

## Research Article

### Manipulation of Slurry Density of Red Mud Clay in the Separation of Fine/Coarse Palm Kernel Shell

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**Abstract:** A work on the manipulation of slurry density of red mud clay in the separation of fine/coarse palm kernel shell is presented. Measured mass quantities of clay were added intermittently into 100 L of water and its density calculated and recorded. Different mass quantities of kernel/shell mixture were poured into the mud clay slurry, and stirred. The part of Kernel/shell mixture that floated were scooped off and the Kernel hand-picked and weighed. The plot of weight of floated kernel against specific gravity of the slurry shows a sigmoidal profile (asymptotic to sp. gravity axis). Curve fitting the profile with the superimposition of a model eqn on it gives an  $R^2$  of 99.85% using MATLAB Toolbox 7.0. The derived equation for floating kernel mass against mud slurry density fitted the profile with  $R^2$  of 99.85%. At near Stokes' regime i.e.,  $n = 2/3$ , the sp. Gravities of kernel and shell as well as shell diameter are 0.8349, 1.037 and 1.04 cm respectively, while, at Newton's regime they are 0.7242, 0.9082 and 1.114cm respectively. As the sp. gravity of the mud clay slurry begins to approach 2.81 the floated kernel mass begins to be constant and highest.

**Keywords:** Coarse, fine, float, kernels, mud slurry density, mass, shells separation

#### INTRODUCTION

Separation of palm kernel and shell mixture depends on the selection of a process in which the behavior of the kernel and shell materials is influenced to a very marked degree by some physical properties (Akubuo and Eke, 2009). The separation of the kernels from the shells is a very difficult process and an issue which continues to be of great importance within the industry.

The unit operations in palm kernels processing have been effectively mechanized with the exception of the kernels and shells separating unit (Khan and Richardson, 1987). The efforts made by some researchers (Dewsbury *et al.*, 2000, Kamalu, 2008) resulted in partial separation and low material capacity even though nut cracking had been mechanized. Separation by hand picking is labor intensive and time consuming and the differential efficiency in the wet and dry methods of separation is attributed to the physical properties of the palm kernels and shells. The present study considers the effects of mud slurry density variation of the wet method on the palm kernels and shells separation design and, testing of a palm kernel and shell separator with the aim of achieving complete separation of the shells and kernels.

Some methods of separating palm kernel and shell are traditional winnowing, sifting, flinging,

hydrocyclone and clay-bath methods (Chhabra and Richardson 1999).

#### THEORY OF DENSITY MEASUREMENT

The density at any point of a homogeneous object equals its total mass divided by its total volume. The mass is normally measured with an appropriate scale or balance; the volume may be measured directly (from the geometry of the object) or by the displacement of a fluid (Khan and Richardson, 1987).

If the body is not homogeneous, then the density is a function of the position. In that case the density around any given location can be determined by calculating the density of a small volume near that location. In the limit an infinitesimal volume the density of an inhomogeneous object at a point becomes:  $\rho(r) = dm/dV$ , where  $dV$  is an elementary volume at position  $r$ . the mass of the body then can be expressed as:

$$m = \int_V \rho(r) dV \quad (1)$$

The density of granular material can be ambiguous, depending on exactly how its volume is defined and this may cause confusion in measurement. A common example is said: if it is gently poured into a container, the density will be low; if the same sand is

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then compacted, it will occupy less volume and consequently exhibit a greater density. This is because sand, like all powders and granular solids, contains an air space in between individual grains. The density of the material including their air spaces is the bulk density, which differs significantly from the density of an individual grain of sand with no air included. (www.ask.com, www.wikipedia.com).

In general, density can be changed by changing either the pressure or the temperature. Increasing the pressure will always increase the density of a material. Increasing the temperature generally decreases the density, but there are notable exceptions to this generalization. For example, the density of water increases between its melting point at 0°C and 4°C; similar behavior is observed in silicon at low temperatures.

**Terminal falling velocity:** If a spherical particle is allowed to settle in a fluid under gravity, its velocity will increase until the accelerating force is exactly balanced by the resistance force. Although this state is approached exponentially, the effective acceleration period is generally of short duration for very small particles. According to Richardson and Harker (2003), Richardson *et al.* (2006), (a) if this terminal falling velocity corresponds to value of  $Re < 0.2$ , the drag force on the particle is  $F = 3\pi\mu du$ , (b) if  $0.2 < Re < 500$ ,  $F = 3\pi\mu du (1 + 0.15Re^{0.587})$  (c) and if  $Re > 500$ , then  $F = 0.55\pi d^2 \rho u^2$ .

The accelerating force due to gravity which is equal to the drag force corresponds to region (a) i:

$$V(Dp)g = \left(\frac{1}{g} \Pi d^3\right)(\ell_s - \ell)g \quad 3\Pi\mu du_0$$

$$U_0^2 = 3dg \frac{(\ell_s - \ell)}{\ell} \tag{2}$$

When the accelerating force due to gravity is equated to the drag force corresponding to region (c) yields:

$$U_0^2 = 3dg \frac{(\ell_s - \ell)}{\ell} \tag{3}$$

The above expressions for drag force and terminal falling velocity are derived with the following assumption:

- The settling is not affected by the presence of other particles in the fluid i.e., free settling.
- The walls of the containing vessel do not exert an appreciable retarding effect.
- The fluid is considered a continuous medium i.e., particle is large compared with the mean free path of the molecules of the fluid; otherwise the particles may occasionally “slip” between the molecules and thus attain a velocity higher than that calculated.

**Property relationship between two solid particles in a fluid:** The terminal falling velocity of particle A of diameter  $d_A$  and of density  $\ell_A$  under Stokes’ law is:

$$U_{0A} = \frac{d_A^2 g}{18\mu} (\ell_A - \ell) \tag{4}$$

And for particle B:

$$U_{0B} = \frac{d_B^2 g}{18\mu} (\ell_B - \ell) \tag{5}$$

For equal terminal falling velocities i.e.,  $U_{0A} = U_{0B}$ :

$$\frac{d_B}{d_A} = \left( \frac{\ell_A - \ell}{\ell_B - \ell} \right)^{1/2} \tag{6}$$

If Newton’s law is applicable:

$$U_{0A}^2 = \frac{3d_A g (\ell_A - \ell)}{\ell} \tag{7}$$

And:

$$U_{0B}^2 = \frac{3d_B g (\ell_B - \ell)}{\ell} \tag{8}$$

For equal settling velocities i.e.,  $U_{0A}^2 = U_{0B}^2$ :

$$\frac{d_B}{d_A} = \left( \frac{\ell_A - \ell}{\ell_B - \ell} \right) \tag{9}$$

The general relationship for equal settling velocities of two different particles is:

$$\frac{d_B}{d_A} = \left( \frac{\ell_A - \ell}{\ell_B - \ell} \right)^n \tag{10}$$

where  $1/2 < n < 1$  for the intermediate region.

**Relationship between mass of floated kernel and clay slurry density:**  $V = \frac{\pi}{\delta} d_k^3$  (Assuming spherical kernel):

$$B = K = \text{kernel}; A = S = \text{shell} \tag{11}$$

And mass of kernel:

$$V = V\ell_k = \frac{\pi}{\delta} d_k^3 \ell_k \tag{12}$$

So that from (10) and (11):

$$\left(\frac{\delta M_k}{\pi \ell_k}\right)^{1/3} = d_s \left(\frac{\ell_s - \ell}{\ell_k - \ell}\right)^n$$

Or:

$$M_k = \frac{\pi d_s^3 \ell_k}{\delta} \left(\frac{\ell_s - \ell}{\ell_k - \ell}\right)^{3n} = \left(\frac{11}{21}\right) d_s^3 \ell_k \left(\frac{\ell_s - \ell}{\ell_k - \ell}\right)^{3n} \quad (13)$$

Differentiating Eq. (13) with respect to specific gravity, yields

- If  $\frac{dM_k}{d_\ell} = 0; \ell_s = \ell \text{ or } \ell_s = \ell_k$
- If  $\frac{dM_k}{d_\ell} = \infty; \ell_s = \ell, \text{ and } \ell_s = \ell \text{ or } \ell_k = \ell$

Particle separation completed.

If Newton's law controls i.e., n = 1:

$$\frac{dM_k}{d_\ell} = \frac{11}{7} d_s^3 \ell_k (\ell_s - \ell_k) \frac{(\ell_s - \ell)^2}{(\ell_k - \ell)^4} \quad (14a)$$

For  $\frac{dM_k}{d_\ell} = 0, \ell_s = \ell$ .

=  $\infty, \ell_k = \ell$  complete separation.

If stokes law controls i.e., n = 1/2:

$$\frac{dM_k}{d_\ell} = \frac{11}{14} d_s^3 \ell_k (\ell_s - \ell_k) \frac{(\ell_s - \ell)^{1/2}}{(\ell_k - \ell)^{5/2}} \quad (14b)$$

Again for  $\frac{dM_k}{d_\ell} = 0, \ell_s = \ell$ .

=  $\infty, \ell_k = \ell$  complete separation

For second derivatives of Eq. (13) we have:

$$\frac{d^2 M_k}{d\ell^2} = \frac{22}{7} n d_s^3 \ell_k (\ell_s - \ell_k) \frac{\left(\frac{(\ell_s - \ell)^{3n}}{(\ell_k - \ell)}\right)}{\frac{\ell_s - \ell}{(\ell_s \ell_k - (\ell_k + \ell_s)\ell + \ell^2)^2}} \quad (15a)$$

$$\begin{aligned} \text{If } \frac{d^2 M_k}{d\ell^2} = 0, \ell_s = \ell \\ = \infty, \ell_k = \ell \text{ or } \ell_s = \ell \end{aligned}$$

At near stoke's regime i.e., n = 2/3.

$$\frac{d^2 M_k}{d\ell^2} = \frac{44}{21} d_s^3 \ell_k \left(\frac{(\ell_s - \ell)}{(\ell_k - \ell)}\right)^2 \frac{\ell_s - \ell_k}{(\ell_s - \ell)(\ell_k - \ell)} \quad (15b)$$

$$= \frac{44}{21} d_s^3 \ell_k (\ell_s - \ell_k) \frac{\ell_s - \ell}{(\ell_k - \ell)^2}$$

For  $\frac{d^2 M_k}{d\ell^2} = 0, \ell_s = \ell$

=  $\infty, \ell_k = \ell$  Complete separation.

## MATERIALS

The main raw materials for this study are clay, cracked kernels and shells water, bath, weighing balance, scooper (basket), shirrer and sifter.

**Experimental procedure:** Centrifugally-cracked kernel/shell mixture were sifted in a sifter of tiny mesh size and winnowed to remove sand; sticks and debris from the mixture.

Different clay masses (Mc) were tied in light water proof and dropped into water containers that are filled to the brim. The spills of each container as a result of the displacements were collected and the volumes found as Vc. The Eq. (16) was used to obtain the specific gravity of the mud slurry:

$$\ell_{s.g} = \frac{1}{\ell_w} \left(\frac{Mw + Mc}{Vw + Vc}\right) = \frac{1}{100} \left(\frac{500 + Mc}{0.5 + Vc}\right) \quad (16)$$

500 L of water was poured into a bath. Different masses of and of clay were weighed out and dissolved into the constant volume of 100 L of water respectively. This was followed by the respective pouring of different masses of kernel/shell mixture, stirring and scooping of floating kernel/shell mixture. The remaining shells in the scooped mixture are hand-picked off and the kernel weighed and recorded as the density of that clay slurry is calculated and recorded. This procedure is repeated for fourteen times.

This is continued until nearly a constant mass of floated and scooped kernel is reached or returned.

**Experimental observations:** Apart from the experimental result, distinct and unique observations were made during the course of the experiment. Among them are:

- As the density was increased by the continual and stepwise addition of clay, the amount of the floating mass increases, with the kernels being in higher proportion.
- As clay is continually added, it reached a point where a constant floating mass of kernel was always observed.
- This trend continues until a point is reached where the floating mass contains almost equal amount of shell and kernel. By now, the slurry is so viscous that stirring becomes difficult.

**EXPERIMENTAL RESULTS**

The experimental Results of the procedure described above is shown in Table 2.

**Modeling by curve-fitting:** The data obtained in the experiment (Table 2) was plotted to obtain a scatter diagram. A mathematical model Eq. (17) was superimposed on the scatter diagram to see the fitness using MATLAB:

$$M_k = a(1 - a_0 \exp(-k\ell_n)) \tag{17}$$

Toolbox 7.0 Version. It declares the values of constants and parameters of the model up to 95% confidence bound as well as give the statistical goodness of fit of the superimposed model on the profile (Table 3 and Fig. 1). Plots of weight of floated kernel versus sp. Gravity for n = and 1 are shown in Fig. 2 and 3. They all shows exponential rise. A plot of

Table 1: Properties of palm kernel, nut and shell (Graham and Jones 1954)

Parameters	Palm nut	Palm kernels	Palm shell
Major diameter, cm	2.6800	1.570	1.390
Intermediate diameter, cm	1.9700	1.210	0.940
Minor diameter, cm	1.5700	0.920	0.480
Geometric mean diameter, cm	2.0200	1.200	0.850
Sphericity	0.8000	0.800	0.600
Bulk density, kg/m <sup>3</sup>	594.31	568.9	565.3
Specific gravity	1.1500	1.100	1.300
Static angle of repose, degree	43.200	38.00	47.90
Unit weight, g	1.8600	1.110	0.400

Table 2: Experimental result data

	0.0000	86.170	191.530	296.990	392.540	498.320	594.36
Clay mass, Mc, (kg)	0.0000	0.0010	0.00111	0.00125	0.00143	0.00167	0.0020
Clay volume, Vc, (M <sup>3</sup> )	1.0000	1.1700	1.38000	1.59000	1.78000	1.99000	2.1800
Slurry sp. Gr., ℓ	0.0300	0.0960	0.19300	0.25700	0.29700	0.32900	0.3550
Floated kernel mass (kg)	700.98	798.60	918.010	1025.07	1119.54	1225.82	1346.2
Clay mass, Mc, (kg)	0.0025	0.0033	0.00500	0.00670	0.00770	0.00910	0.0100
Clay volume, Vc, (M <sup>3</sup> )	2.3900	2.5800	2.81000	3.01000	3.19000	3.39000	3.6200
Slurry Sp. Gr., ℓ	0.3700	0.3890	0.39800	0.41000	0.41900	0.41900	0.4200
Floated kernel mass (kg)							

Table 3: Coefs and goodness of fit for  $M_k = a(1 - a_0 \exp(-k\ell_n))$

Coefs (with 95% confidence bound)	Goodness of fit
a = 0.4343 (0.4259, 0.4426)	SSE = 0.0003141
a <sub>0</sub> = 3.773 (3.344, 4.202)	R <sup>2</sup> = 0.9985000
k = 1.383 (1.284, 1.482)	R <sup>2</sup> Adj = 0.9982000
u: f(12.8529) = 0.434261kg	RMSE = 0.0053430

Table 4: Computational Table from eqn. (13)

3n	1	2	3	4	5	6	7	8	9	10	
n	1/2	2/3	1.0000	4/3	5/3	6/3	7/3	8/3	9/3	10/3	
ℓ <sub>k</sub>	0.2635	0.8349	0.7242	0.7568	0.7744	0.7858	0.7936	0.7992	1.4270	0.8071	
ℓ <sub>s</sub>	0.9967	1.0370	0.9082	0.8930	0.8828	0.8758	0.8706	0.8665	1.4230	0.8609	
d <sub>s</sub>	1.5870	1.0400	1.1140	1.0990	1.0880	1.0830	1.0790	1.0760	0.7503	1.0730	
R <sup>2</sup>	0.9946	0.9969	0.9979	0.9980	0.9981	0.9981	0.9981	0.9981	0.1713	0.9981	
3n	11	12	13	14	15	16	17	18	19	20	21
n	11/3	12/3	13/3	14/3	15/3	16/3	17/3	18/3	19/3	20/3	21/3
ℓ <sub>k</sub>	0.8098	1.188	0.8141	0.8155	0.8168	0.8181	0.8191	0.8200	0.8209	0.8216	0.8224
ℓ <sub>s</sub>	0.8587	1.1186	0.8554	0.8538	0.8526	0.8516	0.8507	0.8498	0.8492	0.8484	0.8479
d <sub>s</sub>	1.0720	0.8046	1.0700	1.0690	1.0690	1.0680	1.0670	1.0670	1.0670	1.0660	1.0660
R <sup>2</sup>	0.9981	0.2880	0.9981	0.9981	0.9981	0.9982	0.9982	0.9982	0.9982	0.9982	0.9982

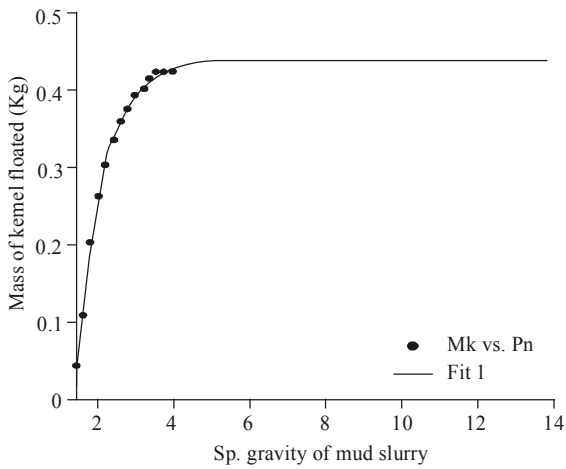


Fig. 1: Mass of kernel floated versus sp.gravity of mud slurry\*

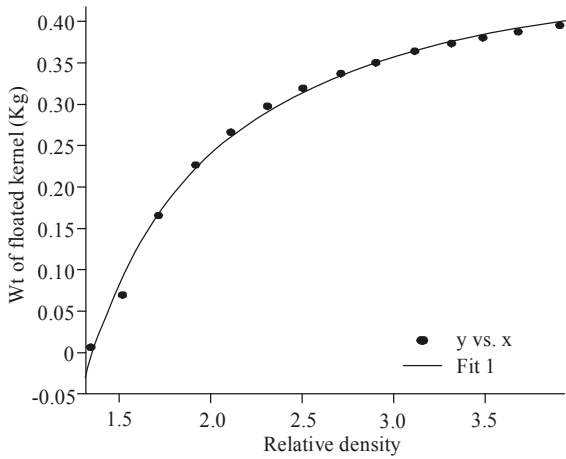


Fig. 2: Weight of floated kernel versus slurry relative density (n = 1/3)\*

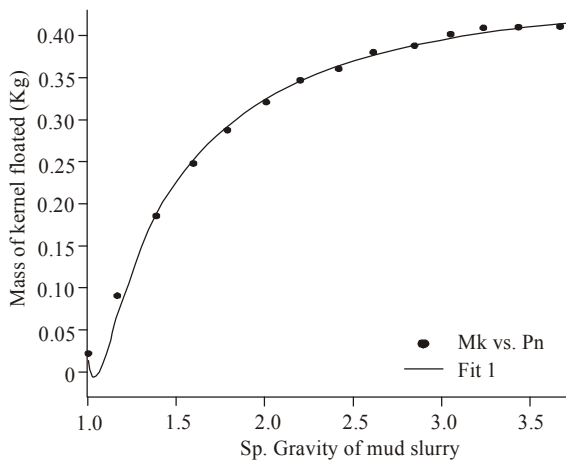


Fig. 3: Mass of kernel floated versus sp.gravity of mud slurry (near Stokes law: n = 2/3)\*

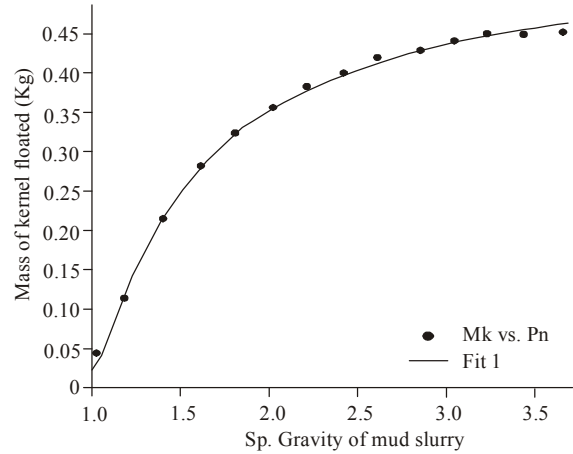


Fig. 4: Mass of kernel floated versus sp.gravity of mud slurry (Newton's law: n = 1)\*

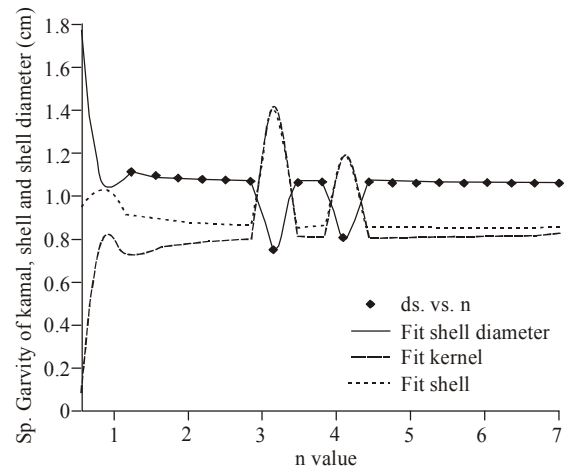


Fig. 5: Sp.gravity of kernel, shell and shell diameter versus n values\*

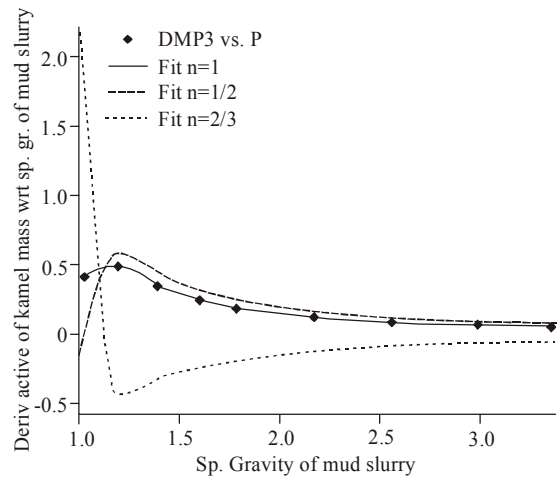


Fig. 6: Derivative of kernel mass w.r.t sp.gr Vs sp.gr of mud slurry\*

n-values versus densities of loaded kernel, shell and shell size (Table 4) is shown in Fig. 4. Derivative of

floated kernel mass versus sp. Gravity of the mud slurry is shown in Fig. 5.

## DISCUSSION

From the experimental result, it is evident that small amount of shell and kernel floated on the water before the addition of clay. Water has a specific gravity of 1.0 while the specific gravities of kernel and shell are 1.10 and 1.90 respectively. Kernel and shell can get drier with their specific gravities getting to 1.0 so that they float.

From Fig. 1 which shows the graph of weight of kernel floated versus specific gravity, it was observed that on addition of clay to the water to form slurry, the kernel and shell mixture gradually separate. The added clay increases the density of the fluid. The graph shows that this increment in density brings about an increment in the quantity of shell and kernel it is less dense than the shell. This trend continues until the maximum point of separation where no matter the increase in clay slurry density there is no more floated kernel mass increase. At this maximum separation, there is little or no floating shells accompanying the floating mass of kernels. This means that the floating kernel mass remains constant as curve of Fig. 1 goes sigmoidal or asymptotic with specific gravity axis i.e., mud clay slurry can be densest to the point that it cannot be stirred, yet the floating kernel mass will never change.

From the derivative of floating kernel mass with respect to mud clay slurry specific gravity, maximum separation of kernel and shell occurs when either.

- $\ell_k \neq \ell_s$  and  $\ell_s = \ell$

Or:

- $\ell_k \neq \ell_s$  and  $\ell_k = \ell$  but not both

Separation of kernel and shell is significant when the specific gravity of the mud clay slurry grows into between those of kernel and slurry: (i) kernel floats when  $\ell_k < \ell < \ell_s$  (ii) shell floats when  $\ell_s < \ell < \ell_k$ .

## CONCLUSION/RECOMMENDATION

From the conducted experiment and analysis of the result, it can be concluded that for separation of the

palm kernel and shell mixture to occur, the density of the slurry must be greater than the density of the kernel but less than the density of the shell or vice versa. When the density of the slurry is increased above the density of the shell, the shell floats, also.

Therefore, to obtain complete separation of the palm kernel-shell mixture, the density of the slurry should be between the densities of the kernel and that of shell.

Based on the findings of this study, it is recommended that clay slurry be used in the separation of palm kernel-shell mixture because it is the cheapest method of separating the mixture and, its efficiency is about 99%.

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