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Using Some Mineral Salts (NaCl, KCl and $CaCl_2$) as Chemical Inhibitors of Steel Corrosion at Presence Different Concentrations of Salts (Calcium Carbonate C.C, Sodium Nitrate S.N, and Potassium Phosphate P.P)

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Abstract
This study investigates the corrosion behavior of carbon steel (Calcium Carbonate C.C, Sodium Nitrate S.N, and potassium phosphate P.P) under different inhibitor concentrations (1%, 3%, and 5%) of some metal chloride salts (Sodium chloride (NaCl), Calcium chloride ($CaCl_2$), Potassium chloride (KCl), and immersion periods (7, 14, and 28 days) using the weight loss method in accordance with ASTM G31. Natural plant extracts (pomegranate, seaweed, and potato peel) were evaluated as green corrosion inhibitors in chloride-containing environments. The corrosion rate (mm/year) was calculated based on mass loss, surface area, density, and exposure time. The results showed that corrosion rate is strongly influenced by inhibitor concentration, immersion time, and specimen diameter. In general, increasing inhibitor concentration from 1% to 3% significantly reduced corrosion rates due to improved adsorption of inhibitor molecules and formation of a protective surface film. However, at 5% concentration, some samples exhibited increased corrosion rates, suggesting possible instability or desorption of the protective layer at higher concentrations. Among the tested alloys, P.P and S.N generally showed better corrosion resistance than C.C, which recorded the highest corrosion rates under most conditions. Starch-based (or plant) extracts demonstrated the highest inhibition efficiency overall, followed by pomegranate extract, while seaweed extract showed moderate performance depending on concentration and exposure time. In several cases, zero corrosion rates or weight gain were observed, indicating the formation of stable passive films on the metal surface. Overall, the study concludes that an optimum inhibitor concentration exists, with 3% providing the best corrosion protection in most cases. The corrosion inhibition mechanism is mainly attributed to adsorption of phytochemical compounds containing heteroatoms and π-electrons, which form a protective barrier that reduces both anodic and cathodic reactions.

Keywords: Rate of Corrosion, Carbon Steel, Green Corrosion Inhibitors

Introduction

Chemical Inhibition in Corrosion of Construction Steel. Steel is among the most utilized metals in construction because of its strength, resilience, and affordable price. Unfortunately, this metal is vulnerable to corrosion in extreme conditions, including marine atmospheres, highly polluted regions, and water bodies. The electrochemical reaction responsible for corroding construction steel causes damage and may lead to failures in engineering systems (Revie & Uhlig, 2008) [6]. To prevent these negative consequences, chemical inhibitors can be used to inhibit metal oxidation and preserve the material. These compounds are chemicals added to metals in minimal quantities that significantly decrease the speed of metal dissolution by interfering with either anodic or cathodic electrochemical reactions or both processes simultaneously (Jones, 1996) [3]. Some examples of chemical inhibitors are phosphates, nitrites, and carbonates. These inorganic inhibitors are applied in many construction-related engineering systems, such as reinforced concrete structures, cooling water circuits, and pipes. Potassium phosphate (K_3PO_4) works mainly as an anodic inhibitor for steel. The potassium phosphate inhibits the formation of a protective film of phosphates on the surface of the steel, made up mostly of iron phosphates. Such a passive film inhibits the corrosion reaction by reducing iron dissolution, thus enhancing its corrosion resistance capacity, especially under conditions of alkalinity in concrete construction (Roberge, 2008) [7]. Another feature of phosphate inhibitors is that they are environmentally friendly compared to some organic inhibitors. Sodium nitrite ($NaNO_2$) is considered one of the best inhibitors used in reinforcing steel bars in concrete constructions. Sodium nitrite oxidizes ferrous ions (Fe^{2+}) to form ferric ions (Fe^{3+}). Thus, it helps to form an oxide film (γ-Fe_2O_3) passively attached to the steel. Such an oxide film prevents the steel from corrosion due to chlorides, which are the leading factor of degradation in reinforced concrete constructions exposed to deicing salts or marine environments (Berke & Hicks, 2004) [2]. The effectiveness of such a corrosion inhibitor strongly depends on the inhibitor-to-chloride ratio. Calcium carbonate ($CaCO_3$) provides corrosion resistance to construction steel in an indirect manner via the formation of scale. When it forms on the steel structure, in water or concrete structures, it acts as a protective layer by forming a dense film that serves as a physical barrier to moisture, oxygen, and harmful ions such as chlorides and sulfates. It also maintains the alkaline nature of the environment, which is necessary for ensuring the passivity of steel in concrete structures (Stumm & Morgan, 1996) [8]. When applied together, these types of inhibitors create a synergy effect by enhancing electrochemical protection (through nitrate and phosphate ions) using physical and pH control provided by calcium carbonate. This study aims to using some chemical and green corrosion Inhibition.

Materials and Methodology

Materials and Equipment's

Carbon steel with diameter (4, 14 and 16) in millimeter, Pomegranates, sea weeds potatoes peel extract (dried, grinded and extracted with distilled water), Sodium chloride (NaCl), Calcium chloride ($CaCl_2$), Potassium chloride (KCl), distilled water, Analytical balance, Beakers or Test containers for Corrosion (250ml) pH meter, Desiccator, incubator (Oven), Digital caliper/ Micrometer (weight loss measurement), Protective gloves & lab coat. Fig 1 shows the chemical inhibitors.

Fig 1: Types of chemical inhibitors

And the corrosion rates and inhibition efficiencies were measured using the Weight Loss Method of ASTMG31 by the following equation:

$$CPR = (\Delta W / (\rho \times A)) \times (365 / t).$$

ΔW – change in weight (or mass) over the period of measurement

ρ (rho) – density of the material

A – area over which the change is measured

t – time interval (in days)

365 / t – animalization factor (scales the result to a per-year rate)

So, conceptually, CPR is an annualized rate of change in thickness, gain or loss, or material change, based on a measured change in weight, normalized over density and area where the length is 5cm and density is 7.85g/cm^3.
CPR ends up as something like mm/year.

Results and Discussion

The affection of inhibitors in 7days immersion of different concentrations show below, Table 1, where C.C decreases as the diameter increases from0.87 to 0.27 to 0.09S.N remains 0 at 4mm and 14mm, while it reaches its peak value at 12mm.P.P remains relatively low and more stable than C.C, Fig 2.

Table 1: The annual corrosion rate in 7 days immersion of 1% of (Calcium Carbonate C.C, Sodium Nitrate S.N, and potassium phosphate P.P) concentration

Diameter(mm)	C.C(mm/year)	S.N(mm/year)	P.P(mm/year)
4	0.87	0	0.09
12	0.27	0.27	0.19
14	0.09	0	0.17

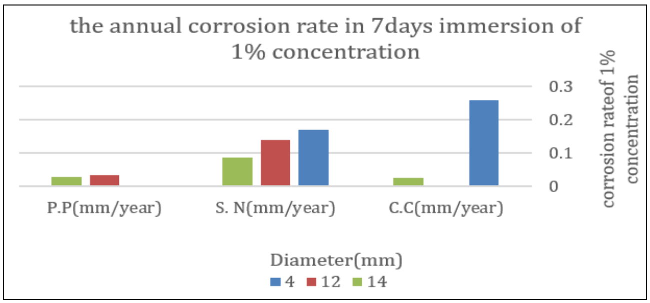

Fig 2: The annual corrosion rate in 7 days immersion of 1% Concentration (Calcium Carbonate C.C, Sodium Nitrate S.N, and potassium phosphate P.P)

Corrosion rate tended to decrease with the increase in diameter. In the case of C.C medium, the highest corrosion rate was found to be 0.26 mm/year at 4 mm, while no corrosion occurred at 12 mm. For the S.N medium, corrosion rates were found to decrease from 0.17 mm/year at 4 mm to 0.087 mm/year at 14 mm.For P.P medium, the specimen having a diameter of 4 mm gained weight, possibly due to the protective effect of corrosion products on the metal's surface. Corrosion rates for 12 mm and 14 mm diameters were small (0.035 and 0.029 mm/year respectively), which indicated that P.P was the least corrosive medium, Table 2 and Fig 3.

Table 2: The annual corrosion rate in 7 days immersion of 3% concentration Calcium Carbonate C.C, Sodium Nitrate S.N, and potassium phosphate P.P)

Diameter(mm)	C.C(mm/year)	S.N(mm/year)	P.P(mm/year)
4	0.26	0.17	Increase in weight
12	0	0.14	0.035
14	0.025	0.087	0.029

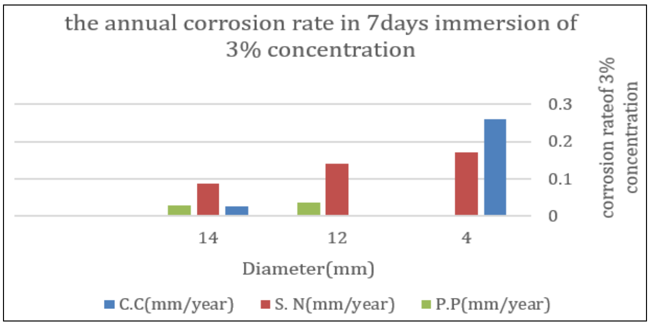

Fig 3: The annual corrosion rate in 7 days immersion of 3% Calcium Carbonate C.C, Sodium Nitrate S.N, and potassium phosphate P.P) concentration

The corrosion rate was calculated using the weight loss method according to ASTM standards. The obtained values ranged from 0.000 to 7.205 mm/year after 7 days of immersion at 5% concentration. The lowest corrosion rate was observed for the S.N sample at 4 mm diameter, indicating improved corrosion resistance compared to the other, Table 3 and Fig 4.

Table 3: The annual corrosion rate in 7 days immersion of 5% concentration (Calcium Carbonate C.C, Sodium Nitrate S.N, and potassium phosphate P.P)

Diameter(mm)	C.C(mm/year)	S.N(mm/year)	P.P(mm/year)
4	0.102	0	1.12
12	7.205	0.315	0.315
14	1.72	0.556	0.371

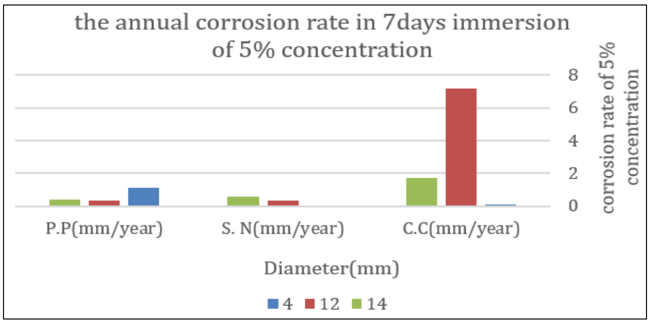

Fig 4: The annual corrosion rate in 7 days immersion of 5% concentration (Calcium Carbonate C.C, Sodium Nitrate S.N, and potassium phosphate P.P)

The rate of corrosion depended on the diameter of the sample and the medium used. The maximum rate of corrosion occurred in the C.C medium at 4mm (1.01 mm/year). The rate of corrosion in the S.N medium was negligible, showing that there was low corrosion effect. There was no corrosion in the P.P medium at 12mm, but it occurred at 14mm (0.265mm/year). Table and Fig 5.

Table 4: The annual corrosion rate in 14 days immersion of 1% concentration (Calcium Carbonate C.C, Sodium Nitrate S.N, and potassium phosphate P.P)

Diameter(mm)	C.C(mm/year)	S.N(mm/year)	P.P(mm/year)
4	1.01	0.000	0.05
12	0.11	0.110	0
14	0.371	0	0.265

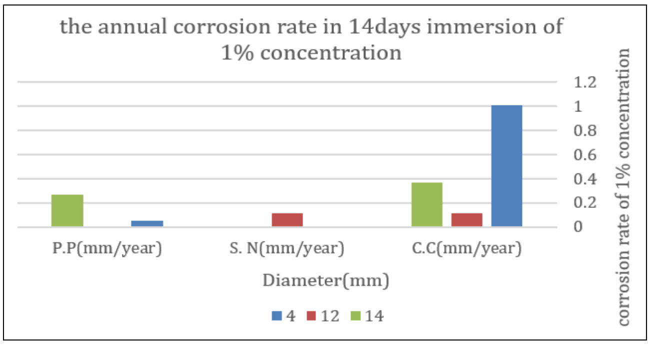

Fig 5: The annual corrosion rate in 14 days immersion of 1% concentration (Calcium Carbonate C.C, Sodium Nitrate S.N, and potassium phosphate P.P)

Corrosion rates generally decreased with increasing diameter in all media. The highest corrosion rate was observed in the S.N medium at 4 mm (0.102 mm/year). No corrosion was recorded in the P.P medium at 4 mm and 14 mm. Overall, the specimens showed better corrosion resistance at larger diameters. Table 5 and Fig 6.

Table 5: The annual corrosion rate in 14 days immersion of 3% concentration (Calcium Carbonate C.C, Sodium Nitrate S.N, and potassium phosphate P.P)

Diameter(mm)	C.C(mm/year)	S.N(mm/year)	P.P(mm/year)
4	0.051	0.102	0
12	0.047	0.063	0.016
14	0.027	0	0

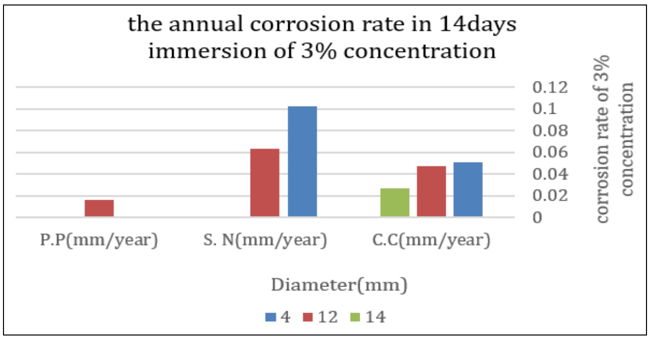

Fig 6: The annual corrosion rate in 14 days immersion of 3% concentration of (Calcium Carbonate C.C, Sodium Nitrate S.N, and potassium phosphate P.P)

The corrosion properties showed variations with diameter and corrosive medium. The highest rate of corrosion was found to be that in the P.P medium at a 4mm diameter (0.55 mm/year). Corrosion was found to increase with diameter in the S.N medium, with 0.239 mm/year at 14 mm. No corrosion was noticed in the P.P medium for 12 mm and 14 mm diameter. Table 6 and Fig 7.

Table 6: The annual corrosion rate in 14 days immersion of 5% concentration of (Calcium Carbonate C.C, Sodium Nitrate S.N, and potassium phosphate P.P)

Diameter(mm)	C.C(mm/year)	S.N(mm/year)	P.P(mm/year)
4	0.051	0	0.55
12	0.063	0.157	0
14	0.08	0.239	0

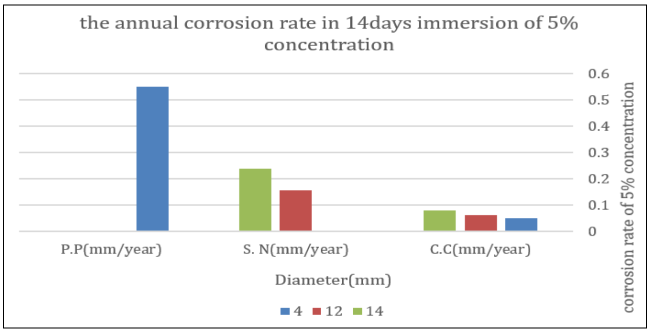

Fig 7: The annual corrosion rate in 14 days immersion of 5% concentration of (Calcium Carbonate C.C, Sodium Nitrate S.N, and potassium phosphate P.P)

Corrosion rates measured at 1% concentration after 28 days were higher compared to those at 3% and 5% concentrations. This suggests that an increase in the concentration of inhibitors increases protection against corrosion. The corrosion rate was between 0.000 and 0.635 mm/year, with C.C being more prone to corrosion. Table 7 and Fig 8.

Table 7: The annual corrosion rate in 28 days immersion of 1% concentration of (Calcium Carbonate C.C, Sodium Nitrate S.N, and potassium phosphate P.P)

Diameter(mm)	C.C(mm/year)	S.N(mm/year)	P.P(mm/year)
4	0.635	0.076	0
12	0.330	0.236	0.03
14	0.477	0.040	0.09

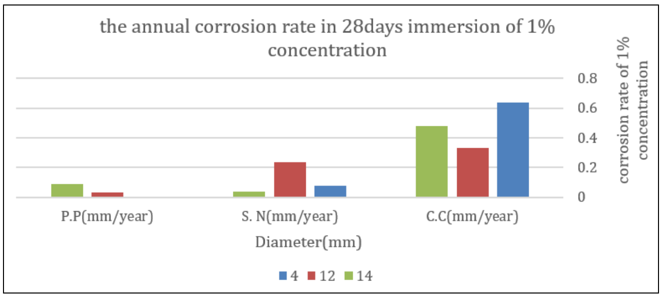

Fig 8: The annual corrosion rate in 28 days immersion of 1% concentration of (Calcium Carbonate C.C, Sodium Nitrate S.N, and potassium phosphate P.P)

Corrosion rate measurements for 28 days with a concentration of 3% indicated that these rates were still quite low, proving the efficiency of the inhibitors when tested over long exposure periods. Their results were between 0.000 mm/year and 0.283 mm/year. As the concentration of the inhibitor increased, the corrosion resistance was enhanced. Table 8 and Fig 9.

Table 8: The annual corrosion rate in 28 days immersion of 1% concentration of (Calcium Carbonate C.C, Sodium Nitrate S.N, and potassium phosphate P.P)

Diameter(mm)	C.C(mm/year)	S.N(mm/year)	P.P(mm/year)
4	0.076	0	0.051
12	0.283	0.26	0.016
14	0.199	0.04	0.027

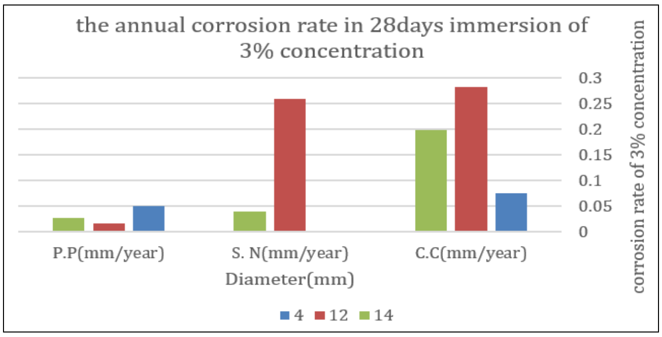

Fig 9: The annual corrosion rate in 28 days immersion of 1% concentration of (Calcium Carbonate C.C, Sodium Nitrate S.N, and potassium phosphate P.P)

Corrosion rates of both alloys at 5% concentration after 28 days were fairly low and varied between 0.000-0.228 mm/yr. This shows that the inhibitors' inhibiting efficiency was retained despite being kept for a long time in solution. It was found that P.P and S.N samples were the least corroded at various diameters. Table 9 and Fig 10 of Calcium Carbonate C.C, Sodium Nitrate S.N, and potassium phosphate P.P).

Table 9: The annual corrosion rate in 28 days immersion of 5% concentration of (Calcium Carbonate C.C, Sodium Nitrate S.N, and potassium phosphate P.P)

Diameter(mm)	C.C(mm/year)	S.N(mm/year)	P.P(mm/year)
4	0.102	0	0.288
12	0.094	0.134	0
14	0.106	0.159	0.053

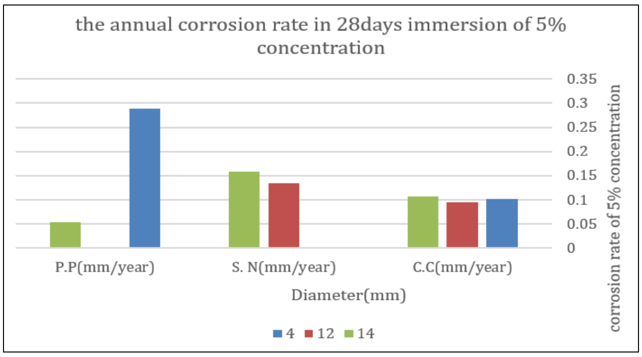

Fig 10: The annual corrosion rate in 28 days immersion of 5% concentration of (Calcium Carbonate C.C, Sodium Nitrate S.N, and potassium phosphate P.P)

Discussion

From the findings of the corrosion rates determined by the immersion test, it is evident that the concentration of the inhibitor, the duration of immersion, and specimen diameters were factors that significantly affected the corrosion performance of the alloys under study (C.C, S.N, and P.P). In general, an increase in the concentration of the inhibitor, from 1%, 3%, and 5%, generally decreased the corrosion rates of the majority of specimens tested. The corrosion rates at 1% concentration were found relatively high as compared to those at 3% concentration after 7 days of immersion. For instance, the corrosion rate of C.C alloy having a diameter of 4 mm was observed to be 0.87 mm/year at 1% concentration; however, it reduced to 0.26 mm/year at 3% concentration. The same was noted for S.N and P.P alloys. It is expected that such inhibition is due to increased inhibitor molecule adsorption onto the surface of metals, which acted as a protective shield between the metal surface and corrosive medium Previously, it has been reported that an increase in inhibitor concentration increases corrosion protection efficiency due to improved surface coverage with inhibitors (Natarajan & Al Shibli, 2021) [5]. Furthermore, the results revealed that some samples had zero corrosion rates or weight gains, particularly at 3% concentration levels. This could mean that a stable passive film or inhibition compound was deposited on the surface of the alloy. This observation is evident when considering the weight gain observed for the P.P sample at 4 mm diameter after 7 days. Similar trends in the formation of a passive film on aluminum alloy were documented by Méndez *et al.* (2023) [4].

On the other hand, some samples demonstrated higher corrosion rates compared to others at 5% concentration after 7 days of immersion. For instance, C.C alloy samples at 12 mm and 14 mm diameter had higher corrosion rates of 7.205 mm/year and 1.72 mm/year, respectively. This could imply that the inhibitor concentration might have caused the adsorbed layer to become unstable. This observation is consistent with past literature that indicates the presence of very high concentrations of inhibitors reduces inhibition efficiency as a result of desorption reactions or non-uniformity of the protective film (Metals, 2017).

During the 14-day immersion, the corrosion rate was lower in 3% concentration than in 1% concentration, indicating that moderate concentrations of inhibitor gave maximum stability during the corrosion process. The lowest corrosion was recorded by P.P and S.N alloys, with some specimens having zero corrosion rate. These results suggest that some of the alloys had better corrosion resistance capability than C.C alloy. The reason behind the better performance of some alloys could be attributed to variations in their compositions and their ability to create stable oxide films (Study on Thymus algeriensis, 2016) [10].

As seen in 28 days immersion test, the inhibitors continued to perform efficiently throughout the entire immersion period. At 1% concentration, the corrosion rate was between 0.000 and 0.635 mm/year, whereas at 3% and 5% concentrations, corrosion rates were relatively low. The low corrosion rates indicate that the inhibitors maintained themselves through adsorption on the metals' surfaces. Therefore, the inhibitors continued to lower the corrosion process even after the long periods of immersion. Similar inhibition characteristics have been documented for the corrosion inhibitors in aluminum alloys in acidic and alkaline media (Ajuga orientalis, 2024) [1]. The P.P and S.N samples demonstrated relatively low rates of corrosion compared to other materials under various conditions. In general, the C.C alloy experienced high corrosion rates at low concentrations of inhibitors. This phenomenon can be caused by metallurgy and microstructure differences between samples and their chemical reactions with the environment (Xhanari *et al.*, 2017) [10]. Fig 11.

Fig 11: Differences between samples and their chemical reactions

On the whole, the study reveals that there is an optimal inhibitor concentration, which ensures maximum corrosion resistance; however, the highest rate of effectiveness occurs with 3%. The main mechanism of action for the compounds includes their adsorption on the alloy surface and the formation of a barrier layer preventing further metal dissolution. The obtained data are consistent with previously conducted corrosion investigations showing higher efficiency of corrosion inhibition when using higher concentrations of inhibitors and prolonged immersion times (Natarajan & Al Shibli, 2021; Méndez *et al.*, 2023) [5, 4].

Conclusion

The corrosion rate (mm/year) was calculated based on mass loss, surface area, density, and exposure time.The results showed that corrosion rate is strongly influenced by inhibitor concentration, immersion time, and specimen diameter. In general, increasing inhibitor concentration from 1% to 3% significantly reduced corrosion rates due to improved adsorption of inhibitor molecules and formation of a protective surface film. However, at 5% concentration, some samples exhibited increased corrosion rates, suggesting possible instability or desorption of the protective layer at higher concentrations.

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