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Enhancement of Solar Water Disinfection Using Nanocatalysts

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ABSTRACT

Solar water disinfection (SODIS) is a simple and low-cost method of increasing water quality. However, it takes about 6 hours of exposure to solar radiation. The elimination of harmful pathogenic germs from drinking water can be accelerated using a combination of sun disinfection and nanotechnology. In this study, a hybrid water purification technique using solar water disinfection, Titanium Oxide (TiO_2), and natural mineral clays was investigated. TiO_2, natural kaolin clay nanoparticles, and a mixture of TiO_2 and natural clay were added to contaminated wastewater containers at different concentrations. After that, the containers were exposed to sunlight for different time intervals. Samples were then collected from all tests to measure the total counts of Total Coliform and *Escherichia coli* (E. coli) using the IDEXX system. The results showed that the addition of TiO_2 and natural kaolin clay to wastewater with solar water disinfection reduced the total count of the pathogenic microorganisms and decreased the time needed time for the disinfection process compared to using solar energy alone. The results also showed that the optimum concentration of the TiO_2, which yielded the shortest purification time and lowest levels of pathogenic microorganisms, was 0.006 g/ml. In contrast, the most effective concentration of natural clay was 0.0015 g/ml. Moreover, the results showed that the optimum concentration of the mixture of TiO_2 and natural clay, which speeds up the purification time and lowest the level of pathogenic microorganisms was 0.006 g/ml for TiO_2 and 1.2 g/ml for the natural clay.

Keywords: solar water disinfection; nanotechnology; water treatment; solar energy.

INTRODUCTION

Contaminated water is a global issue, and the reasons for this pollution are mainly due to agricultural wastes, population growth, and discharge of the domestic and industrial revolution. There are various pollutant removal technologies: conventional methods, the established recovery process, and emerging removal methods. There are multiple drawbacks of these techniques, such as slow biological process, high capital cost, chemicals required, and formation of sludge.

Recently, solar water disinfection has gained popularity as a viable alternative to reach 98% of removal, according to some research. On the other hand, solar disinfection needs time to obtain clean water. One way to speed up the disinfection process is by using nanotechnology.

Several years ago, many experiments were undertaken on silver nanoparticles to use them in water disinfection, aiming to improve traditional water purification. Silver nanoparticles have antibacterial effect, e.g. eliminating E. coli, Pseudomonas aeruginosa, and Salmonella typhi, according to Agnihotri et al. (2013).

Koslowski et al. (2018) concluded that silver nanoparticles with 0.05% in the sample impregnated with polyamide-66 display an antibacterial reduction of 97.89% after 24 hours at a room temperature of 25 °C.

The first report on TiO_2 photocatalyst inactivation of microorganisms was published in 1985, and since then, a significant amount of work was conducted in this field (Keane et al., 2014; Kumar et al., 2014) highlighted that ZnO and TiO_2 are the most common nano-photocatalysts used for water disinfection. TiO_2 has stood out as the best photocatalyst for the degradation of organic chemicals by using the UV region. Its properties include recyclability, ease of preparation, tolerance to both alkaline and acidic solutions, radiation stability, as well as lack of a strong oxidizing agent requirement. Ge et al. (2016) indicated that light absorption can be improved by increasing the photoactivity of TiO_2, including increasing the surface area to volume ratio.

Lydakis-Simantiris et al. (2010) conducted a disinfection test on wastewater samples and evaluated the results in terms of fecal indicator bacteria (total coliforms and enterococci).

The experiment was carried out under several settings, including the type of photocatalyst used (rutile, anatase), photocatalyst concentration (0.5–1 g/l), period (up to 60 minutes), and pH sample (6–8). It was found that the TiO_2 powder with 75% anatase and 25% rutile is better than pure anatase or rutile.

Duarte and Amorim (2017) investigated the use of photocatalysis with TiO_2 in water purification and found that the antibiotic removal effectiveness was between 96 and 98 percent.

Hamdan and Darabee (2017) examined how TiO_2 and Al_2O_3 nanoparticles affected the disinfection process of contaminated water. They discovered that 0.06 percent Al_2O_3 was the best concentration for reducing total counts of Coliform and E. coli, whereas 0.06 percent TiO_2 was the best concentration for reducing total counts of E. coli. They also discovered that TiO_2 has a higher potential for accelerating the disinfection process.

Utami et al. (2019) clarified that the TiO_2 catalysts have immense potential in water purification from other nanoparticles due to mechanical strength properties and thermal stability.

Wang et al. (2018) discovered that TiO_2 increased the photocatalytic activity of nanocomposites, and ZnO/rectorite was responsible for both the photodegradation and adsorption processes. This combination should integrate with other techniques during water treatment, such as biological treatments, photocatalysis, and adsorption, to ensure water quality.

According to Liu et al. (2016), few-layered vertically aligned MoS_2 films may harvest up to half of the radiant solar energy, resulting in extremely significant water disinfection. The bandgap of MoS_2 was increased from 1.3 to 1.55 eV as a result of lowering the domain size. They were able to disinfect water with >99.999 percent bacterial inactivation in about 20 minutes using this method.

This study aimed to speed up solar water disinfection by using two types of nanoparticles were used, namely titanium dioxide and kaolin natural clay. The chemical analysis of this sample (sample 3) is presented by Ibrahim et al. (2016), each with various concentrations and different mixtures of these two catalysts were used in the disinfection process. This method is a low-cost and high-efficiency technology.

EXPERIMENTAL SET-UP

Before the beginning of the experiments, a 100-liter sample of contaminated water was obtained from the Al Zaytoonah University's (ZUJ) water treatment plant. The sample was taken before chlorination and after the filtration process to ensure no impurities and minimum turbidity levels in the contaminated water. The water was then analyzed to estimate the concentration of both Total Coliform and E. coli. presence using the IDEXX setup illustrated in Figure 1. The results returned positive with a value higher than 2419.6 per 100 ml on the IDEXX Quanti-Tray/2000 MPN (Most Probable Number) table. This figure number was later identified as "baseline", which is the highest value of contamination on that table. More details about using the IDEXX system in detecting water contamination are documented in many previous studies (Hamdan and Darabee, 2017; and Aboushi et al. 2021).

The samples were added to 500 ml of contaminated water in sterilized laboratory glass containers. Each container was placed on a digital scale to add the TiO_2 and kaolin natural clay. Table 1 summarizes the concentrations, experiment time, and mineral type of the samples. The samples were placed on beaker holders under direct sunlight for 2.5 and 3.5 hours as well. The holders were used to ensure that the containers were exposed to UV rays from all directions. A total of 84 samples were prepared during the summer season and the outdoor samples were exposed to sunlight between 11:00 AM and 02:30 PM at ambient

Figure 1. (a) The quanti-tray sealer, (b) UV lamp cabinet

Table 1. Nanoparticle type, its concentration, and experiment time

Nanoparticles	Exp. time	Concentration (g/ml) × 10^{-3}				
Titanium Oxide (TiO_2)	2.5 hours	0	4	6	8	
	3.5 hours					
Natural kaolin clay	2.5 hours	0	0.8	1.2	1.6	2
	3.5 hours					

temperatures between 30 °C and 37 °C. Finally, it is to be noted that to ensure repeatability of the obtained data, each measurement was repeated three times and an average value was recorded.

RESULTS AND DISCUSSION

Having accomplished the experimental work, all samples were returned to the lab and tested for the presence of both Total Coliform and E. coli by adding particular agents to the water. The samples were then placed in an incubator at 35 degrees Celsius for 16 to 24 hours to allow any microbial pathogens that had survived the disinfection process to regenerate to a measurable level in the water. The samples were examined under UV light and the results were recorded on IDEXX Quanti-Tray/2000 MPN tables by the laboratory operator. The results were separated into three categories based on the nanoparticle type.

Titanium oxide nanoparticles

Figures 1 and 2 show the MPN for total coliform and E.coli for each sample, respectively. Due to the influence of UV radiation, the overall count of coliform decreases with exposure time, as stated and for all containers. As shown in these figures, the total count in the four containers is virtually comparable at first, but the total count in the container decreases more rapidly, as the exposure period increases. This clearly demonstrated the beneficial effects of UV radiation redirection and adding the TiO_2 nanoparticles on the disinfection process.

Then, in comparison to the control sample and the other concentrations, it is obvious that adding 0.006 g for each 1 ml reveals a pronounced effect on the MPN reduction of total coliform and E. coli. Furthermore, after three hours and a half, it was found that these MPN for all samples were reduced below 1 /100 ml.

The optimum concentration for TiO_2 was 0.006 g/ml, this result is similar to (Hamdan and Darabee, 2017); the optimum concentration (0.006) was obtained using 6 g of TiO_2 in 1000 ml disinfection of contaminated water.

Natural mineral clay

Figures 4 and 5 show the MPN for both total coliform and E. coli of each sample, respectively.

The total count of coliforms declines with time, as reported, and for all containers, as expected. due to the influence of UV rays, as indicated in Figures 3 and 4, the total count in the six containers is nearly identical at first, but as the exposure period is increased, the total count in the container declines more rapidly. This clearly demonstrated

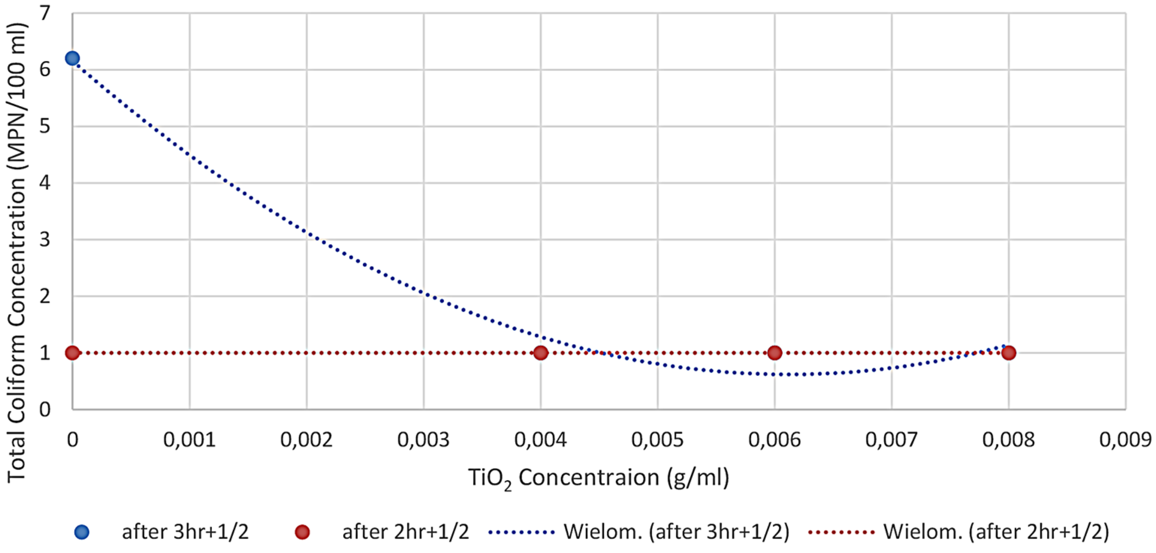

Figure 2. Total coliform with TiO_2 nanoparticles

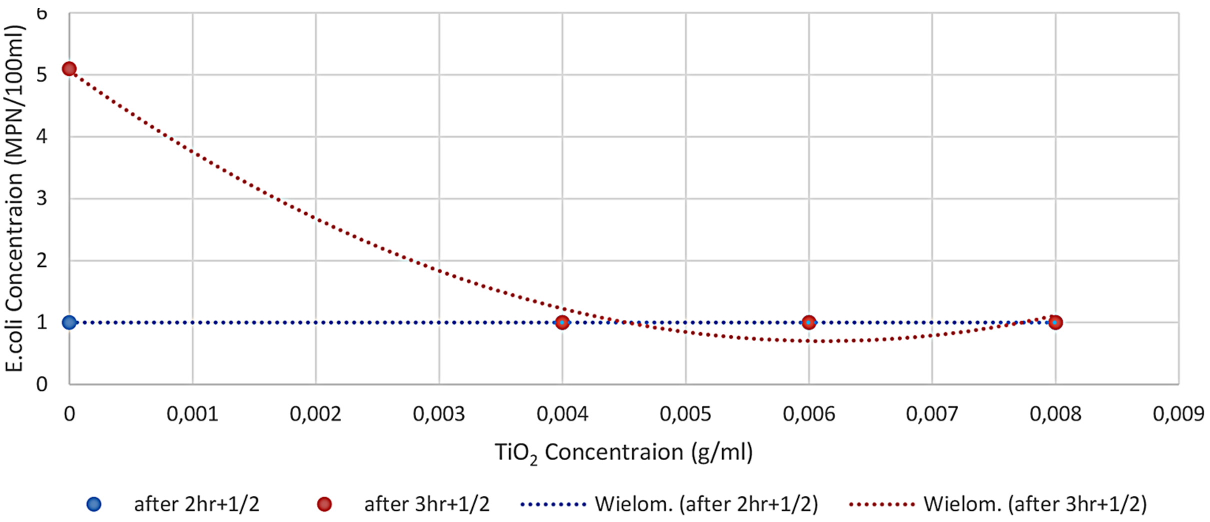

Figure 3. E.coli with TiO_2 nanoparticles

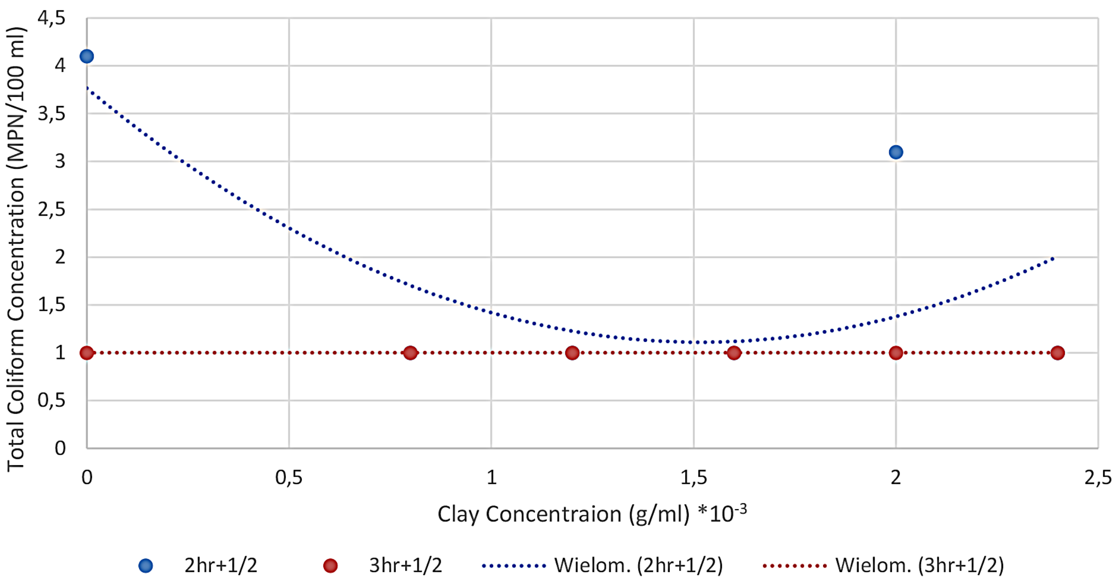

Figure 4. Total coliform with natural clay nanoparticles

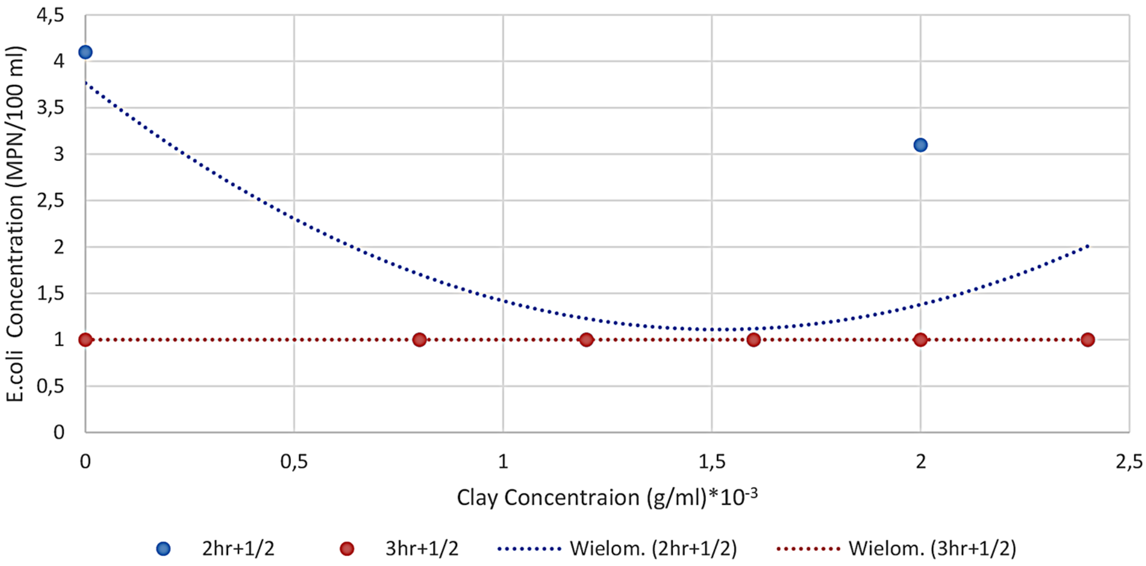

Figure 5. E. coli With Natural clay Nanoparticles

the beneficial effects of UV radiation redirection and the addition of natural clay nanoparticles to the disinfection process. Then, it is clearly noted that adding 0.0015 g for each 1 ml is more pronounced in MPN reduction in the amounts of total coliform and E.coli in comparison to both the control sample and the other concentration. The MPN for total coliform and E.coli concentration for all the samples after 3.5 hours is less than 1 MPN/100 ml.

Mixture of the nanoparticles

In this section, a mixture of TiO_2 and natural clay are discussed. Table 2 shows the sample

Table 2. Mixture concentration

Sample number	TiO_2 concentration (g/ml)*10^{-3}	Natural clay concentration (g/ml) *10^{-3}
1	0	0
2	0	1.5
3	1.2	1.12
4	2.4	0.84
5	3	0.7
6	3.6	0.56
7	4.8	0.28
8	6	0

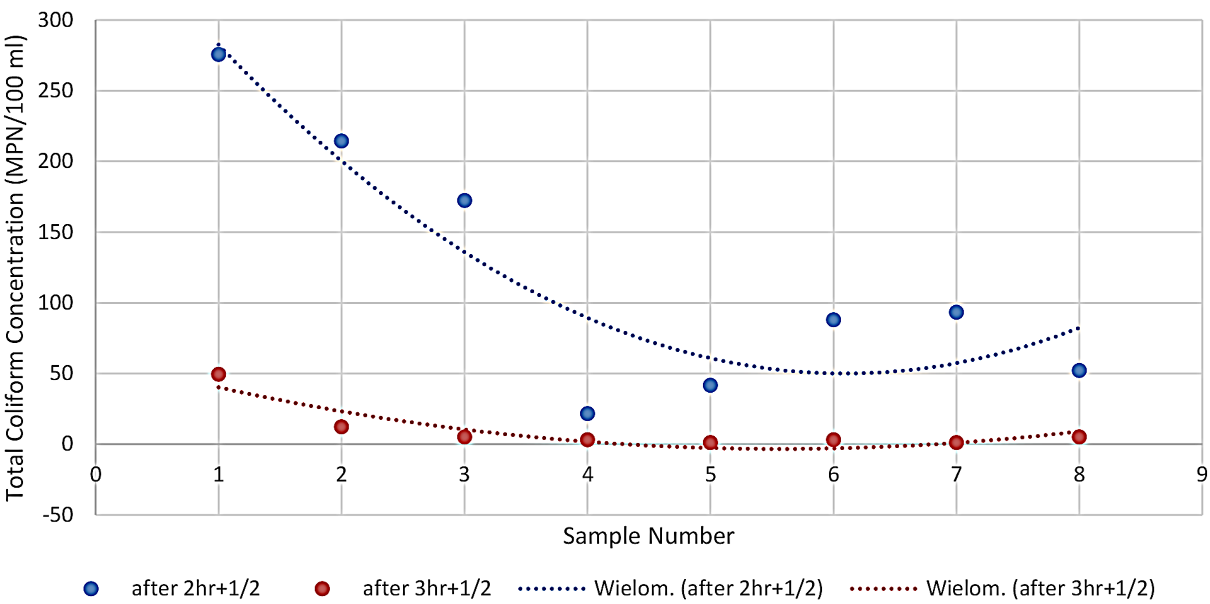

Figure 6. Total coliform with the mixture of nanoparticles

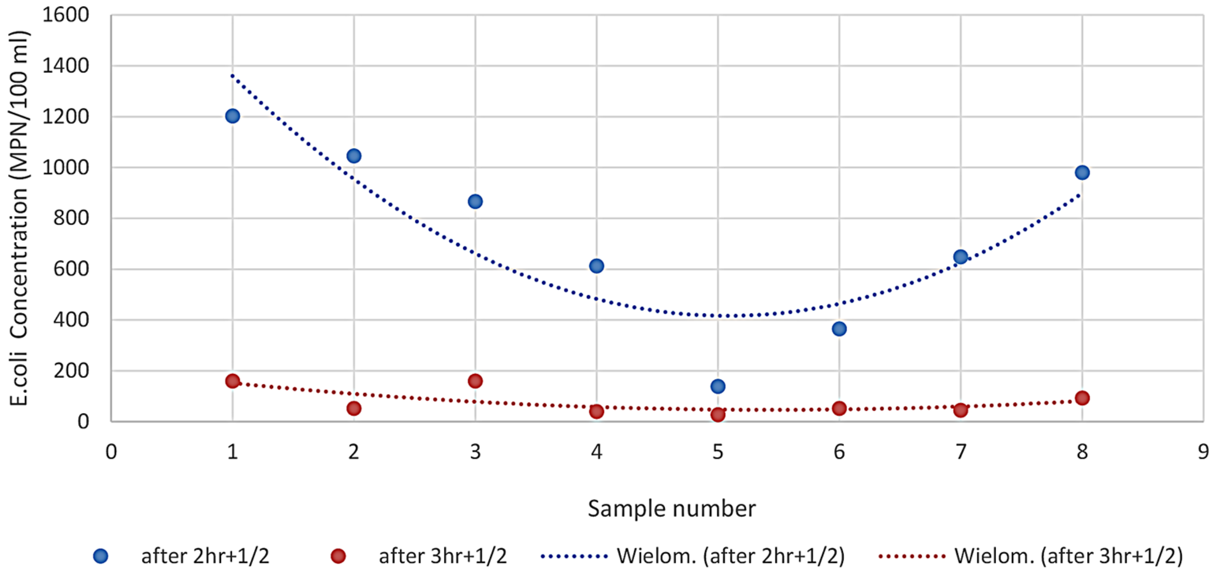

Figure 7. E. coli with the mixture of nanoparticles

number and the concentration of TiO_2 and natural clay in each sample.

Figures 6 and 7 show the MPN for the total coliform and E.coli of each sample, respectively. It may be noted that adding 0.003 g from TiO_2 and 0.007 g from the natural clay for each 1 ml and in comparison to the control sample and other concentrations, is more pronounced in reducing MPN for the E. coli concentration. Moreover, adding 0.0036 g from TiO_2 and 0.0056 g from the natural clay for each 1 ml is more significant in MPN reduction of the total coliform concentration as compared to both the control sample and the other concentration. The MPN for total coliform and E. coli concentration for all the samples after 3.5 hours is less than 1 MPN/100 ml.

CONCLUSIONS

Solar water disinfection can be sped up by using nanocatalysts. TiO_2 and natural clay were used in water disinfection with exposure to solar radiation. This study represented the optimum concentration of TiO_2, the optimum mass concentration of natural clay, and the mixture of both. This disinfection process is a low-cost technique and highly efficient compared with the conventional treatment process.

TiO_2 was tested with different concentrations added to the contaminated water. The results clarified that 0.006 g/ml of TiO_2 meets the healthy drinking water standards after two hours, the concentrations of Total coliform and *E.coil* are less than 1MPN/100 ml, and this sample is the fastest. By testing different natural clay mass concentrations, 0.0015 g/ml is the most effective concentration to obtain the minimum concentration of Total coliform and E. coli after 2 hours and a half.

Water disinfection has been proven to be efficient using a combination of natural clay and TiO_2 nanoparticles. The most effective mixture for the lowest E. coli concentration was 0.007 g/ml of natural clay and 0.003 of TiO_2, whereas the lowest total coliform concentration was 0.0036 g/ml of TiO_2 and 0.00056 g/ml of natural clay.

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