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Defeating Sand with “Sand”

The Development of Ceramic Screens to Prevent Sand Influx and Erosion in Stimulated Production Wells

*By S. MÜSSIG, S. WAGNER, A. KAYSER and S. WILDHACK**

Abstract

The Danish oil and gas fields, operated by Maersk Oil on behalf of the DUC (Danish Underground Consortium), a collaboration between A.P. Møller – Mærsk A/S, Shell Olie- og Gasudvinding Danmark B. V. (Holland) and Chevron Denmark Inc., are mainly tight Cretaceous carbonates with permeabilities in the range of 0.5–2.5 mD. All the wells need to be stimulated before they can be brought into production at economic rates.

Maersk Oil mainly uses two types of completion methods, the CAJ (Controlled Acid Jetting) liner, and the PSI (Perforate-Stimulate-Isolate) completion. The latter is generally used when hydraulic induced massive propped fracture treatments have been selected as the method of stimulation. Experience shows that during clean-up operations and during production, erosion of the horizontal completion can occur owing to backflow of proppants, which makes selective production by manipulation of the sliding sleeves in the PSI-system impossible. As normal platform equipment does not include surface sand removal facilities, operations are faced with the problem that sand may be spread through the facilities and pipelines. Maersk Oil and ESK Ceramics have developed and designed an alternative: a sand screen based on ceramic materials, which is able to keep the proppant out of the wellbore and which has enough resilience to resist the erosive characteristics of the sand. In this paper the development of the ceramic screen together with additional protection measures such as soft coating is described. The screens have been deployed in a production well in the Valdemar field.

Introduction

Maersk Oil is currently producing from 15 fields in Denmark. The average production rate is some 220,000 b/d oil and some 25 million m^3/d natural gas.

Tight chalk reservoirs make development and production difficult. Fit-for-purpose and cost effective technologies have to be used to get the highest possible production per well. The porosity and permeability of the main reservoir unit – the Maastrichtian – is between 25–35% and 1–5 mD, respectively. The most recent developments therefore consist of long horizontal producer/injector pairs, having horizontal lengths between 3,000 and 5,000 m in a defined pattern, with an average distance between the wells of some 200 m. Hydrochloric acid is an effective stimulation treatment for these well completions.

The Lower Cretaceous Valdemar field (Fig. 1), discovered in 1977, is an exception. The Lower Cretaceous chalk has a higher argillaceous content and with exhibits poorer reservoir qualities. The matrix permeability ranges from 0.01–0.4 mD with porosities ranging from 20–35%. The shale content varies over the different reservoir units from 4–70%. Formation and acid compatibility investigations have indicated clay swelling and fracture face collapse.

It is clear that economically attractive production rates can only be achieved using horizontal wells completed with well stimulations having multiple hydraulically induced propped fracture treatments on a massive scale. In order to minimise the execution time of the treatments the so-called “Perforate – Stimulate – Isolate (PSI)”- completion [1] was designed and is in use today. The assembly is designed such that after the sump packer is set, the first zone is perforated using side-mounted guns. After the perforation assembly is pulled, an isolation assembly is run consisting of a sliding sleeve and a

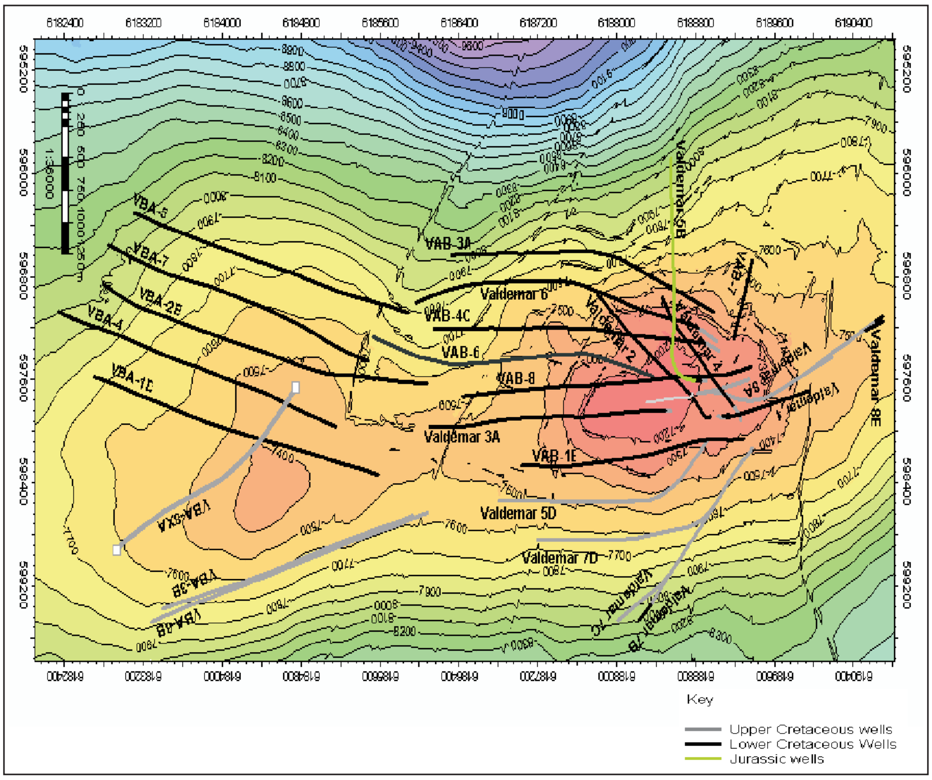

Fig.1 **Valdemar, North Jens and Bo Top Sola map**

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retrievable ISO packer, and the side mounted guns to perforate the next zone. Before the assembly is stabbed into the sump packer the fracture treatment is performed through the assembly. This procedure is repeatable and as many as 22 packers and sliding sleeves have been installed in one well. The sliding sleeves are then opened (or closed, if necessary) using coiled tubing. An overview of a PSI completion is shown in Figure 2.
During the cleaning process of fractured zones screened-out sand can be produced back from the fractured zone, causing erosion in tubulars and sleeves owing to very high production velocities.
It was observed that this erosion could happen very rapidly and it could even lead to creating holes (hot spots, Fig. 3), thus making it impossible to isolate individual zones. This is of particular importance once a zone suffers from an early water breakthrough, possibly putting the remaining reserves in the other zones at risk.

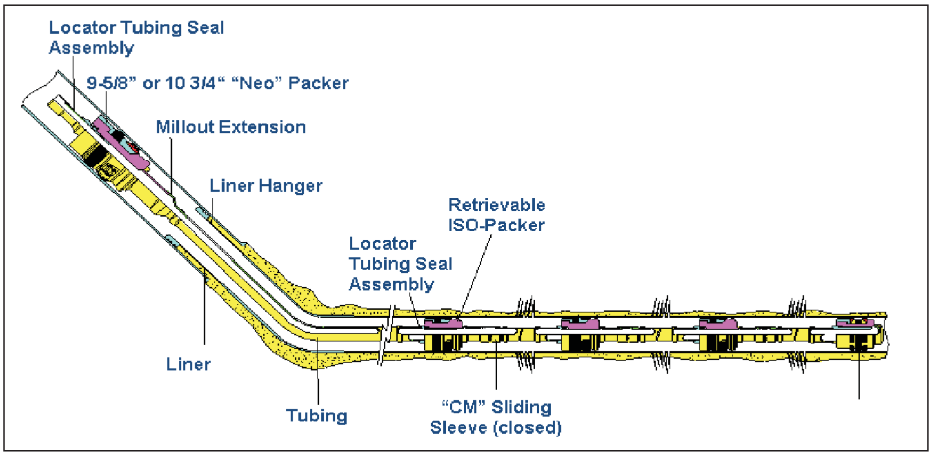


Fig. 2 **PSI completion**

The Development of the Screen

In order to prevent the erosion of sliding sleeves and tubulars a method of efficient protection was sought, which would also allow placing the sliding sleeves directly opposite of the perforations to minimize the pressure drop. We found that in the early 80's of the last century ceramic material had already been considered to control sand, but the method was never matured [2].
To find the right material three conditions must be satisfied. The material must be:
- "Porous" to allow sufficient flow through the filter whilst holding back sand
- Chemically resistant to well treatment fluids deployed during well operations
- Highly resistant to erosion even under perpendicular sand ingress at very high velocities.

Sintered Boron Carbide (B_4C) and Sintered Silicon Carbide (SiC) are known to be extremely hard and wear resistant materials (almost as hard as diamond), and therefore they were selected for a series of tests with the aim of confirming their suitability for the application described. Table 1 summarizes some of the important features of the selected ceramic materials in comparison with stainless steel.

Corrosion resistance was tested first. SiC and B_4C samples were exposed to a number of drilling, completion and treatment fluids, such as
- Hydrochloric acid (HCl), 15% w/w
- Sulphuric acid (H_2SO_4), 70% w/w
- Mixture of acids 1, 3 M H_2SO_4 / 1 M HCl
- Formic acid (HCOOH), 5% w/w
- Mixture of acids 2, HCl 12% w/w / Hydrofluoric acid (HF) 3% w/w
- Salt Solutions, Calcium chloride / Calcium bromide ($CaCl_2$ / $CaBr_2$).

The tests were performed under hydrothermal conditions at 80°C for 14 days and did not show any significant corrosive response of the ceramic materials to the fluids (standard stainless steel samples were heavily corroded or completely dissolved under the same conditions).
Secondly, erosion tests were performed, beginning with porous ceramic materials. It was already suspected, that the erosion resistivity is not too high because the ceramic material gains its hardness by a sintering process where all pores are removed.
These concerns were proven by exposing sintered porous plates as well as fully dense sintered plates to a perpendicular high pressure stream with frac sand used during stimulation operations (e. g. amongst others 20/40 mesh frac sand). The result is shown in Figure 4.
Whereas the porous plates showed a hole after five seconds of exposure, the fully dense sintered plates showed no erosion even after two hours of treatment.
Both dense sintered materials (B_4C, SiC) fulfilled the required conditions of being corrosion and erosion resistant. For cost reasons SiC was selected as the material of choice.
As porous ceramic material was not capable of withstanding any erosional forces, a solution had to be found to create enough area to allow the production rate flow through ceramic material, preferably in a laminar flow regime, whilst making use of the beneficial properties of fully dense ceramic material.
A design concept for ceramic screens was therefore chosen which is well known in the oil and gas industry, the essential elements of a wire-wrap sand screen. It is interesting that the wire shape used in sand screens was first developed by the Dutch State Mines for close sizing and dewatering of abrasive solids.

Table 1 **Comparison of selected ceramic materials with stainless steel**

Material	Density, g/cm³	Vickers-Hardness, GPa	Young's Modulus, GPa
Stainless steel	7.9	3	200
B_4C	2.5	31	420
SiC	3.2	25	410

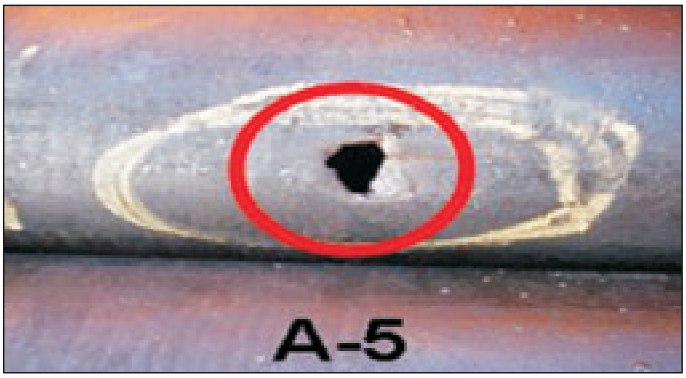


Fig. 3 **Eroded pipe**

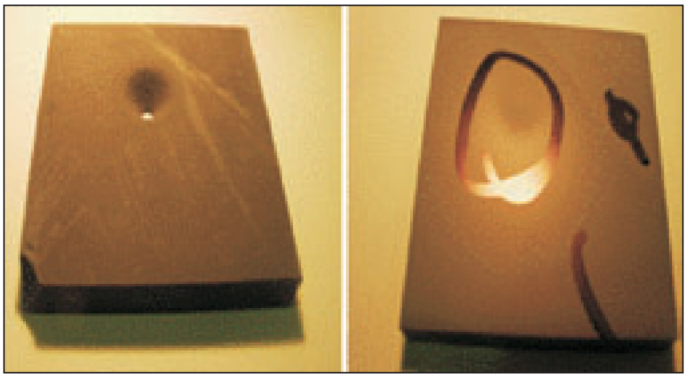


Fig. 4 **Porous versus solid ceramics (both samples SiC) after sand blasting**

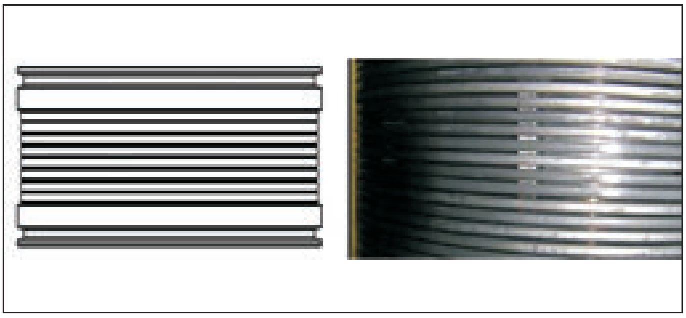


Fig. 5 Stack of ceramic screen elements, left: engineering drawing, right: picture of stacked rings, gap width 320 µm

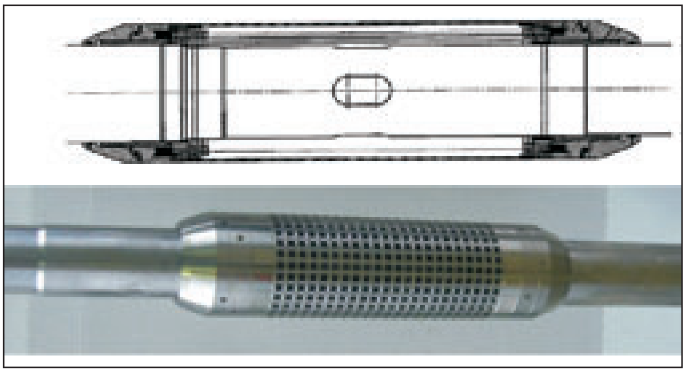


Fig. 6 *PetroCeram*® Sleeve: Ceramic screen mounted on sliding sleeve, top: engineering drawing; bottom: picture of prototype assembly

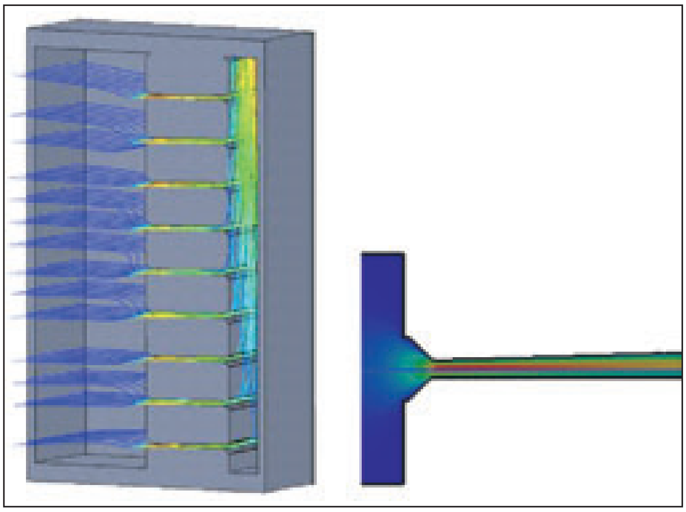


Fig. 8 CFS data for flow rates of 80 m^3/d and a gap width of 250 µm, left: flow lines along the screen; right: gap velocity plot (blue = low velocity, red = high velocity)

Prototype Description and Design

The design of the ceramic screen (*Petro-Ceram*® Sleeve) basically consists of three different construction elements: a stack of ceramic rings, two coupling elements and a fixing device to mount the assembly to a tubular support.

The ceramic rings are made of SiC. Compared with wire-wrapped screen systems, in which an inverted "V" cross sectional areas were described as favourable [3], the ceramic rings are spherically dished on the bottom face of the rings providing Venture shaped gaps that are narrower on the outside surface of the ring. This design allows high laminar flow rates (see section "Flow Tests") and prevents plugging of the gap by fines since any particle passing the gap at the outer diameter will continue to flow through rather than lodging within the gap.

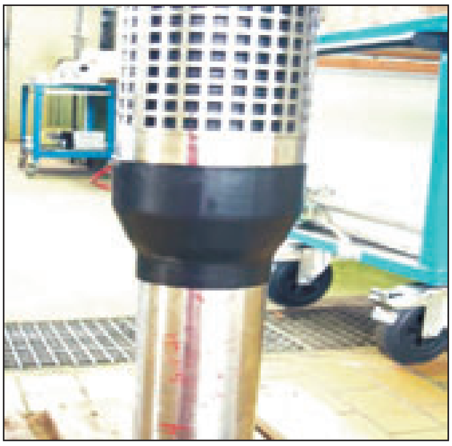


Fig. 7 Example of a Polyolefin shrinking hose

The upper face of the rings shows a number of equally spread bumps that are used to adjust the gap width of the ceramic stack (Fig. 5). The gap width can be chosen according to the frac sand or any other grain size distribution resulting from sand production that is used in the particular application. Ideally, the ceramic rings are manufactured with three bumps shaped as spherical segments ensuring only point contacts between the stacked rings. In combination with the spherically dished ring shape, this design is well suited to ceramics, giving flexibility to the stack of ceramic rings and stability against torsion as well as flexure. The ceramic screen easily passed a dog leg as high as 5°/100 ft without damage (for details see section "Running Test").

The stack of ceramic rings is placed between the upper and lower coupling elements and mounted on the tubular support (e. g. a sliding sleeve). A clamping fixture on both sides of the stack mechanically constrains the ceramic rings. The load is transferred to the stack of rings via a number of springs and the coupling elements. The flexibility of the springs enables the dissipation of any mechanical stress that could be either imposed by torsion, bending, shock waves or temperature induced thermal mismatch between metal and ceramics.

This type of clamping mechanism prevents any accidental damage of the basic sleeve and provides excellent damage-tolerance to the ceramic assembly.

The outer part of the entire ceramic assembly is surrounded by a metallic shroud to protect the ceramic screen from being damaged during installation. The shroud, which can be manufactured in a wide variety of sizes and styles, also enhances the mechanical strength of the assembly, if required.

The ceramic screen (Fig. 6) can be mounted on any type of tubular flow-through device; in the case described the ceramic screen is installed to protect a 3 ½″ sliding sleeve. The length of the ceramic screen is in principle flexible, and the design of the ceramic rings (ID, OD, gap width and gap geometry) can be freely chosen and adapted to nearly any prevailing wellbore geometry or well conditions.

During the development of the screen it was found that soft material acts also as an excellent erosion protection. This is well known in the mining industry, where rubber is frequently used for this purpose in highly erosive environments. In our case corrosion resistance is also required to protect the tubulars effectively. Polyolefin fulfils both criteria and is also available as shrinking hose, which makes deployment on the tubulars very easy. An example of the polyolefine shrinking hose mounted on the prototype screen is seen in Figure 7.

Test Programme

Flow tests

Minimizing pressure losses is always a major issue during oil and gas production. To ensure that the ceramic screen does not show any significant pressure drop, extensive modelling on ring and gap design as well as a set of tests has been performed.

A calculation model was developed determining the theoretical pressure losses as a function of the conveying parameter (flow rate, pressure, temperature, fluid density, viscosity) and the geometric data (screen length, inner and outer diameter, geometry of the ceramic rings, ring gap). The computerised fluid simulation (CFS) given in Figure 8 shows example plots for the flow lines along the screen and the velocity within the gap. The pressure loss over the prototype screen is very low for a broad range of flow rates up to 400 m^3 and never exceeds 0.2 bar (Fig. 9). Under all simulated conditions, the

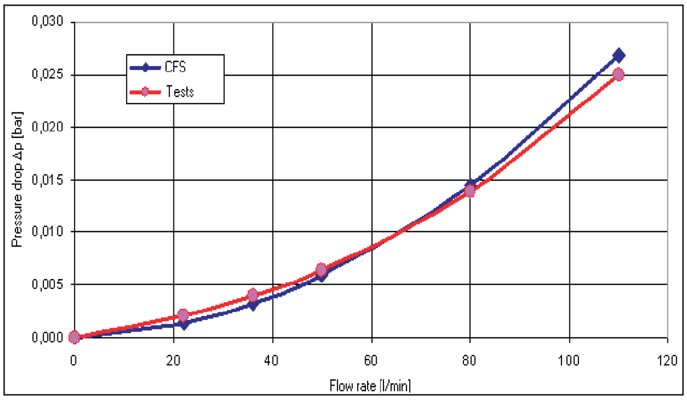


Fig. 9 Comparison of CFS and flow test results

Fig. 10 Screen after packing test

flow within the gap is laminar. This ensures that sand particles – small enough to enter – will be easily transported out of the gap and thus avoid plugging.

After the ceramic screen with corresponding geometries was assembled tests using the same parameter field as in CFS were performed. Figure 9 shows the test results, which are very similar to those obtained in the simulation. This result allows the design to be easily adapted for future applications with differing wellbore parameters.

In a second step tests were performed using sand-loaded fluids with different sand size distributions.

Packing test with a 50/50 mixture of 20/40 mesh and 100 mesh sand (to simulate crushed frac material) showed an increased pressure drop as expected, but the pressure drop remains in a very acceptable range. Even under these very unfavourable conditions (in a real situation the percentage of crushed material is much less), the pressure drop did not exceed 5 bar and the screen did not plug off. In Figure 10 the screen is shown after the packing test.

Running Tests

The ceramic screen/shrinking hose assembly was tested in the 7″ test loop in Måde, Denmark at the premises of Maersk Oil, to confirm that it could withstand deployment forces. The assembly saw a dog leg of 5°/30 m (100 ft) and was run a total distance of 12,000 m (36,000 ft) at an average speed of 24 m/min (80 ft/min). No damage of the ceramic rings was observed, as the shroud absorbed all the wear and tear as expected. The shrinking hose had to be cut off at the edges of the shroud during the test owing to damage; but thereafter, no further damage was observed. In Figure11 the assembly to be run in the test loop is shown. In Figure 12 the disassembled screen is shown after the test.

The ceramic screen/shrinking hose assembly has been deployed in three out of nine zones of a production well in the Valdemar field.

The well is in production and produces at the time of writing some 2000 bbl of oil per day with a water cut of 30%. We have not run a production log yet, however, so far the well is producing to our expectations and no sand has been produced.

In addition to the described tailored solution for Maersk Oil's PSI completion, there is a huge potential to improve the performance of conventional sand control technology by making use of the superior material properties of ceramics.

Therefore Maersk Oil and ESK designed a regular sand control screen with ceramic material – a first of its kind – which will be installed in an existing completion of a gas production well in the Tyra centre of DUC.

Conclusion

The PetroCeram® technology does not only provide a solution for increased lifetime but offers a breakthrough in sand control technology with a single-layer high laminar flow screen system; especially applicable under demanding conditions where abrasion is a major challenge. The design principle is highly adaptable in terms of well bore diameter, well bore declination, filter grain size distribution, modular length and flow- through area. This allows use of the system in nearly all of the presently known sand control sectors and offers a new approach to sand control management. Besides the described PetroCeram® Sleeve application where the ceramic screen protects a sliding sleeve, sand screen applications in open and cased hole completions can also be addressed. The new PetroCeram® Sand Screens are designed for the use in standard workover operations and completions working beyond the limits of state-of-the-art metallic sand screens.

We would like to thank Maersk Oil, ESK Ceramics and the DUC Partners, A. P. Møller-Mærsk A/S, Shell Olie- og Gasudvinding Danmark B. V. (Holland) and Chevron Denmark Inc. for their permission to publish this work. We would also like to thank Smart Drilling GmbH for their contribution to the design of this tool.

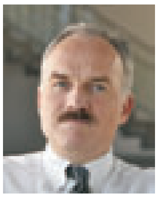
References

[1] Damgaard, A. P., Maersk Energy Inc., and D. S.

Fig. 11 Test run assembly; "*PetroCeram* Sleeve" positioned in the middle

Fig. 12 Wear marks on the metal shroud, ceramic rings after disassembly, no damage

Bangert, D. J. Murray, R. P. Rubbo, and G. W., Baker Oil Tools: A Unique Method for Perforating, Fracturing, and Completing Horizontal Wells. SPE Production Engineering, February 1992.
[2] Maikranz, E.: private communication, 1984 and 2009.
[3] World Oil Modern Sandface Completion Practices, Handbook Second Edition.



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