all sampling points of all the SDWWTP tested (Fig. 1). The highest concentrations of P_{total}

occurred at sampling point under the SDWWTP, which had only a low efficiency of total phospohorus removal during its wastewater treatment process. This reflected on the quality of the water in the recipient.

During the period of our investigation, the highest P_{total} concentrations were detected during the summer time, when the temperature exceeded 20°C.

Environmental quality norms state the limit of 0.15 mg.L^{-1}for total phosphorus. As we can see in the diagram below (Fig. 1), the lowest P_{total} concentrations were found under the SDWWTP B. On the contrary, the highest P_{total} concentrations were present in the recipient under the SDWWTP D, where the values even exceeded 20 mg.L^{-1}(May).

The efficiency of phosphorus removal in the process of activation at SDWWTP is maximally about 40%, as stated in T. G. Masaryk Water Research Institute's studies (Jelínková et al., 2013; Jelínková & Baudišová, 2014; Jelínková & Baudišová, 2015). The average value of phosphorus production is 1.5 – 3g/person/day (Pitter, 2009). This means that a four-member family would have produced from 6 up to 12g of phosphorus per day from secretion only. With such a heavy phosphorus loading and, at the same time, the effectiveness of its removal less than 40% the recipient receives 3.6 to 7.2 g of phosphorus per day.Then it ispartly bound in sediments, in the form of insoluble ferric salts, from which the phosphorus is released just in the reducing environment (Kalff, 2002).

Statistical evaluation of dependence of total phosphorus on other indicators showed its dependence on conductivity. Correlation index for SDWWTP D exceeded 0.7 (Fig. 2).

Speaking of SDWWTP C, the correlation index reaches almost 1, precisely 0.987. The values found in SDWWTP C, demonstrating the functional dependence of total phosphorus on conductivity, can be seen in (Fig. 3).

Table 2. Results of surface water analyses above and below the tested treatment plants, average annual value (mg.L^{-1})

Indicator	**A**		**B**		**C**	**D**	
	Above DWTP	Below DWTP	Above DWTP	Below DWTP	Below DWTP	Above DWTP	Below DWTP
$P_{tot.}$	**0.18**	**0.45**	0.12	**0.27**	**0.38**	0.11	**8.02**
$N\text{-}NH_4$	**2.32**	**4.33**	**1.74**	**3.49**	**1.4**	**1.36**	**5.14**
$N\text{-}NO_3$	1.46	1.82	1.62	2.8	3.68	0.35	1.52
pH	7.86	7.78	7.93	7.96	7.94	7.68	7.63
Suspended solids	0.002	0.004	0.002	0.003	**119.25**	6.92	12.14
Dissolved solids	0.017	0.020	0.016	0.015	279.85	68.9	126.04
Chemical O_2 demand	13.42	16.66	8.28	14.24	**33.72**	10.38	**31.27**
Biochemical O_2 demand	1.64	2.96	1.94	2.24	**5.72**	**4.1**	**10.43**
Temperature	13.5	13.58	13.55	13.62	15.39	12.59	13.2
Dissolved O_2	9.38	**8.66**	9.51	9.31	**5.36**	**8.33**	**6.55**

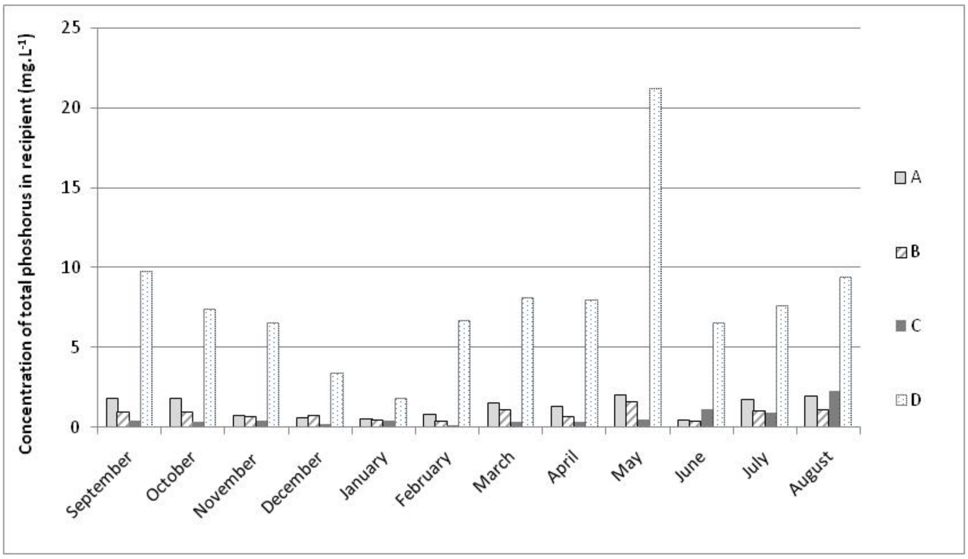

Figure 1. Concentration of total phosphorus below the tested treatment plants

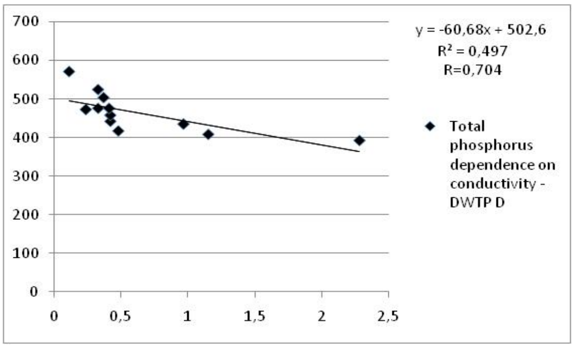

Figure 2. Total phosphorus dependence on conductivity - SDWWTP D

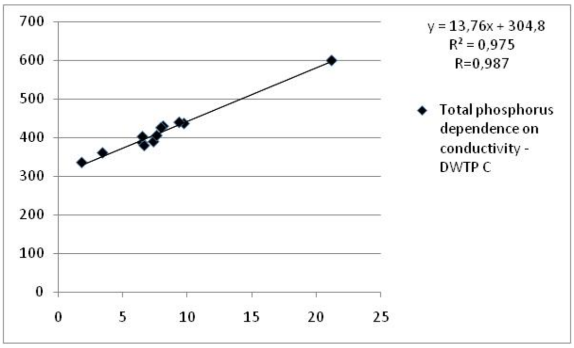

Figure 3. Total phosphorus dependence on conductivity - SDWWTP C

Figure 4 clearly depicts that the concentrations of ammoniacal nitrogen at all sampling points exceeded the limit of 0.23 mg.L^{-1} as established by Government Order No 23/2011. Ammoniacal nitrogen cannot be usually found in mineral form, thus we do not find it in natural water sources at all. For this reason, the ammoniacal nitrogen found in surface water is anthropogenic (Pitter, 2009).

Dissociated ammonia inhibits the microorganisms of both stages of nitrification process, however, the nitrifying organisms are substantially more resistant to this inhibition than nitrating ones. As well, it has been proven that if nitrifying and nitrating microorganisms were exposed to undissolved ammonia for a longer period of time, they would be able to adapt to conditions of a particular environment. At semi-continuous flow of purified water, the nitric nitrogen has become a key factor that inhibits the action of nitrating organisms on a long-term basis in the treatment of sewage containing ammoniacal nitrogen in the concentration range from 150 to 600 mg.L^{-1} (Radechovský et al., 2013).

Ammoniacal nitrogen limits were exceeded up to 20 times. Although these concentrations significantly fluctuated during the year, they pose a great risk to recipients, especially for fish, because ammoniacal nitrogen is toxic for them – namely its undissolved form that prevails over the dissociated one when the temperature in streams exceeds 15°C and the pH is higher than 8 (Miller et al., 1990; Soderberg & Meade, 1991).

Significant temperature oscillation was observable at all SDWWTP during the spring. At SDWWTP C the temperature even oscillated in the range from 12.2°C to 21°C. The streams conditions supporting toxicity of ammoniacal nitrogen (temperature above 15°C and pH above 8) occurred at all sampling points during the summer months (Table 3).

Currently, the removal of ammoniacal nitrogen is problematic not only for SDWWTP, but also for large and root SDWWTP (Huang et al., 2016). Each person produces about 13 g of nitrogen per day. 8 to 10 g of this amount is ammoniacal nitrogen (Höglund, 2001). If we take a four-member family as an example, they would have produced 32 to 40 g of ammoniacal nitrogen per day. There is around 88% success in

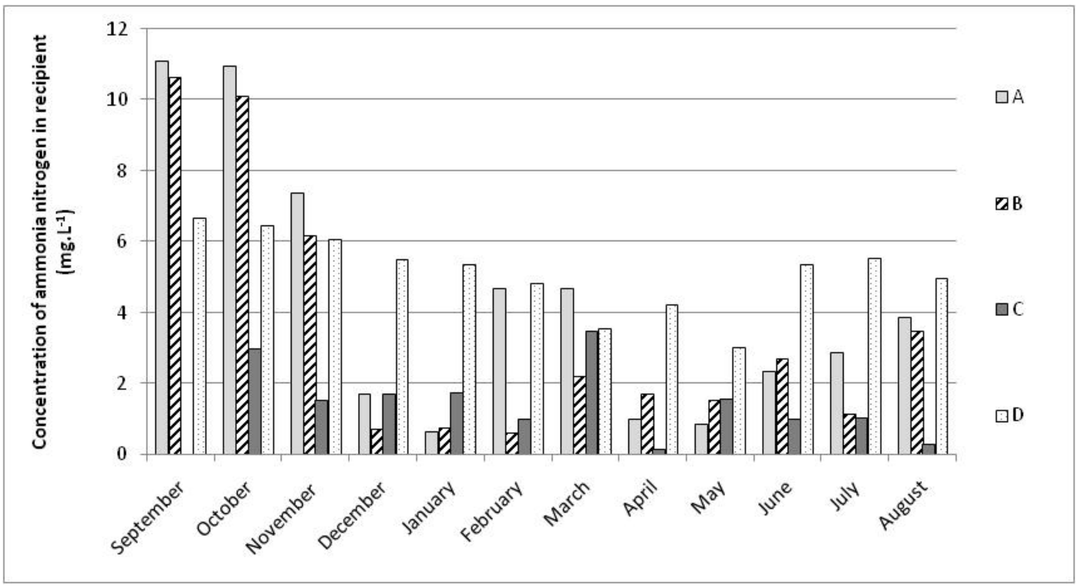

Figure 4. Concentration of ammoniacal nitrogen (N-NH_4^+) under the tested treatment plants A, B, C and D

Table 3. Temperature, pH and concentrations of N-NH_4^+overview on the outflows of selected SDWWTP A, B, C and D

Month	A			B			C			D		
	T[°C]	pH	N-NH_4 [mg.L^{-1}]	T[°C]	pH	N-NH_4 [mg.L^{-1}]	T[°C]	pH	N-NH_4 [mg.L^{-1}]	T[°C]	pH	N-NH_4 [mg.L^{-1}]
September	19.4	7.58	11.1	19.3	7.73	10.65	18.6	7.5	0.33	18.9	7.74	6.69
October	15.2	8.6	10.95	15.2	7.84	10.1	10.3	7.47	2.98	14.8	7.61	6.43
November	9.6	7.48	7.38	9.7	7.68	6.2	12.7	7.5	1.52	9.2	7.56	6.10
December	5.2	7.68	1.69	5.4	7.86	0.72	12	8.26	1.72	5.3	7.49	5.52
January	5.1	7.63	0.64	5.1	7.85	0.77	7.8	8.29	1.75	5.4	7.45	5.38
February	4.9	7.45	4.66	5	7.79	0.61	13	6.9	1	5.2	7.4	4.83
March	6.5	7.74	4.66	6.4	7.78	2.2	12.2	8.32	3.49	6.5	7.61	3.56
April	11.6	7.99	0.99	11.7	8.24	1.72	8.5	7.97	0.16	11.4	8.11	4.13
May	16	7.73	0.85	16.1	8.1	1.55	21	8.23	1.57	16.3	8.17	3.11
June	20.3	8.37	2.33	20.4	8.53	2.72	23	8.2	1	20.9	8.18	5.36
July	22.1	7.93	2.87	22.2	8.17	1.16	19.8	8.37	1	21.2	8.36	5.56
August	21.5	7.91	3.88	21.6	8.9	3.49	21	8.11	0.28	21.1	8.19	4.99

removing the ammoniacal nitrogen at treatment plants working on the principle of the activation process, thus up to 5g of N-NH_4^+ can be absorbedby the recipient. Such pollution is alarming, since undissolved form of ammonia is toxic for aquatic organisms (Boyd & Tucker, 1998).

On the contrary, the concentrations of nitrate nitrogen meet environmental quality standards at all sampling points.

With respect to the other parameters in Table 2, it is evident that two treatment plants, C and D, did not meet EQS in BOD and COD. Moreover, extreme values of suspended solids appeared there as well.

At the same time, treatment plants A, B and D negatively affected the amount of dissolved oxygen in the recipient (Table 2). On the other hand, the concentrations of nitrate nitrogen meet all the EQS at all sampling points. Similarly, at all sampling points EQS were met for the dissolved substance indicator, and they also fulfill pH range that the EQC indicates.

The content of dissolved oxygen in water depends on the water temperature. When the temperature is higher, water requires less of dissolved oxygen to achieve 100% water saturation than in cooler water (Pitter, 2009). Dependence of dissolved oxygen on the temperature of recipient is depicted in Figure 5.

We can see that at lower temperature the content of dissolved oxygen in the stream is higher. When temperature increases in spring and summer, dissolved oxygen content decreases. At SDWWTP A and B, dissolved oxygen in recipient was rather stable. Its values ranged from approximately 7 to 11 mg.L^{-1}. For comparison, SDWWTP C and D affected the dissolved oxygen contents much more. The values ranged from 2 to 11 mg.L^{-1}. The content of dissolved oxygen in recipient was a bit higher in some months, especially when water temperature was higher as well. However, this was caused by a large number of obstacles in the flow, such as stones and branches that change the water flow from laminar to turbulent, hence leading to water oxidation.

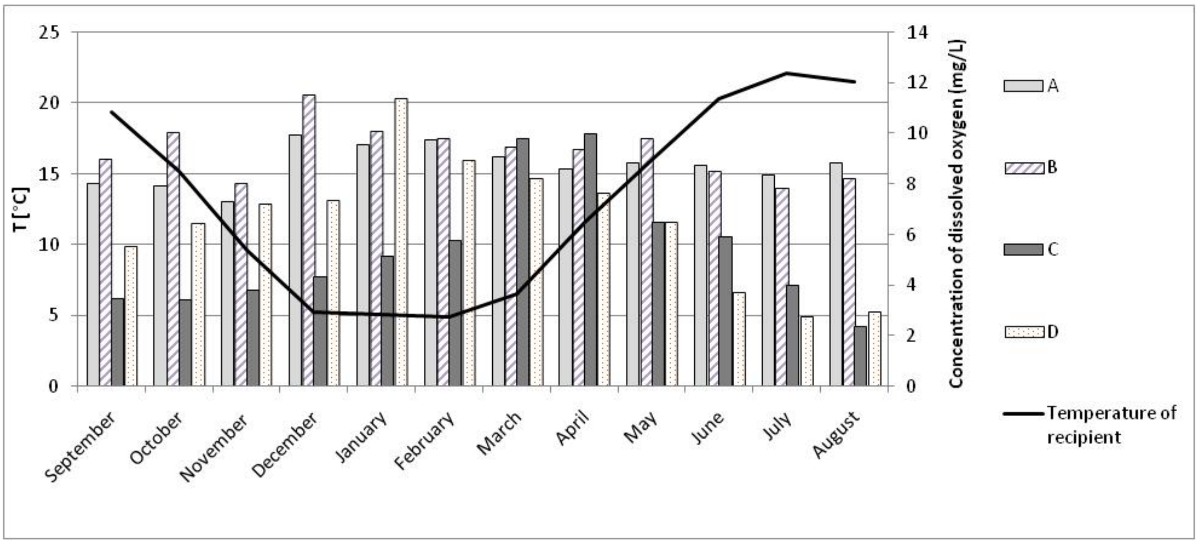

Figure5. Dependence of dissolved oxygen on the temperature of recipients under the tested treatment plants A, B, C and D

4. CONCLUSION

From the analyses carried out from over SDWWTPs it is obvious, that the recipients are polluted even without the add-on influence of small domestic wastewater treatment plants, mostly by ammoniacal nitrogen and total phosphorus. This pollution can be caused by nitrogen and phosphate fertilizers used on the surrounding agricultural fields. However, some other anthropogenic activities may also be a reason of this pollution.

Surface water analyses under all SDWWTPs showed the increasement of concentrations of ammoniacal nitrogen and total phosphorus.

Initial studies of the chemical status of the surface water under the SDWWTPs, carried out by Institute of Environmental Engineering, Faculty of Mining and Geology, proved that under the real conditions, in the most widespread types of SDWWTPs - activation type - removal of ammonia does not occur to an extent similar to laboratory conditions. Under SDWWTPs discharges, even up to 20 times higher concentrations of ammoniacal nitrogen were recorded. According to the environmental quality standards (EQS), such values are in admissible. Such a pollution is very alarming, since the undissolved form of ammonia is toxic for aquatic organisms, especially when the stream temperature exceeds 15°C and the pH is higher than 8.

High concentrations of phosphorus that affect the development of phytoplankton, namely algae and cyanobacteria, have also been repeatedly recorded.

Under the treatment plants C and D, high values of BOD were measured, indicating large pollution caused by biodegradable organic substances. Under the treatment plants A, C and D, low values of dissolved oxygen were measured. This condition has a negative impact on quality of the water in the recipients and, subsequently, on the organisms living in these recipients.

There is not much research analysing the surface water samples under point source of pollution, in particular domestic wastewater treatment plants, therefore we will continue our study of this issue.

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