Test of precoat filtration technology for treatment of swimming pool water

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ABSTRACT

The technical performance of a precoat filter was compared with that of a traditional sand filter. Particle concentration and size distribution were measured before and after the filtration of swimming pool water. Both the sand and precoat filters could reduce the particle concentration in the effluent. However, higher particle removal efficiency was generally observed for the precoat filter, especially for particles smaller than 10 μm in diameter. Adding flocculant improved the removal efficiency of the sand filter, resulting in removal efficiencies comparable to those of the precoat filter. Three powders, i.e., two types of perlite (Harbolite® and Aquatec perlite) and cellulose fibers (Arbocel®), were tested for the precoat filter, but no significant difference in particle removal efficiency was observed among them. The maximum efficiency was reached within 30–40 min of filtration. The energy required for the pumps increased by approximately 35% over a period of 14 days. The energy consumption could be reduced by replacing the powder on the filter cloth. The sand filter was backwashed once a week, while the powder on the precoat filter was replaced every two weeks. Under these conditions, it was possible to reduce the water used for cleaning by 88% if the precoat filter was used instead of the sand filter.

Key words | filter aids, filtration, sand filter, swimming pool

INTRODUCTION

Public swimming pools, popular destinations for sport and leisure activities, are found worldwide. To ensure swimmer health, it is important to maintain high-quality clear and clean swimming pool water by treating it to remove harmful substances. The bathers introduce skin, sweat, urine, faecal matter, pathogens and care products into the water (Lakind et al. 2010). The supply of pollutants from bathers has been divided into three categories: initial, continuous and incidental anthropogenic pollutants (Keuten et al. 2014). The initial anthropogenic pollutants can be reduced by pre-swim showering whereas the continuous anthropogenic pollutants cannot be avoided (Keuten et al. 2012, 2014). Methods are therefore required to disinfect and clean swimming pool water. In Denmark, swimming pool water is usually treated using a combination of sand filtration, activated carbon filtration, and chlorination. Sand filters are used to remove suspended particles. The water is often flocculated to improve the removal efficiency during sand filtration (Croll et al. 2007). Sand filter operation, however, takes up considerable space and may be resource intensive in terms of energy and water consumption. Alternative technologies to sand filtration may therefore be economically attractive if similar or better removal efficiencies can be achieved. Various alternatives already exist, including membrane filtration, drum filtration, and precoat filtration technologies. Membrane filtration has previously been used to treat swimming pool water, for example, ceramic microfiltration (Skibinski et al. 2016) and ultrafiltration (Glauner et al. 2005; Barbot & Moulin 2008; Klüpfel et al. 2011). Precoat filtration is another alternative in which filters are coated with a filter aid (Heertjes & Zuivedveld 1978; Bennett 2000). Precoat filtration is used, for example, in wine-making (Boittelle et al. 2008) and protein recovery (Wang et al. 2006), but is also used for treating swimming pool water. However, the efficiency of precoat filtration is poorly documented for swimming pool water.
water. Perlite has been used as a filter aid for precoat filters, and it has been demonstrated that adding perlite improves the performance, for example, of a sand filter (Amburgey 2011).

This study tests the technical performance of a precoat filter and three different filter aids: two different perlites and cellulose fibers. The test data are compared with data obtained from a conventional sand filter. For sand filtration, the swimming pool water was tested both with and without flocculant. The removal of particles larger than 3 μm was monitored during filtration. Both laboratory- and full-scale filters were tested.

**METHODS**

**Swimming pools**

Water from two Danish public swimming pools was analysed. Precoat filtration experiments were conducted using swimming pool water from the Haraldslund public swimming pool. The water was pumped directly from the overflow outlet of the pool and filtered using a laboratory filtration setup designed for testing different types of filter aid powder. The pool was 14 m long, 6.8 m wide and contained 114 m$^3$ of water. The equalization tank contained 17 m$^3$ of water and 250 m$^3$ of water was cleaned every hour i.e. the theoretical hydraulic retention time was 31 min. Approximately 15 m$^3$ of tap water was added to the pool every week. The temperature of the water in the pool was 34 °C. During the 5 hour experiment, three groups of approximately 15–20 swimmers were active in the pool. Each group spent between 1 and 1.5 hours in the pool.

Full-scale experiments were conducted in the Varde public swimming pool, which has two pools: 1) a 25 m long and 15.5 m wide pool with a water volume of 935 m$^3$, and 2) a 14.5 m long and 8.5 m wide wave pool with a total volume of 80 m$^3$. The water flow was 82 m$^3$ h$^{-1}$. The number of swimmers visiting the pool was approximately 110 in the morning and 120 in the afternoon. The filtration experiments were only done using water from the wave pool. The temperature of the water in the pool was 31.8 °C, the chlorine level was kept at 1.2 ppm, and the pH was 7.2. The amount of water added to the pool was 130–150 m$^3$ per month, of which a third was used in the wave pool. The water treatment system consisted of an equalization tank, a sand filter and a precoat filter in parallel, two activated carbon filters, and chlorination equipment. The diameter of the sand filter column was 2.71 m and the cross-sectional area was 5.8 m$^2$. The depth of the sand filter was 1 m. The sand filter consisted of 2 tonnes of sand with grit size 1.8–3.5 mm, 2.8 tonnes of sand with grit size 0.8–1.5 mm, and 6.6 tonnes of sand with grit size 0.4–0.8 mm. Flocculant (polyaluminium chloride) was added if the number of swimmers was unusually high; this happened approximately five times per year. The sand filter was backwashed every week and at peak times twice per week (peak times approximately five times per year). The flow during backwash was 210 m$^3$ h$^{-1}$ for 3–3.5 min i.e. the backflush rate was 36.4 m$^3$ h$^{-1}$ m$^{-2}$. Under normal operation, the precoat filter was used for 14 days before the powder was replaced. Two activated carbon filters were installed and loaded with Aquasorb 2000 activated carbon powder (Jacobi Carbons AB, Sweden). The volume of the filter was 530 L and the length of the filter was 160 cm. A total flow of 3 m$^3$ h$^{-1}$ was treated by the two activated carbon filters. The particle removal efficiencies of both the sand and precoat filters were tested.

**Laboratory filtration setup**

A laboratory filtration setup was built to simulate a full-scale precoat filter (Figure 1). The filtration setup consisted of a pump, a filtration cell, a funnel, and a bucket to collect the filtrate. The filter cloth was polyester mesh taken from one of the tubes of the full-scale precoat filtration tank. The thickness of the polyester twill woven mesh (2 × 1) was approximately 1 mm and the thickness of the thread was approximately 0.5 mm (Figure 2).

Data on the laboratory setup are shown in Table 1.

Before each experiment, the filter cloth was coated with a layer of filter aid powder. Three types of powder were analysed: two different perlites (Harbolite® 900S and Aquatec perlite) and cellulose fibers (Arbocel® B 800) hereafter called Harbolite, Aquatec perlite and Arbocel. The filter cloth was inserted horizontally to ensure that the powder...
Full-scale experiments were conducted in the Varde public swimming pool to compare the performance of a precoat filter and a sand filter. The water flow was 82 m$^3$ h$^{-1}$, the volume of the sand filter was 11 m$^3$, and the volume of the precoat filtration tank was 3.1 m$^3$. The precoat filtration tank was equipped with 88 tubes (the total capacity of the precoat filtration tank being 121 tubes). All tubes were 96.5 cm high wrapped in 0.26 m$^2$ of polyester mesh. The surface area of all 88 tubes was 23 m$^2$. Before filtration, Harbolite powder was suspended in water and the water was filtered to coat the polyester mesh with powder. The amount of powder used was approximately 11 kg, i.e., 0.43–0.52 kg of powder per m$^2$ of filter area. The water was recirculated during coating in order to avoid contamination of water in the swimming pools with powder particles that could pass through the polyester mesh.

Full-scale testing was conducted 5 days after precoating the precoat filter and backwashing the sand filter. Testing was conducted at a flow of 41 m$^3$ h$^{-1}$ (50% of maximum flow) and 74 m$^3$ h$^{-1}$ (90% of maximum flow) of swimming pool water through the precoat filter and the sand filter. This corresponded to a filtrate rate equal to 7.1 m$^3$ h$^{-1}$ and 12.8 m$^3$ h$^{-1}$ (90%) for the sand filter and 1.8 m$^3$ h$^{-1}$ (50%) and 3.2 m$^3$ h$^{-1}$ (90%) for the precoat filter. The quality of the filtered swimming pool water was analysed by measuring the particle size distribution before and after filtration. Full-scale testing was also conducted 5, 30, and 60 min after the precoat filter was rinsed and the filter cloth was coated with new filter aid powder. Furthermore, full-scale testing was conducted 0, 30, and 60 min after backwashing the sand filter.

The sand filter was subjected to filtration testing with and without flocculation of the swimming pool water. Polyaluminium chloride (Sactoklar®, Sachtleben Chemie, Germany) was used and the dose was set at 0.1 L day$^{-1}$, i.e., approximately 0.05 mL per m$^3$ of swimming pool water. Dosing started 1 hour before taking measurements, and the quality of the filtered water was measured 20 min after the dosing ended.

### Hydraulic resistance and powder density

The hydraulic resistance was determined for Harbolite, Aquatec perlite, and Arbocel, respectively, by filtering 1–5 g of powder suspended in 700 mL of tap water. The filter area was 0.00656 m$^2$ and the pressure difference was 50 mbar, ensured by the water level above the filter cloth. The hydraulic resistance increased linearly with the amount of powder on the filter cloth, allowing the specific cake resistance to be calculated (Friso et al. 2015).

The specific cake resistance ($\alpha$) was calculated using Equation (1):

$$\alpha = \frac{P}{\eta J}$$

where $P$ is the pressure difference (Pa), $\eta$ is the filtrate viscosity and is equal to the viscosity of water (Pa s), $J$ is the...
measured flux through the filter cloth (m s⁻¹), and ω is the amount of powder per filter area (kg m⁻²). The hydraulic resistance of the filter cloth was measured and was found to be negligible compared with the resistance of the powder layer.

The specific cake resistance has been described theoretically for hard spherical particles (Carman 1938).

\[
\alpha = \frac{180(1 - \varepsilon)}{\rho \varepsilon d_s^2}\]

(2)

where \(\rho\) is the density of the particles (kg m⁻³), \(\varepsilon\) is the porosity (−), and \(d_s\) is the Sauter mean diameter (m). The total volume and surface area of the particles was calculated from the measured particle size distribution assuming spherical particles. The Sauter diameter was then found as the diameter of a sphere with the same volume/surface ratio as estimated for the particle mixture (Equation (3)).

\[
d_s = \frac{\sum_i (n_i d_i^3)}{\sum_i (n_i d_i^2)}
\]

(3)

where \(n_i\) is the number of particles with a given diameter \(d_i\).

The dry density of Harbolite was measured using an Ultrapycnometer 1200eT (Quantachrome Instruments, Boynton Beach, FL, USA) with helium during the experiments. It was assumed that no helium adsorbed to the powder. This may result in minor underestimation of the density of particles with large surface areas, but the error would be below 0.3%.

Particle size analysis of powder and particles in swimming pool water

An Accusizer 780 (Particle Sizing Systems, Port Richey, FL, USA) particle size analyser was used to measure the number and volume distribution of particles in swimming pool water. The number particle size distribution was also measured for Harbolite powder suspended in tap water. To test the precoating procedure, newly formed particle layers deposited on the filter cloth were resuspended in tap water and analysed. Particle size analysis was conducted for experiments in which the particle suspension both was and was not recycled during the precoating procedure. The particle size analyser measured particle sizes in the 1–400-μm range. Particle size standards were used to validate the measurements. These analyses documented that the quality criteria was met down to particle sizes at 3 μm.

Below 3 μm the measurements were uncertain. Thus, only particle sizes between 3 and 400 μm was included in this paper. The measurements were replicated three times. The x-axis is logarithmic for all figures showing particle size measurements.

The removal efficiency was calculated using Equation (4):

\[
E = \frac{n_0 - n_f}{n_0}
\]

(4)

where \(n\) is the measured number of particles within the given size interval measured before (\(n_0\)) and after (\(n_f\)) filtration.

The relative concentration of particles was determined using Equation (5):

\[
n_{rel,x} = \frac{n_x}{\sum_i n_i}
\]

(5)

where \(n_x\) is the number of particles at a given particle diameter.

Turbidity measurement

Turbidity was measured immediately after sampling using a 2100Q Portable Turbidimeter (Hach, Loveland, CO, USA).

Conductivity measurement

Conductivity was measured immediately after sampling using a Cond330i conductivity meter (WTW, Weilheim, Germany) equipped with a TetraCon 325 electrode (WTW); the temperature of all samples was 30–30.2 °C.

Measurement of total organic carbon

Total organic carbon (TOC) was measured within 15 min of sampling using a Sievers 900 portable TOC analyser (GE Analytical Instruments, Boulder, CO, USA). Sample vials were flushed with the sample before filling.

RESULTS AND DISCUSSION

Analysis of filter aid powder

The density of Harbolite powder was measured to be 2.317 g mL⁻¹. Harbolite powder is porous, and more than
100 s was required before constant density (equilibrium) was reached due to the large surface area of the particles (Figure 3).

The specific cake resistance was measured for all three filter aid powders, and was found to be low in all cases, i.e., below $5.2 \times 10^{10}$ m kg$^{-1}$ (see Table 2).

The measured data for Harbolite 900S fitted well with literature values giving at density of 2.3 g mL$^{-1}$ and mean particle size of 35.8 $\mu$m (Imerys Filtration Minerals 2017).

Test of precoat filtration using the laboratory cell

The laboratory filtration cell was loaded with 7.6 g of Harbolite powder, and the number-weighted particle size distribution was measured for the powder and for the layer coating the filter cloth, but before filtering the swimming pool water (Figure 4(a)). Data indicate that some of the small powder particles were able to pass through the filter cloth. The number-average diameter of the particles in the coated layer was measured to be 9.6 $\mu$m compared with 8.0 $\mu$m for the suspended powder. Measurement of particles in the outlet of the filtration cell documents a high concentration of particles in filtrate during the coating process. Some of the small particles were therefore lost during precoating, meaning that the particle size distribution shifted towards larger particles. If the filtrate was recycled, the small particles were caught in the powder layer on the filter cloth and the particle size distribution of the powder layer was similar to the distribution of Harbolite powder suspended in water. The number-average diameter of the particles within the recycled Harbolite coating layer was measured to be 8.2 $\mu$m compared with 8.0 $\mu$m for the suspended powder. This also confirmed that the powder layer was able to catch smaller particles than the filter cloth.

Three types of powder were tested. The filter cloth was coated with powder with no recycling of the filtrate and the number particle size distribution was measured for the powder (Figure 4(b)). The Sauter diameters for the three powders were calculated from the measured particles’ size distribution (Table 2). The diameter did not correlate with the specific cake resistance e.g. the highest Sauter diameter was observed for Arbocel powder, but Arbocel powder also resulted in the highest specific resistance. This indicated that parameters such as particle morphology, particle porosity and cake packing varied for the three different types of powder (Yu et al. 1996). The particle size distribution of Arbocel powder was broad (Figure 4(b)) and cakes often pack to a denser structure when the particle size distribution is broad (Mota et al. 2003). Furthermore, the morphology of the cellulose fibers (Arbocel) differs from that for perlite (Harbolite and Aquatec perlite).

The particle size distribution in the inlet and outlet of the filtration cell was measured after 30 min of filtration. The filter cloth was precoated with 0.43 kg of Aquatec perlite powder per m$^2$ of filter area (Figure 5). The particle concentration and distribution in the inlet were measured before (measurement 1) and after (measurement 2) measuring the particle concentration in the outlet. Measurement 2 was taken 8 min after measurement 1. The concentration of small particles in the inlet was lower in measurement 2 than 1, indicating some variation in the inlet concentration of

![Figure 3](https://iwaponline.com/wst/article-pdf/77/3/748/212845/wst077030748.pdf)  
Measured density of Harbolite as function of time. The measured density will asymptotically approach the correct density.

<table>
<thead>
<tr>
<th>Specified cake resistances of three different powder types</th>
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<tr>
<td><strong>Harbolite</strong></td>
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<tr>
<td>Specific cake resistance (m kg$^{-1}$)</td>
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<tr>
<td>Sauter diameter (μm)$^a$</td>
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$^a$Sauter diameter was calculated from the data shown in Figure 4(b).

By guest on 07 November 2018
particles. Two groups of particles were observed in the inlet swimming pool water: one group of particles with a diameter of less than 10 μm and another group with a peak diameter around 15 μm. The precoat filter effectively removed particles larger than 10 μm and more than 80% of particles larger than 3 μm.

The three filter aid powders were compared. The filter cloth was coated with 0.43 kg of powder per m² of filter area and the number of particles was counted in the inlet and outlet (Figure 6). In the last run with Harbolite powder, the filtrate was recycled during precoating. For all types of powder, the initial particle count was more than 10 times higher than that in the inlet, indicating that filter aid powder passes through the filter cloth and ends up in the outlet water. After 30 min of filtration, the particle concentration was lower in the outlet than the inlet, and more than 1 hour was required for the precoat filter to reach maximum efficiency. Looking more closely at the specific particles, the number of large particles (diameter, 8–400 μm) was reduced by 90% with a high removal rate by 15–30 min after startup. The concentrations of small particles (diameter, 2–8 μm) in the outlet were initially high but then declined, and after 1 hour the removal efficiency was 60–75%, depending on the powder used. The best results were obtained with Arbocel and Aquatec perlite powders, with removal efficiencies of 77% and 75%, whereas for Harbolite it was 60%. The specific cake resistances for Arbocel and Aquatec perlite are four to five times higher than the resistance for Harbolite, indicating a more densely packed cake. This was in good agreement with the higher particle removal. Particles were captured on or within the powder cake and thereby also changed the filter efficiency with time.
Full-scale comparison of precoat filter and sand filter

In full-scale tests conducted at the Varde public swimming pool, where a sand filter and precoat filter were run in parallel, the particle removal efficiency was measured (Figure 7). When the flow rate was increased from 41 m$^3$ h$^{-1}$ to 74 m$^3$ h$^{-1}$, the removal efficiency declined for the precoat filter but seemed to be unaffected or fall slightly for the sand filter. Furthermore, the best removal efficiency was obtained using the precoat filter at both flow rates, with the difference between filter types being most pronounced at a low flow rate of swimming pool water. The measurement was made between 5 days after precoating (for the precoat filter) and backwashing (for the sand filter). The removal efficiency for the powder filter was measured to be 90% at a flow rate of 41 m$^3$ h$^{-1}$ and 80% at a flow rate of 74 m$^3$ h$^{-1}$. The removal efficiency for the sand filter was measured to be 80% at a flow rate of 41 m$^3$ h$^{-1}$ and 75% at a flow rate of 74 m$^3$ h$^{-1}$. For particles above 10 μm the removal efficiency was higher than 90% for both the powder and the sand filter.

The particle removal efficiency was measured after precoating the filter with Harbolite (Figure 8(a)–(c)). The particle removal efficiency was higher than 90% for large particles (diameter, approximately 15 μm). For particles below 10 μm in diameter, the particle removal efficiency increased during the first hour, as was also observed when using the laboratory cell.

In similar testing conducted using the sand filter (Figure 8(d)–(f)), the particle removal efficiency was monitored during the first hour after backwash. The removal efficiency was poor after backwash, but improved over the first few hours of filtration. Comparing the precoat filter and the sand filter indicated that the precoat filter produced the best results. Based on these results, it is recommended that backwash be conducted only after swimmers have left the pool, allowing sufficient time to establish a high particle removal efficiency before new swimmers enter the pool.

Testing was conducted with swimming pool water that had been flocculated before sand filtration (Figure 9). Adding flocculant significantly improved the removal efficiency, especially for small particles. The removal efficiency for particles of 3–10 μm is measured to be 25% whereas it is 70% after flocculation. The flocculant was expected to aggregate small particles so that they would be more easily retained in the sand filter. The high removal efficiency was sustained for at least 20 min after flocculant dosing ended. This could indicate that a thin compact layer of particles and flocculant left at the top of the sand filter continued to catch the small particles; alternatively, flocculant could have adhered to the sand, retaining small particles.

The turbidity of the swimming pool water was measured (Table 3) and was found to decrease after filtration, as expected, as particles were removed from the water. However, the particle concentration was low and it was difficult to make precise measurements of the water quality in terms of turbidity. The conductivity and TOC remained unchanged after sand filtration and filtration through the precoat filter. This showed that most of the organic carbon is dissolved or suspended as small colloidal particles that were not removed in the precoat filter or the sand filter.

The energy consumed by the precoat filter was used mainly to operate the pump, ensuring a water flow of 82 m$^3$ h$^{-1}$. The powder was changed every second week and the experiment was repeated three times (Figure 10). During the operation of the precoat filter, the energy consumption increased by approximately 35% from...
approximately 2.3 kW to 3.0 kW. The energy consumption increased almost linearly over the two weeks, i.e., by 0.06 ± 0.01 kW day⁻¹, because of the increasing resistance within the powder layer as particles from the swimming pool water were deposited and clogged the powder layer. After changing the filter aid powder on the filter, the energy consumption was re-established at 2.3 kW. This indicated that the particles were caught in the powder layer and not

Figure 8  Filtration efficiency of a precoat filter 5 min (a), 30 min (b), and 60 min (c) after loading with new filter aid powder; and of a sand filter 5 min (d), 30 min (e), and 60 min (f) after backwash. The flow rate was 41 m³ h⁻¹.
in the filter cloth. The energy consumption of the sand filter varied between 2.4 kW and 3.7 kW at a water flow of 82 m³ h⁻¹ without addition of flocculant (normal procedure at Varde public swimming pool). The sand filter was operated for 6 days before cleaning (backwashing). The average energy consumption was 2.7 kW (64.8 kWh per day) for the powder filter and 2.9 kW (69.6 kWh per day) for the sand filter i.e. the energy consumption can be reduced by approximately 5% when using the powder filter.

Cleaning the sand filter consumed 12–14 m³ of water, while cleaning and coating the precoat filter consumed 8–10 m³. Water consumption was therefore 1.7–2.1 m³ day⁻¹ for the sand filter and 0.67–0.83 m³ day⁻¹ for the precoat filter. The water was heated from approximately 8 °C to 31.8 °C. The minimum energy required to heat the water was calculated as 47–58 kWh per day for the sand filter and 19–23 kWh per day for the powder filter. Thus, the energy required for heating water is important for the overall energy consumption. Whether a reduction of water consumption is possible depends on several parameters such as regional rules and norms, activity in the swimming pools and water evaporation from the pools. According to
the German DIN Standard water in swimming pools, for example, water has to be replaced at a rate of 30 L/bather/day, which may reduce the potential for saving water. Thus in Germany, it may therefore be difficult to reduce water compared to e.g. Denmark, where the water can be replaced at a lower rate.

CONCLUSIONS

The technical performance of a precoat filter technology was tested and compared with that of a conventional sand filter. In the testing, swimming pool water was filtered and the particle removal efficiency measured.

The particle concentration and particle size distribution were measured before and after filtration of the swimming pool water. In unfiltered water, two main groups of particles were observed: one group of particles below 8 μm in diameter and another group around 15 μm. Significant variation in particle concentration was observed over time, largely related to the varying swimming activity in the pool.

Both the sand and precoat filters were able to reduce the particle concentration in the effluent. The removal efficiency was measured to be above 90% for particles above 8 μm. However, higher particle removal efficiency, especially for small particles, was generally observed for the precoat filter. The removal efficiency for particles for the sand filter was 25% without flocculation and 70% after flocculation. Three filter aid powders, i.e., Harbolite, Aquatec perlite, and Arbocel, were tested, and the highest particle removal efficiency for small particles (2–8 μm) was observed when using the Aquatec perlite (77%) and Arbocel powders (75%) whereas it was lower for Harbolite (60%). For all types of powders, 30–40 min of filtration was required before the maximum filtration efficiency was reached. Neither the precoat filter nor the sand filter was able to reduce the TOC.

The energy consumed by the pumps increased by approximately 35% over the 14 days when the precoat filter was used. This energy consumption could be reduced by replacing the filter aid powder on the filter cloth. At the Varde public swimming pool, the sand filter was backwashed once a week, while the powder on the precoat filter was replaced every two weeks. It would therefore be possible to save 60% of the water for the filter cleaning procedure if the precoat filter was used instead of the sand filter.

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