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RESEARCH ARTICLE

EVALUATION OF PASSIVE NATURAL CONVECTION SOLAR CHIMNEY DRYER FOR RURAL FARMERS USING GIANT AFRICAN SNAILS.

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Abstract

The performance evaluation of a solar chimney dryer for rural farmers using Giant African Snails has been carried out and the results compared with the open-sun drying. The solar dryer consists of the solar collector and the chimney drying chamber with four trays with dimensions of 1.00 x 0.70 x 0.20 m^3 and 1.00 x 0.70 x 0.50 m^3 respectively. The experiment was carried out at Uyo (Latitude $5^{\circ}\,2'60$ N and Longitude $7^{\circ}55'60$ E). The results show a reduction in mass from 20.00 kg to 3.70 kg and from 20.00 kg to 4.65 kg for dryer and open-sun drying respectively. The average drying temperature was about 46.06 $^{\circ}$C and the average insolation on the horizontal surface was about 393.09 Wm^{-2}. The results also show that the moisture content left in the Giant African Snails after drying was about 24.48 % in the dryer. The solar chimney dryer efficiency was about 20.43 %.

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Introduction:-

Drying is an excellent way of preserving food that can add variety to meals and provide delicious and nutritious snacks like the Giant African Snails. The Giant African Land Snail is the common name used to two genera and three species within the family *Achatinidae* native to Africa: the Giant African Snail (*Achatina achatina*), in the genus *Achatina*, which grows to be the largest land snail on Earth; the Giant East African Snail (*Achatina fulica*) and the Giant West African Snail (*Archachatina marginata*). The Giant African Snails are large, terrestrial snails that can reach up to 20 cm in length and 10 cm in maximum diameter and can live up to 10 years (Dean *et al.*, 1970; Hodasi, 1979; Wu *et al.*, 2007; Cowie *et al.*, 2009). The Giant African Land Snail is one of the largest of all the terrestrial species. They have light to dark brown shells with vertical stripes of a darker shade of brown on them. These snails are herbivorous. They consume a wide variety of plants, fruits and vegetables. In Africa, the Giant African Land Snail is considered to be a very delicious source of food. They are nutritional and very expensive in many areas, so rural dwellers harvest these snails in order to eat and to sell the excess to make money. In West Africa and other parts of Africa, snail meat has traditionally been a major ingredient in the diet of people living in the forest area (Beckett, 1964; Cobbinah, 1993; Engmann *et al.*, 2012). Snails are in abundance during the rainy season when they are collected in large quantities by rural communities and are very cheap, but become scarce and expensive during the dry season when they aestivate and are difficult to find (Asibey, 1986; Wilson, 2007; Ahmed and Raut, 2008; Rahman and Raut, 2010; Engmann *et al.*, 2012). Their unavailability throughout the year, coupled with acclaimed health benefits, had led to many countries encouraging the rearing of snail to alleviate poverty and to address malnutrition due to protein deficiency at the rural and sub-urban areas (Akinnusi, 1998; Thiengo *et al.*, 2007; Appiah *et al.*, 2009; Engmann *et al.*, 2012). From the mean sensory ranking test scores for farm-reared Giant African Snails (*Achatina achatina*) as studied by Engmann *et al.*, (2012) the results show that in terms of flavour: Smoke-dried 17.50; Tray-dried 14.50; Solar-dried 23.50; Asymptotic significance

0.08; in terms of appearance: Smoke-dried 16.50; Tray-dried 14.50; Solar-dried 24.50; Asymptotic significance 0.03; and in terms of taste: Smoke-dried 16.08; Tray-dried 24.13; Solar-dried 15.29; and Asymptotic significance 0.07. Giant East African Snail (*Achatina fulica*) also has been very useful in menu of many African tribes and beyond as they act as a fairly cheap source of protein. The nutritional value of *Achatina fulica* meat in relation to other meats shows that snail meat has the highest carbohydrate about 80 % and the highest protein about 21 % (Jummai and Okoli, 2013).

Drying the Giant African Snails by solar energy is of great economic importance especially in rural areas where most of the crops harvested are lost due to fungal and microbial attacks (Itodo *et al.*, 2002). These wastages could be prevented by proper drying which enhances storage (Twidell and Weir, 1986). Preserving the Giant African Snails by solar drying requires only the heat of the sun. Dried Giant African Snails require no energy to maintain it while stored. Related expenses are practically cut-off and little storage space is required. Dried Giant African Snails are light in weight and compact in size; also all dried food is delicious and remains nutritious. In remote localities Giant African Snail is dried by the open-sun method which has some obvious disadvantages (Irtwange and Adebayo, 2009; Eze, 2010; Aliyu *et al.*, 2013). This method of open-sun drying is unhygienic since the Giant African Snails are easily contaminated by flies, dust and birds droppings and consequently infected by fungi and bacteria. Human health could thus be endangered as a result of food poisoning. This method also prolongs drying and could result in the deterioration of the Giant African Snail. Moreover, open-sun drying is labour intensive as the Giant African Snails are moved frequently in and out during the day and night and from rain. In rural areas, conventional sources of energy are totally absent for the development of active dryers which have higher rates of performance (Gatea, 2011; Sundari *et al.*, 2013). In this work, a low temperature passive natural convection solar chimney dryer was used for drying the Giant African Snails at low temperature and high relative humidity period of the year. One obvious advantage of low temperature drying is that it enables the Giant African Snails to be dried evenly without burning and hence minimizes the exposure of the Giant African Snails to fungal and bacterial infection and wastages (Forson *et al.*, 2007). This method is very suitable for bulk drying for long-term storage. The objective of this work is to evaluate the performance of a low temperature passive natural convection solar chimney dryer using Giant African Snails at high relative humidity at Uyo, Nigeria.

Theory

Declination (δ): This is the angle between the sun's direction and the equatorial plane and is given by (Duffie and Beckman, 1974; Twidell and Weir, 1986; Forson *et al.*, 2007; Eze and Chibuzor, 2008) as,

$$\delta = 23.45\sin\left[0.9863\,(284 + n)\right] \quad (1)$$

where (n) is the day number of the year from n = 1 to n = 365.

Length of the Day (N): The length of the day is given by (Duffie and Beckman 1974; Twidell and Weir, 1986; Henry and Price, 1999) as

$$N = \left(\frac{2}{15}\right)\cos^{-1}\left(-\tan\varphi\tan\delta\right) \quad (2)$$

Optimum Collector Slope (β): The optimum collector slope, (β) is determined from

$$\beta = \delta + \varphi \quad (3)$$

where (δ) is the angle of declination for Uyo, Nigeria and (φ) is the latitude of the Uyo, Nigeria.

Collector Efficiency (η): The collector efficiency (η) is computed from

$$\eta = \frac{\rho V c_p \Delta T}{A I_c} \quad (4)$$

where ρ is the density of air (kgm^{-3}); I_c is the insolation on the collector; ΔT is the temperature elevation; c_p is the specific heat capacity of the air at constant pressure (Jkg^{-1}K^{-1}); V is the volumetric flow rate (m^{3}s^{-1}); and A is the effective area of the collector facing the sun (m^2).

Dryer Efficiency (η_d): The dryer efficiency η_d is given by

$$\eta_d = \frac{w\Delta H_L}{I_d A_c} \quad (5)$$

where w is the moisture evaporated (kg), ΔH_L is the latent heat of vaporization of water (2320 kJkg^{-1}), I_d is the total hourly insolation on the collector and A_c is the area of collector (m^2). Dryer efficiency (η_d) of a system is the ratio of energy used to evaporate the moisture from the product to the energy supplied to the dryer, (Saravanan *et al.*, 2014).

Rate of Heat Flow into the Dryer: This is the sum of the convective heat (q_c), conductive heat (q_k) and radiative heat (q_r) transfers (Twidell and Weir, 1986; Jin, 2005), i.e.,

$$q = q_c + q_k + q_r \quad (6)$$

$$\frac{q}{A} = \frac{T_a - T_d}{\frac{1}{h_a} + \frac{\Delta x}{k} + \frac{1}{h_d}} + \varepsilon\sigma(T_a^4 - T_d^4) \quad (7)$$

where q/A is the rate of heat transfer per unit area, h_a is the heat transfer coefficient for the ambient, h_d is the heat transfer coefficient for the dryer chamber, T_a is the ambient temperature, T_d is the drying chamber temperature, σ is Stefan-Boltzmann constant, Δx is the thickness of the glass cover, A is the effective area of the collector, and ε is the emissivity and k is the thermal conductivity.

Heat Energy *Q* needed for Crop Drying at Moderate Temperature: This is given by

$$Q = M_w L = \rho c_p V(T_a - T_b) \quad (8)$$

where L is the latent heat of vaporization of water, M_w is the mass of meat before drying, ρ is the density of water, c_p is the specific heat capacity of air at constant pressure (J/kgK), V is the volumetric flow rate (m^3/s), T_a is the ambient temperature and T_b is the dryer temperature (K).

Moisture Content (*MC*): The moisture content is given as

$$MC(\%) = \frac{M_i - M_f}{M_i} \, x \, 100\% \quad (9)$$

where M_i is the mass of sample before drying and M_f is the mass of sample after drying.

Moisture Loss (*ML*): The moisture loss is given as

$$ML = (M_i - M_f)(g) \quad (10)$$

where M_i is the mass of the sample before drying and M_f is the mass of the sample after drying.

Average Drying Rate (*R_d*): The average drying rate (R_d) is given by (Ajao and Adedeji, 2008; Hassanain, 2011) as

$$R_d = \frac{M_i - M_f}{t} \quad (11)$$

where M_i is the initial mass of dried samples, M_f is the final mass of the dried samples and t is the drying time.

The effectiveness factor is the ratio of the drying rate in the solar dryer to that in the open-sun drying, (Saravanan *et al.*, 2014):

$$Effectiveness\ factor = \frac{Drying\ rate\ in\ solar\ dryer}{Drying\ rate\ in\ open{-}sun\ drying} \quad (12)$$

Global Solar Radiation Model

Several models have been developed (Duffie and Beckman, 1974; Al-Ajlan *et al.*, 2003; Jin, 2005; El-Sebaii and Trabea, 2005; Tarhan and Sari, 2005) for predicting global solar radiation on a horizontal surface at a given location. The extraterrestrial solar radiation incident on a horizontal surface H_o is given by

$$H_o = \frac{23(1367)}{\pi}\left[1 + 0.033\cos\varphi\cos\left(\frac{360n}{365}\right)\right]\sin\varphi\sin\delta + \cos\varphi\cos\omega_s\sin\delta \quad (13)$$

where n is the day number, φ is the latitude (degrees), δ is the declination angle (degrees) and ω_s is the hour angle (degrees). The declination angle δ and the hour angle ω_s are determined from the expressions in equations 14 and 15, respectively (Duffie and Beckman, 1974):

$$\delta = 23.45\sin\left[360\left(\frac{284 + n}{365}\right)\right] \quad (14)$$

$$\omega_s = \pm\cos^{-1}(-\tan\varphi\tan\delta) \quad (15)$$

Solar radiation at any location is a function of several parameters like latitude, declination, hour angle and altitude (Jin, 2005). A model has been developed (Jin, 2005) given in equation 16;

$$H_g' = H_o\left\{\begin{aligned}&(0.0218 + 0.0033\varphi + 0.0443H_{asl}) + (0.9979 - 0.0092\phi - 0.0852H_{asl})\frac{S_p}{S_a}\\ &+ (-0.5579 + 0.012\phi - 0.1005H_{asl})\left(\frac{S_p}{S_a}\right)\end{aligned}\right\} \quad (16)$$

where H_g' is the general daily global solar radiation on a horizontal surface (MJm^{-2}), S_p is the number of possible sunshine hours in a particular day, S_a is the actual sunshine hours in a particular day, and H_{asl} is the height (km) above sea level. A set of equations to determine the hourly global solar radiation I_g (Wm^{-2}) incident on a horizontal surface are given in equations 17-19, in which ω is the hour angle (degrees) such that
for $n \leq 120$:

$$I_g = 1.2545\left[\frac{\pi}{24} H_g \left(a_j - b_j \cos\omega\right)\right]\left[\frac{\left(\cos\omega - \cos\omega_s\right)}{\left(\sin\omega_s - \frac{\pi\omega_s}{180}\cos\omega_s\right)}\right]\left[1 + 0.033\cos\left(\frac{360n}{365}\right)\right]^4 \cos^2\delta. \quad (17)$$

For $120 < n < 310$:

$$I_g = 1.0816\left[\frac{\pi}{24} H_g' \left(a_j + b_j \cos\omega\right)\right]\left[\frac{\left(\cos\omega - \cos\omega_s\right)}{\left(\sin\omega_s - \frac{\pi\omega_s}{180}\cos\omega_s\right)}\right]\left[1 + 0.033\cos\left(\frac{360n}{365}\right)\right]\cos^2\delta \quad (18)$$

And for $310 \leq n \leq 365$:

$$I_g = 1.4235\left[\frac{\pi}{24} H_g' \left(a_j - b_j \cos\omega\right)\right]\left[\frac{\left(\cos\omega - \cos\omega_s\right)}{\left(\sin\omega_s - \frac{\pi\omega_s}{180}\cos\omega_s\right)}\right]\left[1 + 0.033\cos\left(\frac{360n}{365}\right)\right]^2 \cos^4\delta \quad (19)$$

The parameters a_j and b_j are evaluated using the expressions in equations 20 and 21 (Jin, 2005):

$$a_j = 0.409 + 0.5061\sin\left(\omega_s - 60\right) \quad (20)$$

and

$$b_j = 0.6609 - 0.4767\sin\left(\omega_s - 60\right) \quad (21)$$

Materials and Methods:-

The solar chimney used was made of four lengths of single iron bars, two steel pipes of length 5.08 m each, two steel plate sheets of 1.5×10^{-3} m each, Perspex glass of 1.00 x 0.70 m^2 and 1.00 x 0.50 m^2, wire mesh, four racks and a solar collector of 1.00 m x 0.70 m x 0.20 m tilted 45° facing South, Fig. 1.

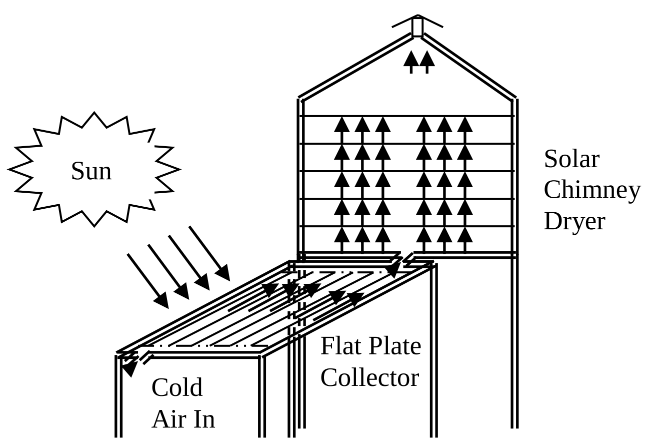

Fig. 1:- Passive Solar Chimney Dryer

Giant African Snails were bought from the local market at Uyo, washed in water and removed from their shells and rinsed. They were then soaked in a 5 M solution of common salt from 5 to 10 minutes. Salt was used only

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as a seasoning, not as a preservative. The snails were weighed and about 20.00 kg were placed on the racks. During drying they were turned over occasionally to maintain uniform drying and brought out every hour for weighing using a digital chemical balance. Two thermocouples were positioned at the inlet and outlet portions of the solar collector and chimney dryer to measure the air temperature. The ambient temperature was recorded using a mercury thermometer. The experiment was carried out at Uyo, Nigeria (Latitude 5º2´60 N and Longitude 7º55´60 E) (Anon., 2011) in March for three days. The finished product was hard, brittle and dry.

Results and Discussion:-

The results obtained from the passive natural convection solar chimney drying and open-sun drying of Giant African Snails are presented in Figs. 2 – 7. The system temperatures i.e., ambient, collector and dryer temperatures for the three days are presented in Figs. 2 – 4, while the weight loss for the three days is presented in Figs. 5 – 7.

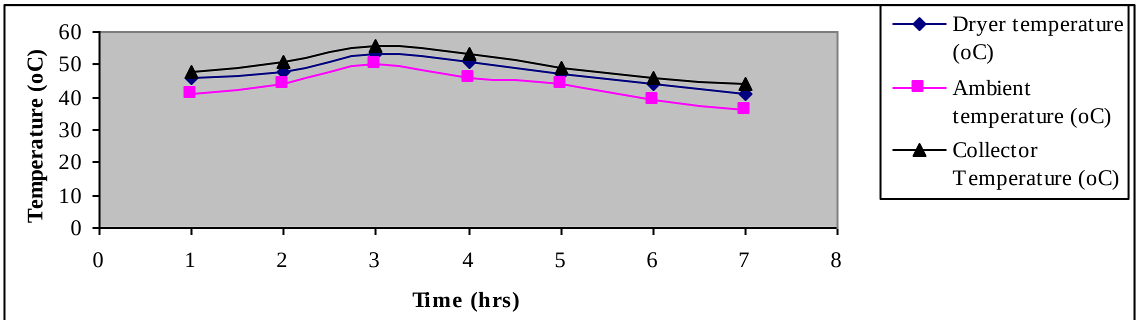

Fig.2: System Temperature - Day 1

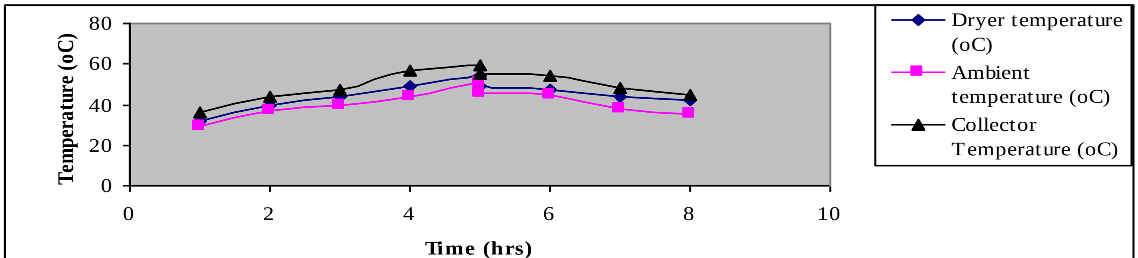

Fig.3: System Temperature - Day 2

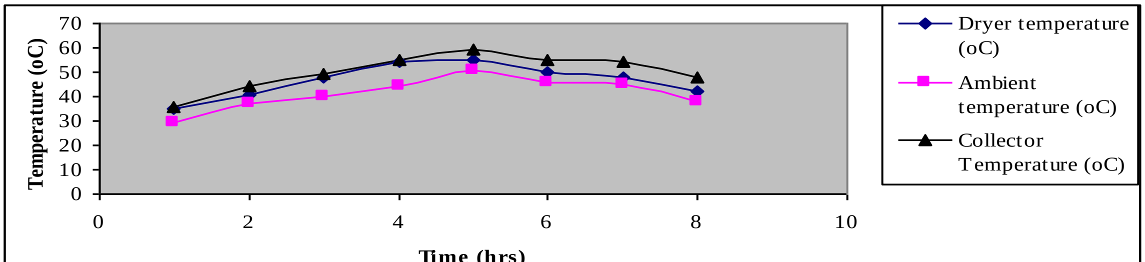

Fig.4: System Temperature - Day 3

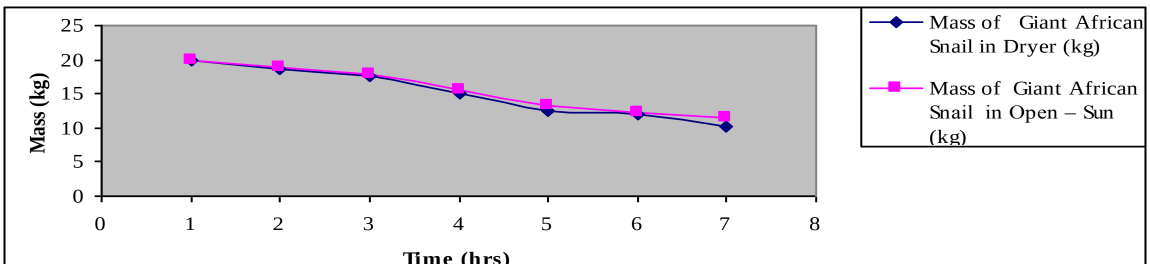

Fig.5: Weight Loss - Day 1

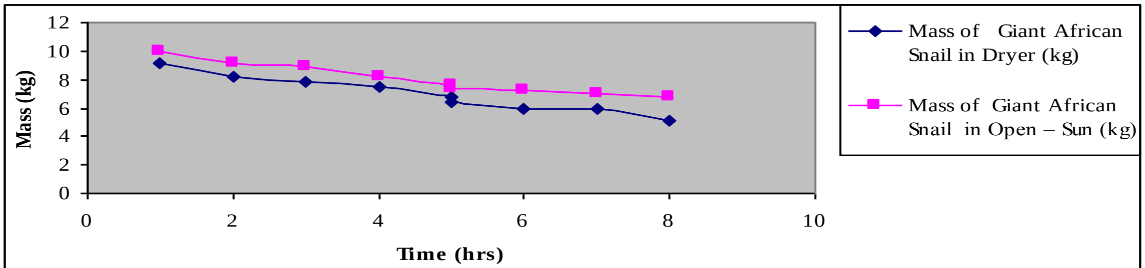

Fig.6: Weight Loss - Day 2

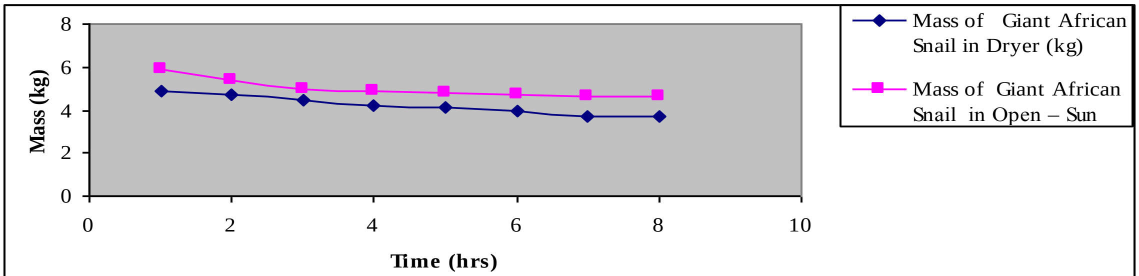

Fig.7: Weight Loss - Day 3

The results indicate that the dryer temperature was higher than the ambient temperature but lower than the collector temperature during the three days, the minimum and maximum temperatures were 32 ºC and 55 ºC for the dryer, 29 ºC and 51 ºC for the ambient and 36 ºC and 59 ºC for the collector. The highest temperatures occur at 1:00 PM. The average drying temperatures were 47.1 ºC, 44.5 ºC and 46.6 ºC for day 1, day 2 and day 3, respectively. The average drying temperature was about 46.06 ºC and the average insolation on the horizontal surface was about 393.09 Wm^{-2}. The average weight loss for the Giant African Snails in the dryer and open-sun were 9.90 kg and 8.60 kg for day 1, 4.00 kg and 3.20 kg for day 2, 1.20 kg and 1.25 kg for day 3. The results obtained also reveal that the moisture content left in the snails after three days was 24.48 % in the dryer. Properly dried food has a moisture content which varies from 5 % to 25 % depending on the food (Whitefield, 2000; Ogheneruona *et al.*, 2011), so the Giant African Snails were properly dried for long term storage. The passive natural convection solar chimney dryer efficiency was about 20.43 %. This is low because the dryer was opened at the top of each hour to collect the sample for weighing (Ojiki, 2010; Wansah *et al*., 2011; Wansah *et al.*, 2014). The final mass of the dried snails was 3.70 kg in the dryer and 4.65 kg in the open-sun. The snails in the dryer attained a lower final mass than that in the open sun.

Conclusion:-

The performance evaluation of a passive natural convection solar chimney dryer for rural farmers using Giant African Snails at Uyo has been carried out. The amount of moisture content decreased progressively to a minimum in the dryer due to the flow of dry warm air as a result of the amount of insolation on the solar collector. The solar chimney dryer efficiency could have been higher if it was closed all day. The colour of the dried Giant African Snails in the solar chimney dryer was brown with the appearance and flavour enhanced. The passive natural convection solar chimney dryer is therefore recommended to rural farmers at Uyo to enhance and utilize the free solar energy resource found abundantly in Uyo which is within the tropics.

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