

Greenhouse Gas Emissions from Wastewater Treatment System

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Abstract: Besides its great potential in controlling water pollution from different sources, waste water treatment system generates significant amount of greenhouse gases. Hence, reducing the emission of greenhouse gases from the wastewater treatment plants is the major concern. The correct understanding and estimation of the greenhouse gases emitted from different points of the plant is essential to tackle this challenge. This research has attempted to evaluate and quantify the greenhouse gases, mainly methane and nitrous oxide, emissions from the wastewater treatment system under varying conditions of temperature and oxygen.

The sludge samples were collected from the septic tank, aeration tank, denitrification tank and digestion tank to examine the emission of greenhouse gases from the samples with and without nutrients and volatile fatty acids(VFA). To examine the effect of temperatures on the emission of greenhouse gases, experiments were designed under different temperatures by keeping reactors at 4° C, 20° C, 25° C, 30° C, 37° C and 50° C. Similarly, experiments were carried out at 37° C under different amount of oxygen supply (0, 0.1, 0.4, 1.0 and 2.0 mg/L) to examine the role of oxygen in greenhouse gases emission.

Experimental results showed that the rate of emission of CH₄ gas from the sludge sample was enhanced with the presence of glucose, nutrients and VFA. Rate of CH₄ production was well correlated with sludge temperature. It was similar for all sludge samples taken from different points of the treatment plant. Rate of production was found highest for digestion sludge and least for septic sludge. CH₄ production was started earlier and found fastest from the digestion sludge. An inverse relationship was found between the rate of CH₄ emission and the amounts of oxygen present in the sludge sample. However, N₂O emission was not detected at all.

Keywords: Methane, Anaerobic, Temperature, Nutrients, Wastewater, Sludge

1. Introduction

Water scarcity and water pollution are serious environmental problems in many the urban areas. The rapidly increasing population in the urban areas of developing countries has added to the scarcity of water. The inappropriate management of domestic sewage and industrial discharge has exacerbated the water pollution. This situation has necessitated water treatment system and different techniques are in practice for the treatment of waste water. These systems are, now, proven to be effective means not only in meeting the demand of water for different purposes, but also in restoring the degraded aquatic ecosystem and environment.

Wide ranges of wastewater treatment systems are available to maintain the chemical, physical, and biological integrity of water. Physical, chemical, and biological units have been developed and are applied for the treatment of wastewater. The wastewater treatment systems are not totally environmentally friendly as they generate various greenhouse gases (GHGs). GHGs like CO₂, CH₄ and N₂O are released from different components of the treatment system. There has been gradual increase in the trend of these CH₄ and N₂O gases emission from 1998 to 2004 (Figure1).

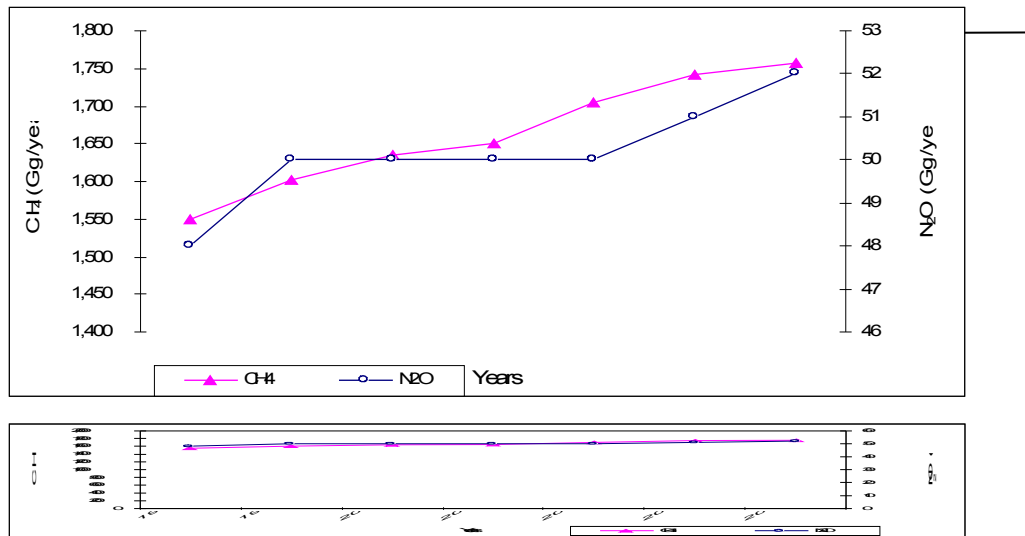


Figure 1: Greenhouse gas emissions from waste and wastewater treatment systems.

Source: IPCC annual report (2005)

The study has focused on evaluating and quantifying greenhouse gases emission from the wastewater treatment sludge. The aim of study is to evaluate and quantify the GHG emissions from it. This study mainly focuses on the role of nutrients (NO_3^- , NH_4^+), glucose and VFA, temperature and oxygen on the GHG emissions from wastewater treatment sludge.

2. Methods and Materials

Sludge samples were collected from septic tank, aeration tank, denitrification tank and digestion tank of the wastewater treatment system which is shown schematically in Fig 2. 60 Sludge samples of 500 ml were taken from 4 and glucose, NH_4^+ , NO_3^- and volatile fatty acids (VFA) were added to examine their effect in the emission of greenhouse gases. Experiments were carried out under different sets of temperatures and oxygen levels. The effects of temperature and oxygen in the emission of GHGs from the wastewater sludge can be done only in those places where we can control these parameters. The quantity of methane and nitrous oxide emitted from these sludge samples were measured by using Gas Chromatograph (GC) with thermal conductivity detector.

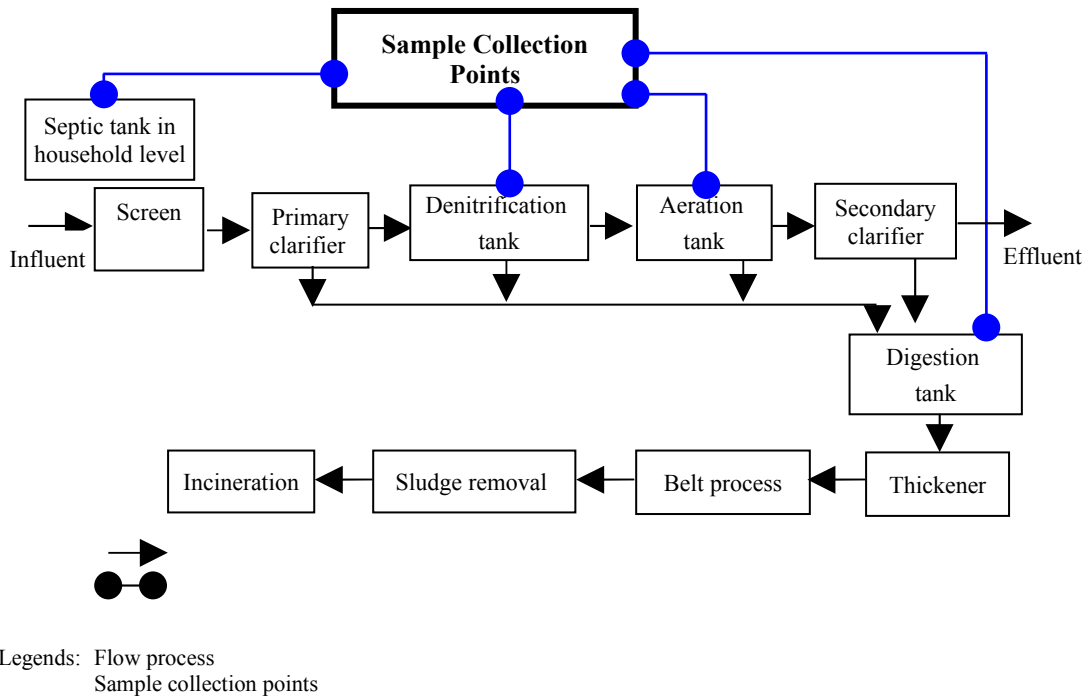


Figure 2: Block diagram of the system indicating the sampling points

3. Results and Discussion

3.1 Effect of Temperature on GHGs Emission from Denitrification Sludge

The measured rates of produced CH_4 methane from the denitrification tank with and without VFA are presented in Table 1. The P- value obtained from hypothesis testing at 95 % confidential level and R^2 obtained from regression analysis are also given in Table 1. The emission rate of CH_4 from denitrification sludge sample was found high in the sludge temperature increase and the effect of VFA contain at 20°C . In this temperature the ratio of the rate of emission of CH_4 from the sludge sample that contained VFA came to be almost 150% more than that from the sludge alone. In other temperatures, this ratio is almost equal to 1. It can be seen in Fig. 3 in which methane emission rate was plotted against temperature. The optimum temperature for CH_4 emission from denitrification sludge was above 37°C . Both rate of CH_4 emission and CH_4 production (from dry weight) increases with increase in temperature of denitrification sludge.

Table 1: Methane production rates and dry weight of denitrification sludge with and without VFA at different temperatures

Temperature	Activities	CH_4 Emission (mg/L/d)	P - value	R^2	CH_4 production from dry weight (mg CH_4 /gdw sludge)
4°C	Sludge	0	–	–	–
	Sludge + VFA	0	–	–	–
20°C	Sludge	6.0	0.000000126	0.98	65

	Sludge + VFA	6.7	0.00073	0.92	108
25°C	Sludge	9.4	0.034	0.89	136
	Sludge + VFA	9.7	0.290	0.92	150
30°C	Sludge	10.4	0.000147	0.94	144
	Sludge + VFA	11.6	0.89	0.96	183
37°C	Sludge	11.7	0.0127	0.87	87
	Sludge + VFA	12.2	0.39	0.87	86
50°C	Sludge	12.2	0.124	0.89	141
	Sludge + VFA	12.1	0.033105	0.75	177

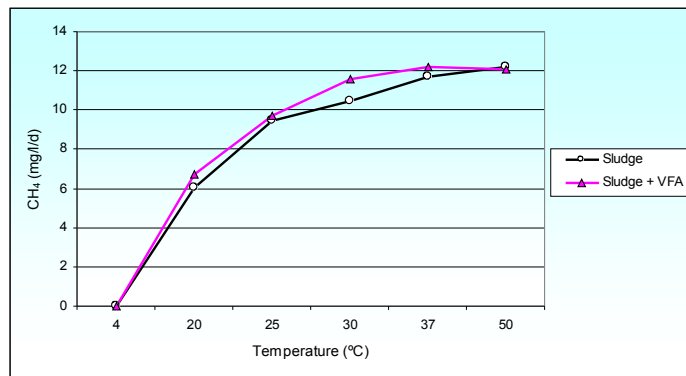


Figure 3: Methane production rate from the denitrification sludge at different temperatures

In all the experiments CH_4 emissions took place from sludge samples taken from denitrification tank while N_2O emission could not be traced at all. There is a positive relationship between CH_4 emission and temperature. The emission of CH_4 gas from the sludge is slow at lower temperature and becomes faster with the increase in temperature. It should be due to slower microbial activities at lower temperatures. It is due to the fact that at higher temperature, biological activities that affect CH_4 emission increase (Zhu et al., 2006). This finding is in conformity with that of (Lin's, 2001) conclusion i.e. temperature affects chemical reaction and biological activities. (Gupta et al, 2006) stated that there was a significant correlation of solid manure with respect to ambient temperature and consequent CH_4 emission. In this study also similar results were obtained regarding the effect of temperature on GHGs emission.

In similar, CH_4 was found emitted but the N_2O emission could not be detected as in those experiments without VFA. The results show that, the rate of CH_4 emission increases from the combination of sludge +VFA with temperature, although there was a slight decrease in the emission at 50 °C than that of 37 °C. The total amounts of CH_4 emitted at the end of the experiment for the setup at different temperature were equal. The rate of CH_4 emissions from sludge was optimum from 30°C and 50°C. This finding is in conformity with Zinder et al. (1984) conclusion optimum temperature for mesophiles bacteria is 30 - 40°C.

3.2 Greenhouse Gas Emission from Different Sludge Samples at 20° C

Two sludge samples were taken from each of the Aeration tank, Digestion tank, Denitrification tank and Septic tank sample points at 20° C. The coefficient of regression is more than 90% in every case except 'sludge +VFA' combination in which it assumes a value slightly lower than 90%. The tests carried out at 95% confidential level also showed that there is a significant relationship between CH₄ production and time in days. The rate of CH₄ production is higher from the sludge that contains nutrients than the sludge without nutrients (Figures 4, 5, 6, and 7)..

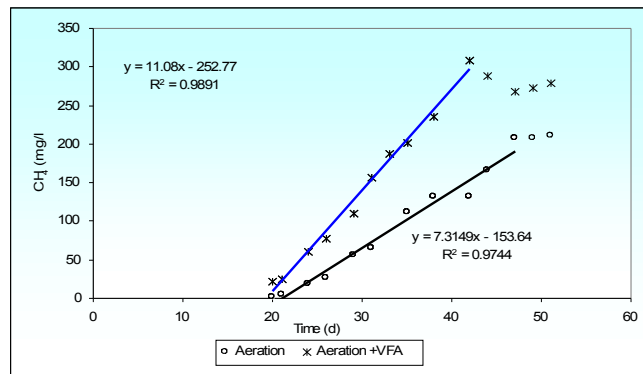


Figure 4: Effect of VFA on CH₄ production from aeration sludge at 20°C

The emission rate of CH₄ of the sludge sample taken from aeration tank came to be 7.3 mg/L per day ($R^2 = 0.98$, P-value = 0.000192) whereas it came to be 11.0 mg/l per day when the sludge containing VFA ($R^2 = 0.95$, P-value = 0.000029). The CH₄ production was found to be 76 mg per g dw for sludge alone while this value came to be 118 mg per g dw sludge for the sludge containing VFA. Not only the rate of production but also the amount of CH₄ production was found high when there was nutrient in the sludge. In the same way, it was found that production of CH₄ started from sludge as well as 'sludge + VFA' samples taken from Aeration tank almost at same days (after 20 days) and continued till 48 days, after which production was almost stabilized.

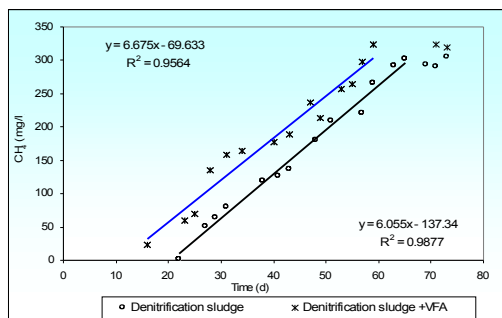


Figure 5: Effect of VFA on methane production from denitrification sludge at 20°C

Similarly the emission rate of CH_4 of the sludge sample taken from denitrification tank came to be 6.3 mg/L per day and ($R^2 = 0.98$, P-value = 0.0000126) whereas it came to be 6.6 mg/L per day when the sludge contains VFA ($R^2 = 0.95$, P-value = 0.00073). The methane production from the samples taken from Denitrification tank was found to be 65 mg per g dw for sludge alone while this value came to be 108 mg per g dw sludge for the sludge containing VFA. In this case the rate of production was found somewhat comparable in both cases but the amount of CH_4 production were found higher when there was nutrient in the sludge. Likewise, CH_4 production started from denitrification sludge and the combination of ‘denitrification sludge + VFA’ samples in different days i.e. CH_4 was emitted from the sludge sample after 20 days while emission took place after 14 days from the start of the experiment when there was VFA in the sludge. The emission of CH_4 continued up to 48 days and 63 days for “sludge sample” and “sludge + VFA sample” respectively.

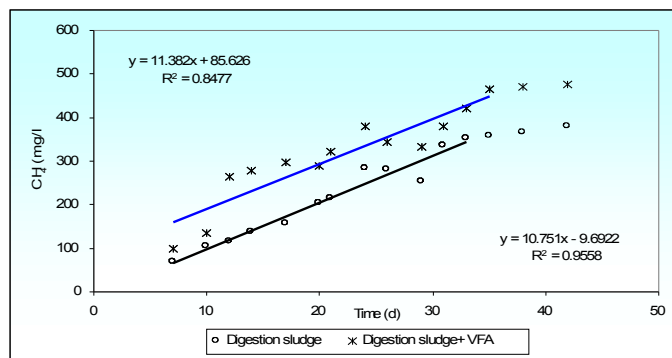


Figure 6: Effect of VFA on methane production from digestion sludge at 20°C

The emission rate of CH_4 of the sludge sample taken from digestion tank came to be 10.7 mg/L per day and ($R^2 = 0.95$, P-value = 0.0412) whereas it came to be 11.3 mg/L per day, when the sludge contains VFA ($R^2 = 0.84$, P-value = 0.001). The CH_4 production from the samples was found to be 13 mg per g dw for sludge alone while this value came to be 17 mg per g dw sludge for the sludge containing VFA. In this case the amount of CH_4 production was found low in both cases. In the same way, CH_4 production occurred from both the sludge and “sludge + VFA” samples of digestion tank after 7 days and continued up to 46 days. After 46 days the production became almost nil (zero).

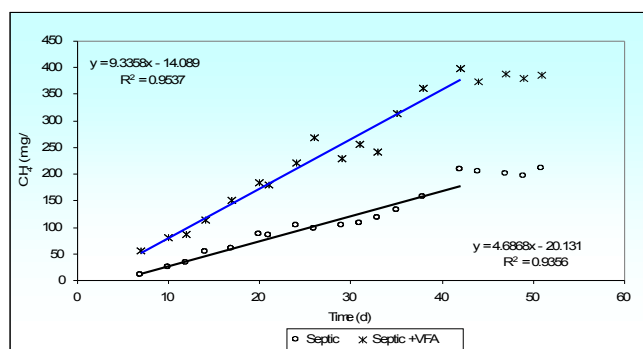


Figure 7: Effect of VFA on methane production from septic sludge at 20°C

Likewise, the emission rate of CH₄ of the sludge sample taken from septic tank came to be 4.7 mg/L per day ($R^2 = 0.93$, P-value = 0.640). This value came to be 9.3 mg/L per day when the sludge contains VFA ($R^2 = 0.95$, P-value = 0.360). The CH₄ production was found to be 4 mg per g dw for sludge alone while this value came to be 6 mg per g dw sludge for the sludge containing VFA. The rate of methane production was found higher when there was nutrient in the sludge. Similarly, CH₄ production had started from the sludge of the Septic tank with and without VFA almost at the same days (after 20 days) and continued up to 46 days. Emission of gases ceased after 46 days. Start of methane production was found fastest from the digestion sludge. Rate of production after the start of emission was found highest for digestion sludge and least for septic sludge. The rates of emission of CH₄ from different sludge and dry weight sludge at VFA combination are given in Table 2.

Table 2: GHGs emission and dry weight of different sludge sample points.

Activities	CH ₄ Emission (mg/L/d)	P- value	R ²	CH ₄ production from dry weight (mgCH ₄ /gdw sludge)
Aeration sludge	7.3	0.000192	0.97	76
Aeration sludge + VFA	11.0	0.000029	0.98	118
Denitrification sludge	6.0	0.0000126	0.98	65
Denitrification sludge + VFA	6.6	0.00073	0.95	108
Digestion sludge	10.7	0.640	0.96	12
Digestion sludge + VFA	11.3	0.001	0.89	17
Septic sludge	4.6	0.0412	0.93	4
Septic sludge + VFA	9.3	0.360	0.95	6

The optimum temperature, presence of acetic acid - hydrogen, and anaerobic conditions favour methanogenic process for methane production (Chen, et al, 2006). Aeration and denitrification sludge are exposed to atmospheric air during the wastewater treatment process. The concentrations of organic matter in the sludge are lower compared to digestion and septic sludge. Also, digestion and septic sludge have anaerobic condition favouring for more methane production. However, septic sludge sample was used with longer storage time. This may be the reason for less significant methane production rate.

Nitrification and denitrification are pH sensitive and their rates decline significantly at pH values below 6.8 and optimal in the range of 7.5-8.0 (Metcalf and Eddy et al., 2002). However, the general trend is that as the pH decrease, the rate of nitrification (Shammas, 1986). It shows that pH does not affect the nitrification and denitrification processes in this research. It can, therefore, be concluded that there is no effect of pH on N₂O production inside the reactors.

3.3 Effect of oxygen on GHGs emission from sludge

To examine the effect of oxygen on greenhouse gas emissions from the digestion sludge of the wastewater treatment plants, experiments were carried out under different levels of oxygen. Reactors were setup at 37 °C with 500 ml of digestion sludge.

The rate of CH₄ emission, P-value and R² from the digestion sludge thus obtained are given in Table 3. The amount of oxygen supplied to the sludge reactors, rate of CH₄ emission, P-value R²,

and dry weight are shown in Table 3. It shows that CH₄ production from dry weight digestion sludge was almost equal at different level of O₂ concentration.

Table 3: Emission rate of methane and dry weight of sludge under different levels of oxygen on the sludge at 37°C

Activities	Amount of oxygen (mg/L)	CH ₄ Emission (mg/L/d)	P -value	R2	CH ₄ production from dry weight (mg CH ₄ /gdw sludge)
Digestion sludge	0	20.8	0.00844	0.89	32
Digestion sludge	0.1	18.8	0.01978	0.96	28
Digestion sludge	0.4	18.2	0.01874	0.81	29
Digestion sludge	1.0	18.0	0.11994	0.81	26
Digestion sludge	2.0	17.8	0.05311	0.83	25

Fig. 8 shows the methane emission rate under different amounts (0, 0.1, 0.4, 1.0, and 2.0 mg/L) of oxygen supplied to the sample. It can be clearly seen from the figure that rate of methane emission decreases with increased amount of oxygen present in the sludge.

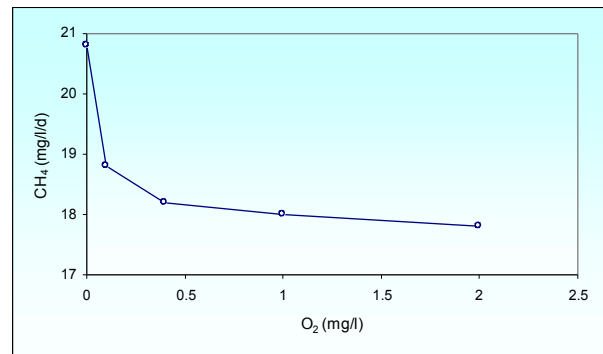


Figure 8: Methane production rate from different level of O₂ at 37°C

During the experiments, CH₄ emitted from the reactor could be measured. However, N₂O emission could not be detected. The measured CH₄ from each experiment was plotted to examine the trend of emission and rate of emission in each level of oxygen supplied (Fig. 8). It was found that the production of CH₄ started after 2 days and continued up to 25 days. These rates were 20.8, 18.8, 18.2, 18.0, and 17.8 mg/L per day respectively for the sludge samples with oxygen supply of 0, 0.1, 0.4, 1.0 and 2.0 mg/L. It shows that higher the presence of oxygen in the sludge, lower the methane production from the sludge. This hypothesis is also supported from the total amount of CH₄ produced from sludge samples. The total amounts of CH₄ produced were respectively 580, 571, 535, 495, and 505 mg /L from for 0, 0.1, 0.4, 1.0, and 2.0 mg/L of O₂ supplied. Moller et al. (2004) also found that the total amount of methane production was less for the case where oxygen supplied was more. In terms of dry weight, methane production was 32, 28, 29, 26, and 25 mg CH₄ per gram of dw of sludge.

This research and that if the oxygen level is low in the sludge, the production of CH₄ is high and vice versa. It is because of the fact that by lacking sufficient oxygen to consume the carbon content of the organic compound of the waste, anaerobes get rid of the excess carbon by

combining with hydrogen thus resulting into more CH₄. Wezernak et al. (1967) also pointed out that generation of methane takes place in the absence of oxygen, i.e., anaerobic decomposition of organic matter in the wastewater emits methane. Degradation of organic compounds to CO₂ by aerobic decomposition and to CH₄ and CO₂ through anaerobic degradation will lead to emissions of CH₄ and CO₂. Moller et al., (2004) also support the experimental results of this study. Therefore, it concludes that rate of methane production is significantly affected with oxygen level and the relation is inverse.

4. Conclusion

Methane production was enhanced when there was glucose or nutrients or VFA in the sludge. If the sludge contains both nutrients (NO₃⁻ and NH₄⁺) and VFA the rate of emission is further enhanced. Rate of methane production was more when the sludge temperature is high. It is due to fact that at higher temperature, microbial activities that affect methane emission increase. It is applicable for all sludge samples taken from different points of the treatment plant. The optimum temperature for methane production is higher than 37°C. An inverse relationship was found between the rate of emission of methane and the concentration of oxygen in the sludge. Further, the presence of oxygen decelerated the rate of methane production. Rate of production was found highest for digestion sludge.

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