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Two New Chemical Components for Sand Consolidation Techniques

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Abstract

Sand production problems are encountered throughout the world and recently detected in Saudi Arabian oil fields. Therefore an increased emphasis is being placed on proper initial well completion as the value of non-renewable oil reserves increases and cost of remedial work skyrockets. Sand control by consolidation involves the process of injecting chemicals into the naturally unconsolidated formation to provide in situ grain-to-grain cementation. Techniques for accomplishing this successfully are perhaps the most sophisticated ones undertaken in completion work.

Many methods have been suggested to consolidate the wall of the wellbore for few inches or feet around the hole. These methods are either expensive or temporarily. This paper introduces two new cheep chemical components to be used to consolidate friable sand formation at temperature up to 300ºC. The paper introduces these two components, discusses the physical and petrochemical properties of the consolidated sand and the factors affecting this consolidation and highlight the laboratory process and field application of these two components.

Introduction

Sand production problems are experienced in many oil and gas productive formations [1]. They are most significant in unconsolidated sandstone reservoirs. Sand influx into the wellbore may lead to various problems such as erosion of valves and pipelines, plugging the production liner and sand accumulation in the separators. Cleaning and repair works related to sand production plus loss of revenue due to production rate restriction amounts to great costs incurred by the industry every year. Furthermore, undetected erosion of production equipment may pose a major safety hazard in case of high-pressure gas wells. Therefore, sand control has attracted much research effort for more than six decades [2].

Sand production is explained in several ways. The most convincing theory attributes sand production to friction and resultant pressure drop as well fluid passes through the small pores of the sand body. If the cementing materials are not strong enough and that the pressure drop is high, the individual sand grain is displaced and carried into the wellboe. Another plausible explanation considers the fact that the formation compaction as the bore pressure decreases, and the variations of the load, tends to shift sand grains and shear the cementing material. Another strong explanation highlights the chemical difference between the water initially present when the sand grains were first deposited and that water contained in the aquifer. Water production can actually dissolve a part of the cementing material between sand grains.

Several methods were proposed and adopted for the control of sand productions in the past [3-5]. These control methods are intended either to prevent or reduce the flow of sand particles into the wellbore during the course of production. Three processes are employed predominately for the control of sand production in oil and gas wells. These methods include mechanical means such as sand screens, filters, perforated or slotted liners, gravel packing [3-7]; chemical agents such as plastic, phenolic, epoxy, furan, and enzymes consolidations or a combination usually introduced to the oil industry [8-22]. Certain completion and production practices are also used to reduce or totally prevent sand production. Each method has brought some useful achievements.

Low and high temperature oxidation of crude oil has been used to test its potential as sand consolidation material [23-25]. The crude oil reacts with oxygen through numerous and complex reactions. These reactions in turn depend upon the temperature. Low temperature oxidation is found below 500^{o} C and is characterized by products such as oxygenated hydrocarbons like aldehydes, alcohol, ketones, acids and hydro-peroxides with carbon oxides [21]. Light oils were found to be more susceptible to low temperature oxidation than heavy oils, because low temperature increases the viscosity and density and hence alters the distillation characteristics of the oil. It also affects the quantity of the fuel available for combustion [24].

In sand consolidation, there are two major factors: The first concerns the placement of a binding film in the pores. The binding film must adhere to the surface of sand grains and do not obstruct the flow of the fluid. The second factor regards the strength. This is particularly useful in the design of consolidation method of steam displacement wells, where temperatures in the stimulation phase goes up 700^{o}F.

A high temperature sand consolidation system that is stable to the wellbore temperatures of 372^{o} C was developed [25]. The development resulted from two improvements in the technique. First a controlled amount of catalyst is adsorbed on the sand, so that consolidation takes place near the sand grains. This action is useful for obtaining higher permeability consolidation. The second improvement comes from the elimination of the adverse effects of water by driving the reaction to completion. The resin used, in achieving this accomplishment, is a very viscous derivative of furlfuryl alcohol, which requires a dilution to make it easy to inject. A hydrolyzable ester that reduces viscosity is employed for dilution.

The screening of these proposed methods shows that they are either expensive or incapable to prevent the flow of sand particles into the wellbore. This work presents the results of testing a byproduct of steel industry that is defined as slag for potential use in friable sand consolidation. This byproduct is a waste and causes an environmental problem, if dumped on land.

Experimental Procedures

The sand used in this study was brought from Half Moon beach, Eastern Province, Saudi Arabia. The sand was sieved using ASTM set of sieves and shaker. The friable sand was packed in a Hoek Cell to measure its permeability. The absolute permeability of the friable sand pack before use with slag is 0.5 Darcy while the permeability of that before use with sodium silicate is 1.5 Darcy. These values are used as a reference for the consolidated samples.

Preparing Sample with Slag

To prepare consolidated sand samples with slag, chemical activators ($Ca(OH)_2$ and $CaCO_3$) have been mixed with water using cement blender for 10 minutes. Slag has been added to the water and activator mix at a low rate during blending rotation to ensure complete mix with the water. After adding the amount of slag to the mix, blending process continued for another 10 minutes. Amount of sand was weighed and added to the slag mix and blended for another 10 minutes. Cement moulds were tightened, greased and prepared for making cubical samples. The slag mix was poured in the moulds. The moulds were tapped continuously using electric vibrator to allow any gasses in the mix to peculate and escape from the mixture. After ensuring complete gas percolation, the moulds were covered with aluminum foil, put into oven and cured for 24 hours. The oven temperature increased gradually to simulate wellbore temperature till 95° C and kept constant for the specified curing time.

After curing time, the samples are picked up, cooled and dismantled from the moulds. Some samples were used to evaluate the compressive strength using Versa Tester machine. Other samples were used to measure the rock permeability using Ruska gas permeameter. Finally, other samples were immersed in kerosene or water to measure their deterioration in water and oil. The samples immersed in kerosene and water was kept for 30 days under these fluids, and then they were dried and tested for compressive strength and permeability. The amount of activators as well as slag was changed to find out the optimum composition to be used for sand consolidation.

Preparing Sample with Sodium Silicate

To prepare consolidated sand samples with Sodium Silicate, sodium silicate solution has been added to the dry sand and blended for 10 minutes. For wet sand, water is added first to the dry sand and blended thoroughly. After that sodium silicate is added to the wet sand and blended for 10 minutes to ensure complete mix. Cement moulds were tightened, greased and prepared for making cubical samples. The silicate mix was poured in the moulds. The moulds were tapped continuously using electric vibrator to allow any gasses in the mix to peculate and escape from the mixture. After ensuring complete gas percolation, the moulds were covered with aluminum foil, put into oven and cured for 24 hours. The oven temperature increased gradually to simulate wellbore temperature until the specified temperature is reached and kept constant for the proposed curing time.

After curing time, the samples are picked up, cooled and dismantled from the moulds. Some samples were used to evaluate the compressive strength using Versa Tester machine. Other samples were used to measure the rock permeability using Ruska gas permeameter. Finally, other samples were immersed in kerosene or water to measure their deterioration in water and oil. The samples immersed in kerosene and water was kept for 30 days under these fluids, and then they were dried and tested for compressive strength and permeability

Results and Discussion

Sand Consolidation Using Slag

For any friable sand consolidation technique, compressive strength, rock permeability and rock stability under fluid flow are the major important factors. Therefore, the work is concentrated on these factors to evaluate the consolidation process using both Blast Furnace Slag (BFS) and Steel Making Slag (SMS). The amount of slag is changed between 20% and 50% relative to the amount of water. The amount of calcium hydroxide and calcium chloride lies between 20% and 40% of the amount of water added. The amount of sand is kept constant at 2250 gm for all experiments. Three samples were used for each experiment and the average value is taken as a result of that experiment. The results are shown in Tables 1 and 2

Table 1 Composition and results of samples consolidated using Blast Furnace Slag

Composition						Curing Conditions		Results	
No	H_2O cc	Slag %	$Ca(OH)_2$ %	$CaCl_2$ %	Sand gm	Temp. °C	Time Hrs	Comp. Str. psi	Perm. Darcy
1	750	20	20	20	2250	95	24	Soft	NM
2	750	30	30	30	2250	95	24	102	0.2
3	750	40	30	30	2250	95	24	102	0.28
4	750	40	30	30	2250	95	24	84	0.18
5	750	50	30	30	2250	95	24	100	0.19

Table 2. Composition and results of samples consolidated using Steel Making Slag

Composition						Curing Conditions		Results	
No	H_2O cc	Slag %	$Ca(OH)_2$ %	$CaCl_2$ %	Sand gm	Temp. °C	Time Hrs	Comp. Str. psi	Perm. Darcy
1	750	20	20	20	2250	95	24	Soft	NM
2	750	30	30	30	2250	95	24	10	NM
3	750	40	30	30	2250	95	24	20	0.35
4	750	40	30	30	2250	95	24	85	0.21
5	750	50	30	30	2250	95	24	155	0.14

Compressive strength

The compressive strength of the friable sand consolidated using the above materials is measured by Versa Tester and plotted in Figure 1. The compressive strength is taken as the average of three samples prepared at the same conditions. It is measured after curing the samples at 95° C for 24 hours.

For BFS, the compressive strength of Mix 2 to Mix 5 lies between 102 and 83 psi. However, Mix 1 does not produce any compressive strength because the sample stayed soft without consolidation. The figure shows that there is no clear trend for compressive strength. Also the there is a recognizable increase or decrease in the compressive strength as the amount of slag or chemical activators is increased. This means that the process of depositing cementing material using BFS is limited to a certain value and is not affected by increasing the amount of slag or the chemical activators.

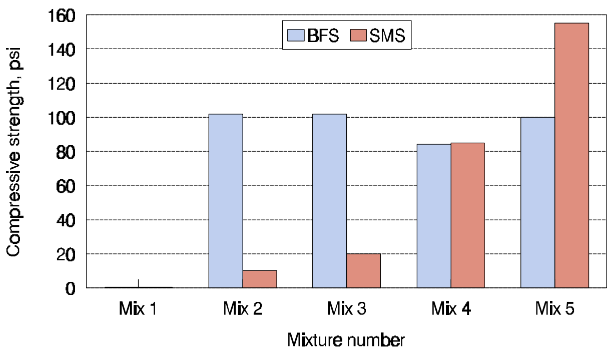

Fig. 1 Compressive strength of friable sand consolidated with BFS and SMS

For SMS, the compressive strength increases from 10 psi at 30% of slag and 30% of chemical activators to 158 psi at 50% of slag and 30% chemical activators. Mix 1 that contains 20% slag and 20% chemical activators does not produce any compressive strength. This means that the compressive strength of consolidated sand increases by increasing the amount of SMS. Also, Mix 4 and Mix 5 are suitable for friable sand consolidation because they have shown relatively higher compressive strength after 24 hours curing time.

5.1.2 Absolute Permeability

Absolute permeability of the consolidated samples is measured using Ruska Gas Permeameter and the liquid permeability is calculated by correcting Klinkenburg effect based on the measurements obtained. The results are plotted in Figure 2 for Mix 2 to Mix 5 for both BFS and SMS.

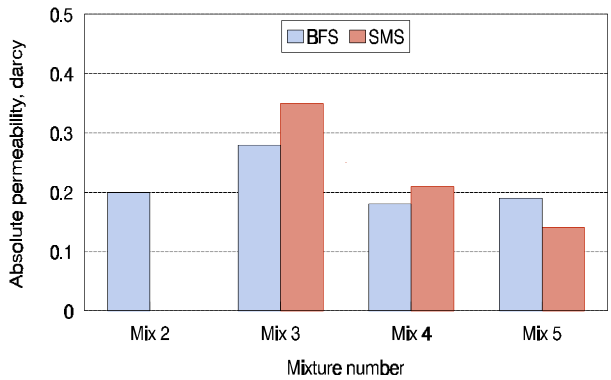

Fig. 2 Absolute permeability of friable sand consolidated with BFS and SMS

For BFS, the absolute permeability changes between 0.28 to 0.18 Darcy. It shows also no trend of absolute permeability change with changing mixture composition. Knowing that the absolute permeability of the friable sand is 0.5 Darcy, BFS reduced the absolute permeability between 44% and 64% of the original absolute permeability. This reduction can be considered very reasonable for the case of Blast Furnace Slag. But one cannot predict the absolute permeability reduction because of the flocculation of the results and the absence of the trend in these mixtures.

For SMS, the absolute permeability lies between 0.375 and 0.14 Darcy. There is a reduction in the absolute permeability as the amount of slag and chemical activators increases. Relative to the absolute permeability of the friable sand the SMS reduced the absolute permeability of the consolidated sand in the range of 30% to 72% of the original absolute permeability. From these results, one can conclude that to avoid high reduction in absolute permeability, Mix 3 is the recommended mixture for the friable sand consolidation. In case of the need of high compressive strength Mix 3 and Mix 4 can be applied.

5.1.3 Aging in Water and Kerosene

Aging samples in water and kerosene as a representative of crude oil is used to evaluate the deterioration of the samples due to production of fluids that is normally water and oil. For this test, the samples are immersed in water and in kerosene for 30 days and tested for compressive strength and absolute permeability.

For the BFS, the samples are deteriorated after 24 hours. This means that sand starts to be produced after BFS consolidation process just as the well is put on production. From this, it can be concluded that BFS is not suitable for friable sand consolidation.

For SMS, the compressive strength is plotted in Figure 3. The figure shows that there is a remarkable increase in the compressive strength due to aging in both water and kerosene. This increase is higher when using kerosene. This means that the flow of formation fluids through the consolidated sand increases the compressive strength and there will be no sand production when production resumed later on.

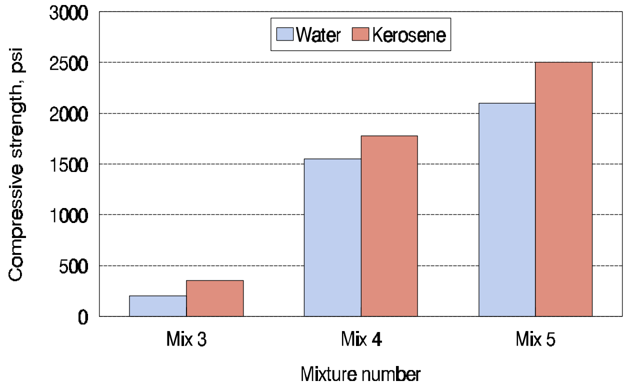

Fig. 3 Compressive strength of friable sand consolidated with SMS and aged in water and kerosene

The absolute permeability of the aged samples is shown in Figure 4. The figure shows that the absolute permeability increases by aging in both water and kerosene. This can be attributed to the solution of some salt that was previously precipitated between the grains, in both water and kerosene, resulting in the absolute permeability increase. However, more research is needed to prove this phenomenon.

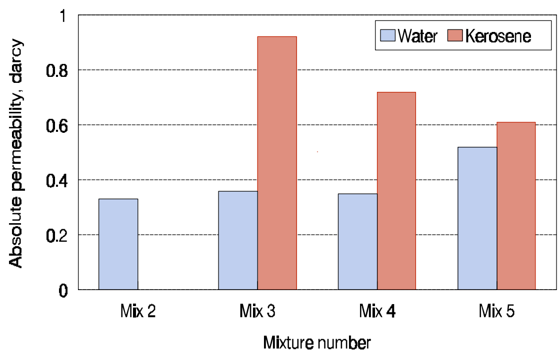

Fig. 4 Absolute permeability of friable sand consolidated with SMS and aged in water and keroseen

Sand Consolidation Using Sodium Silicate Solution

Samples are prepared from 450 gram of sand and different amount of sodium silicate solution. The silicate solutions were as 15%, 20%, 25%, and 30% by weight of sand. The silicate solution is blended with the dry sand, poured in steel moulds and cured at different temperatures. The curing temperature ranged from 50° to 300° C with a step of 50° C. Samples cured at temperature lower than 150° C did not bring any compressive strength at all.

Compressive Strength

The compressive strength of the consolidated sand samples is illustrated in Fig. 5 to Fig. 8. Figure 5 shows the effect of sodium silicate concentration on the compressive strength of the consolidated samples cured at 200º C. It shows that concentration between 20% and 25% provides the highest compressive strength. This results changes with samples cured at 300º C, Fig. 6. It shows that the high compressive strength is obtained at 15% and 25% concentration.

The effect of curing temperature on the compressive strength of samples consolidated with 30% is shown in Fig. 7. It shows that the highest compressive strength is achieved above 200º C. Wetting the sand grains with 10% by weight water brings a discrepancy in the curve at 200º C. The means that reservoir conditions should be applied for lab tests to simulate the in situ consolidation process.

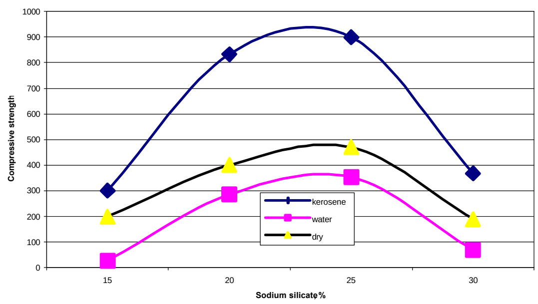

Fig. 5 Effect of sodium silicate on compressive strength of sand consolidated at 200 C

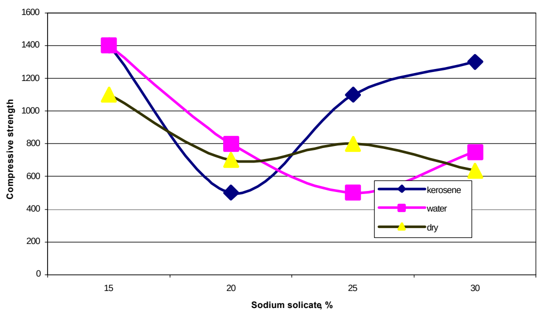

Fig. 6 Effect of sodium silicate concentration on compressive strenght of consolidated sand at 300 C

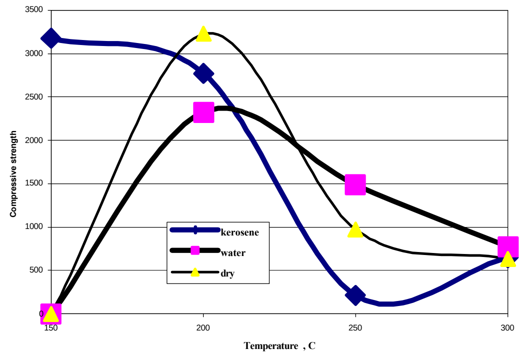

Fig. 7 Effect of temperature on compressive strenght of consolidates sand with 30% soldium silicate

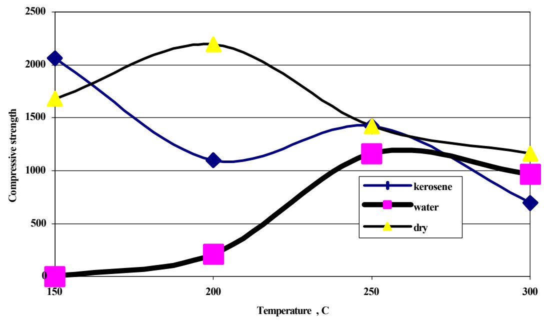

Fig. 8 Effect of temperature on compressive strength of sand consolidated with 30% soldium silicate and 10% water

Absolute Permeability

The permeability of the consolidated samples is measured by liquid permeameter. The results are plotted in Figures 9 to 12. Figure 9 shows the permeability of the consolidated sand sample as a function of the sodium silicate concentration at 200º C. It shows that the highest permeability is obtained at 20% concentration. Moreover, in all cases, the absolute permeability is higher than that of the friable sand (1.5 Darcy). This increase is caused by the expansion of the sample due to gases percolated when the sample is heated. At 300º C the absolute permeability suffer increase as well as decrease without trend, Fig. 10.

The effect of curing temperature on the absolute permeability of samples with 30% sodium silicate concentration is illustrated in Fig. 11. It shows that the highest permeability is obtained at temperature between 200º C and 250º C. Wetting the sand grains with 10% water decreases the absolute permeability of the consolidated samples except at 200º C, Fig. 12. This also confirms that the reservoir conditions should be identified before lab testing of sand consolidation using sodium silicate solution.

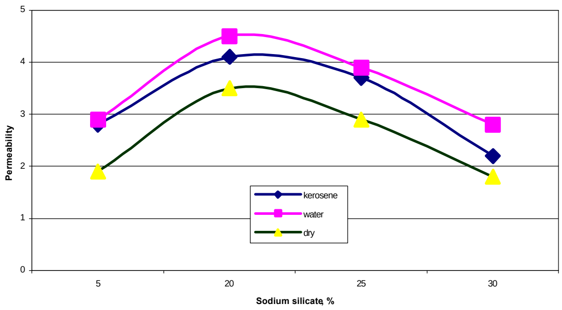

Fig. 9 Effect of sodium silicate on permeability of sand consolidated at 200 C

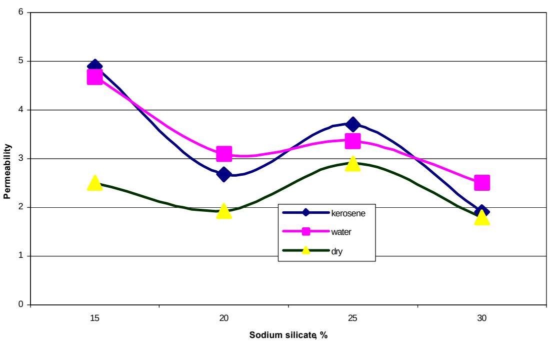

Fig. 10 Effect of sodium silicate concentration on permeability of consolidated sand at 300 C

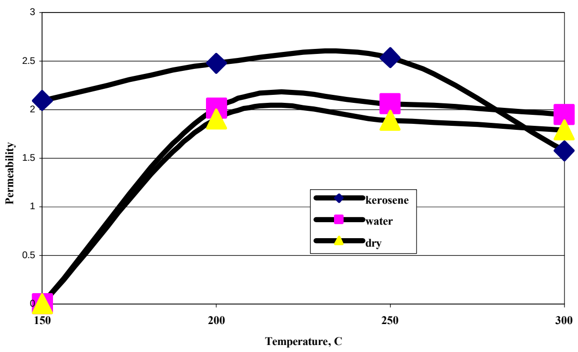

Fig. 11 Effect of temperature on permeability of sand consolidated with 30% soldium silicate

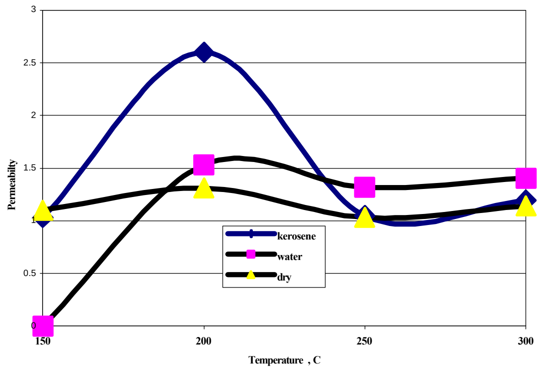

Fig. 12 Effect of temperature on permeability of sand consolidated with 30% sodium silicate and 10% water

Aging in Water and Kerosene

Figures 8 to 12 shows the results of dry samples as well as samples aged in water and kerosene. They show that aging the samples in water or in kerosene sometimes increase and sometimes decrease both compressive strength and the absolute permeability. However aging samples cured at 150º C in water deteriorate the samples completely. This means that the matrix precipitate at 150º C is soluble in water

CONCLUSIONS

Based on the experimental results achieved for salg and sodium silicate, the following conclusions are reached:

- Steel Making Slag mixed with 30 to 50% calcium hydroxide and 30 to 50% calcium chloride can consolidate friable sand.
- Steel making slag mixed with 30 to 50% sodium chloride and 30 to 50% sodium carbonate can also consolidate friable sand.
- The compressive strength is increased form 0 to 80 to 100 psi after 24 hours while the permeability is reduced from 0.5 Darcy to 0.14 Darcy.
- The samples immersed in kerosene or water attained an increase in both compressive strength and permeability.
- Steel Making Slag mixed with calcium chloride and calcium hydroxide is suitable for sand consolidation.
- Consolidating sand with sodium silicate

increases both compressive strength and absoluite permeability.

- Optimum consolidation condotions sould be evaluated based on the reservoir conditions.
- Aging samples in water or kerosene increases both comprssive strength and absolute permeability for curing temperature above 200º C.
- Aging samples cured at 150º C in water deteriorate the samples completely while aging it in kerosene increases the compressive strenght and the absolute permeability.
- Sodium silicate can be used for sand consolidation at temperatures higher than 200º C.
- More research is needed to investigate the consolidation pheomena.

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