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The impact of mechanised stirring and scraping operations in a coffee and cocoa beans drying unit in Cameroon

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Abstract: The work performed in this paper concerns «The impact of mechanised stirring and scraping operations in a coffee and cocoa beans drying unit in Cameroon». The aim was to evaluate the impact of an equipment designed to perform the stirring and scraping operations during a drying cycle. In the case these operations are performed manually, some problems such as the risks of accident on the operators, enormous losses in time and work shutdowns are notified. Then a machine have been designed and sized to fulfil these functions. To evaluate the impact of this mechanisation, the adopted methodology start by the study of the existing mechanism. Come next the evaluation of the impact, based on the mixing degree, drying time and scraping duration criteria. The corresponding values for these criteria have been reported for ten non-mechanised drying cycles. The results obtained show the grains drying will be more homogeneous, with a mixing degree improved of 47.7% in lower value and 22.44% in upper value. The drying time will be reduced by 30% and the scraping duration will be reduced by 49.5%, both in lower value. Finally, the whole drying cycle will be reduced by 28.7% in lower value, which represent 01h24min42s.

Keywords: Drying unit, Beans, Mechanisation, Stirring, Scraping

I. INTRODUCTION

In the actual context of enhancing the production of coffee and cocoa for local transformation or exportation, Cameroon should particularly pay attention to the quality of these products. After harvesting of coffee and cocoa beans, next are in order pulping and peeling, sorting, fermentation and drying. The drying operation is an important step for this beans and determining for the beans final quality. By acting on the fermentation and drying conditions, we can obtain a significant improvement of the beans quality. In fact, according to the ONCC (2017)[1], among the defaults intervening in the quality depreciation, two are particularly important: dark-eyed beans and mouldy beans. This second default results from an insufficient drying and represent the most recurrent cause of decommissioning of packages or their non-conformity to the standards requested at the exportation. After the drying performed by farmers, the beans presents an average moisture content of 25% [1], knowing the normalised moisture content for coca beans is 7% according to ISO 2451(2017)[2] and coffee beans is 12% according to ISO 3509 (2009)[3]. This is the direct cause of beans darkening and mould growth. Then it becomes necessary to proceed to an additional drying by the way of static dryers. In this type of dryers, the beans are dried by convection; the humid beans are crossed by a hot airstream and the heat exchange produced allowed the dehumidification. For a thick layer of beans, there is a problem of temperature gradient. This gradient represent the temperature contrast between the layer close to the heat source and the farthest layer. As result of this phenomenon, we have non-uniformly dried beans. In order to solve this problem, a mechanism able to fulfil the double functions of stir the humid beans and scrape the dried beans have been designed and sized. In order to measure the contribution of this mechanisation, it is essential to proceed at an evaluation of the impact on drying cycle. The work realised to complete this evaluation begins by the description of a dying unit, followed by the description of the stirring and scraper devices studied. Come next the methodology of machine sizing which present the different steps followed to size the parts of the machine. The next step consist of the evaluation of the impact of the stirring and scraping mechanisation. The work is ended by the presentation of the results obtained.

II. MATERIALS

2.1. Description of a drying unit

A drying unit based on the convection principle is as represented in fig. 1. It is a platform consisting of: (i) fuel tank; (ii) forced-air furnace including: a fuel burner self-aspirating, with a combustion chamber, a fan to aspire the room air and a heat exchanger. The hot air generated will be propelled inside the dryer by a centrifugal fan. (iii) a concrete drying cell to contain the hot air; (iv) a perforated aluminium sheet metal floor, fixed on the concrete cell and containing the humid beans; (v) an emptying hatch is installed and allowed the evacuation of the dried beans.

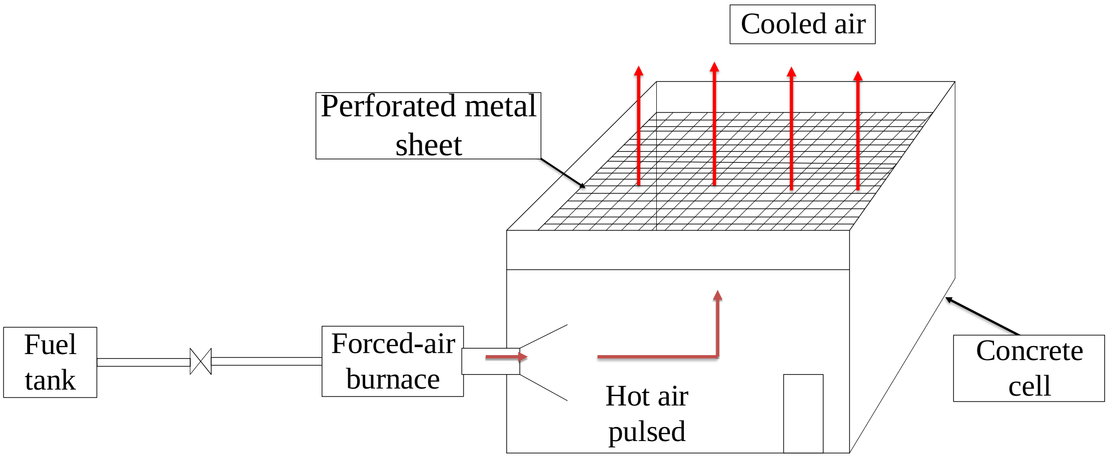

Fig. 1: Description of a drying unit

During the drying, the gradient of temperature appears between the upper and the lower layers. To homogenise the temperature, one remedies with manual stirring and scraping of the beans. This traditional solution present three (03) significant problems: (i) According to K. Mamadou, et al. (2008) [4], the risks of contamination to Ocratoxine A (OTA) is raised because of the continuous touch between the operators who stir the beans and the coffee beans. (ii) The proximity between the operators equipped with shovels present a problem of health and security at work and can induce serial injury. (iii) Because of the manual stirring, the stirring efficiency is variant and the slowness of the scraping involve a slowdown or an arrest of the production chain. Thus it is necessary to design a device able to stir and scrap the beans. In this design approach, it is important to study the existing scrapers and stirrers machines; this is the purpose of the next paragraph.

2.2. Description of the stirring and scraping mechanism

2.2.1. Stirring/Scraping sub-set

2.2.1.1. Stirrers studied

Stirrers are mechanism allowing to put in movement materials (solid or liquid). According to Uhl Gray (1967) [5] and J. Cullen (2009) [6], we have the following stirrers: (i) Drum stirrers and tumblers released by a closed vessel rotating around the axis in a tumbling stirrer. (ii) Paddle and plough stirrers are composed of U-shaped channel and an impeller consisting of rotating single shaft or twin shafts carrying ploughs or paddles at a regular pitch. (iii) Forberg or fluidizing paddle stirrers: Paddles are installed on twin shafts in a twin trough and fluidizing is done with counter rotating paddles. (iv) Ribbon stirrer: mixing is done by pushing the particles in a trough along the axis in both ways and centrifugal force is used to displacing them. (v) Vertical Orbiting Screw Stirrers: Orbiting screw stirrer is equipped with a conical vessel or hopper which is fixed with and Archimedes screw orbiting along the hopper wall. (vi) Sigma-blade or z-blade stirrers which are categorized as agitated stirrers, consist of twin troughs fitting with a heavy-duty Z-shaped blade. (vii) Special mixing shovels: consist of a set of shovels, fixed on a frame or shaft. The whole system is mounted on a circular or rectangular tank, and can rotates or translates.

2.2.1.2. Scrapers studied

From Belmoral Mines (1978) [7], the three scrapers scoops can be classify as: the box type of scoop with its side plates providing a large running. The hoe type of scoop, with its side triangular and plate. The shovels type, with its sides rectangular and curved. From this three (03) types of scraper scoops, considering the criteria of judgment established by Ngakwe (2017) [8], the box type is the most indicated for this case for its good application on bulk material, its durability, and more. Depending on the mode, the stirring or scrap will be released by shovels regularly disposed on a rectangular profiled steel as support. Sprockets mounted on the upper end of each shovels, will allowed the rotation motion of the shovels, by the help of a chain and a gear motor. Pneumatic cylinders mounted on the main support will order the rotation motion of the rectangular profiled during the scraper mode, such as scrap the bed of beans gradually.

2.2.2. Base/Transmission sub-set

This sub-set support the whole mechanism and ensure its running on the dryer length. It include a profiled steel, supporting the weight of the structure, recovering the dryer largeness and based on girders. The whole is mounted on four (04) cylindrical gears. The two driving gears are ordered by two gears motors.The fig. 2 below represent the kinematics diagram of the stirring and scraping mechanism described previously.

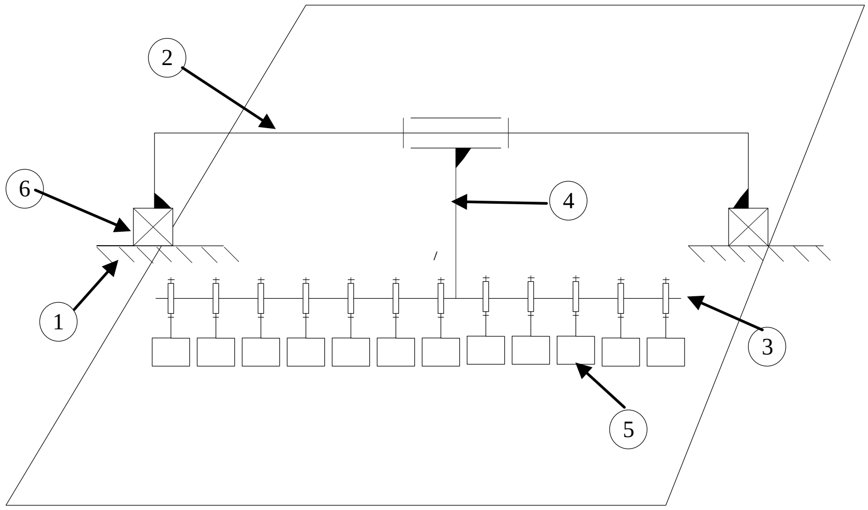

Fig.2 : Kinematic diagram of the selected solution

Where 1 is the Concrete dryers support, 2 is the IPE profiled steel, 3 is the Rectangular profiled steel, 4 is the Pin connections, 5 is the Shovel and 6 is the Set of girders and driving system.

III. METHODOLOGY

3.1. Sizing methodology

For the retained solution, the machine sizing will be done by following the algorithm given at fig. 3.

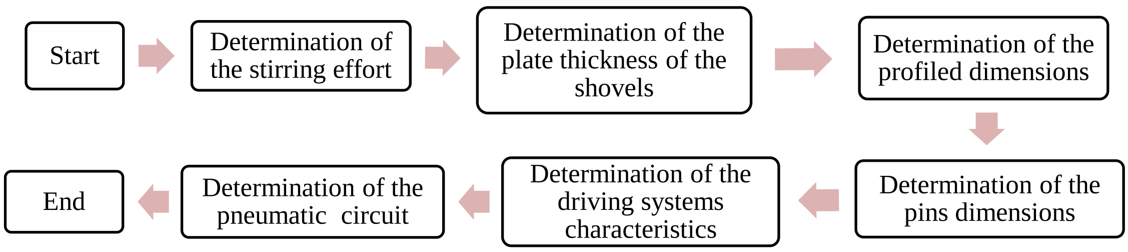

Fig. 3 : Machine sizing algorithm

For the stirrer/scraper sub-set: from the stirred mass of grains, the scraping velocity, the discharging area and the engineering properties of the beans, the stirring force is determined. The thickness of the shovels plate is determined according to the both bending moment and the deflection hypothesis. The profiled steels are entirely determined by the flexural and torsional modulus. The pin thickness and the pin-hole diameter are determined depending on the applied shear force. The parts of the base/transmission system sub-set are defined by parameters such as the motor torque, the motor power, the shaft diameter, etc. For a given available pressure, the pneumatic circuit is sized: the cylinder characteristics are obtained based on the cylinder thrust and the abacus. The free air consumption, the valve flow and the junction's diameter are obtained from the cylinder stroke, the piston and piston rod diameters.For the problem data and the sizing hypothesis, the equations, data values and results are specified [8].

3.2. Impact of mechanical stirring and scraping on drying cycle

The impact of the mechanical stirring and scraping on the drying cycle is determined by three (03) mains criteria which are mixing degree, drying time and scraping duration.

3.2.1. Mixing degree

Mention as *M*, the mixing degree represent the degree of homogeneity of a mixture and is given by the equations (1), (2) and (3) in the case of bulk material mixing, according to Jolanta Krolezyk (2013) [9].

$$M = 1 - S_n / S_o \quad (1)$$

$$With \quad S_n = \sqrt{\frac{\sum_{i=1}^{n} (x_i - p)^2}{n}} \quad (2)$$

$$S_o = \sqrt{p(1-p)} \quad (3)$$

Where*M* is the mixing degree, *n* is the number of samples, *p* is the proportion of the phase dispersed during mixing, S_n is the standard deviation among the*n* samples, $S_0$is the standard deviation before mixing and $x_i$is the concentration of the dispersed phase at sample *i*.

3.2.2. Drying time

This criteria represent the evaluation of the drying time in the case of mechanised stirring. After identifying the drying model corresponding to static dryer, the graph representing the variation of moisture content depending of the drying time can be represented. Then the necessary time allowing to obtain a desired moisture content value depending of the drying condition can be determine. Sirelkhatim Abbouda (1979) [10] give the corresponding drying model for coffee and cocoa beans, expressed in equation (4).The values of *K* and *Me* are given according to Díaz Martínez Jorge Alonso (2011) [11].

$$M_c(t) = (M_o - M_e)e^{-Kt} + M_e \quad (4)$$

Where*Mc* is the moisture content at the moment *t*, M_0 is the initial moisture content, *Me* is the moisture equilibrium, *t* is the drying time and *K* is the experimental drying coefficient.

3.2.3. Scraping duration

The theoretical scraping duration for a mechanised scraping is given by the equation (5), according to Denis Weisse (1991) [12]. By recording the manual scraping duration for ten (10) drying cycles, and by comparing to the value of the mechanised scraping, the gain in time is obtained. I_e and I_c are given constant values [12].

$$t_r = m / (I_c \times I_e(\rho v S)) \quad (5)$$

Wheret_r is the theoretical scraping duration, *m* is the total mass of the beans, I_c is the flowability of the beans,I_e is the floodability coefficient of the mass, ρ is the density of the bulk material, *v*is the scraping velocity and *S* the area of the emptying hatch.

IV. RESULTS

The results obtained after evaluation of the impact due to mechanised stirring and scraping operations on drying are given below, for the three (03) criteria given previously.

4.1 Mixing degree

Before presenting the results obtained by applying equation (1), it is important to present the experimental results obtained for ten (10) drying cycles with manual stirring. Then for the recorded values of the experiments performed atSynergie Nord Sud (2017)[13], the fig.4 represent the obtained graph. This graph shows the variation of the mixing degree, from a smallest value of 0.51 to the highest value of 0.76.

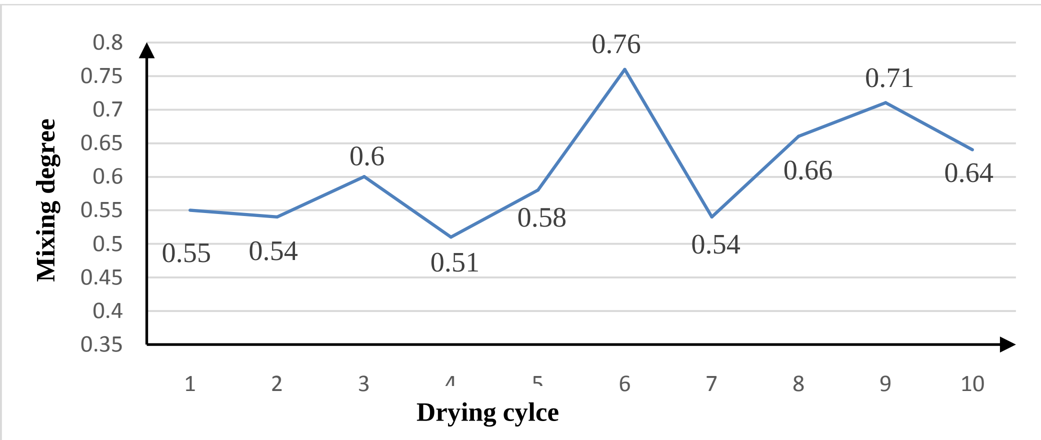

Fig. 4: Variation of the mixing degree for ten drying cycles with manual stirring

Beside, for a stirring time between 20 and 60 minutes, and experimental work have been performed [9] on coffee and cocoa beans, and corn grains, stirred with an equipment similar to the one studied. For different samples and by applying the equation (1), the values of the mixing degree M were obtained, and all includes between 0.97 and 0.98 for coffee and cocoa beans. A comparative analysis shows the minimal homogeneity for a mechanised stirring is 0.97 while for a manual stirring it is 0.51. Also the maximal homogeneity for a mechanised stirring is 0.98 while for a manual stirring it is 0.76 then the gap of the mixing degree $\Delta M = 0.01$ for a mechanised stirring and $\Delta M = 0.25$ for a manual stirring. The mixing degree will then vary from 47.4% in lower value and 22.44% in upper value which imply a better homogeneity for a drying cycle with mechanised stirring.

4.2 Drying time

For coffee beans, the constants K are Me are given:K = 0.384; Me=6.054% [11]. The fig. 5 below represent the values obtained by applying the equation (4).

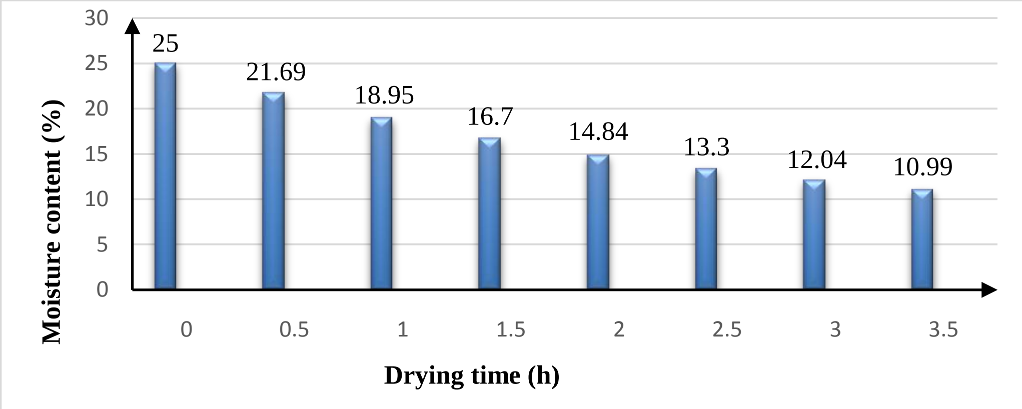

Fig.5 : Variation of the moisture content with the drying time

Before applying a comparative study, it is important to give the actual values of coffee drying times for a manual stirring cycle. Then, the following fig. 6 present the data recorded [13] for ten (10) drying cycles.

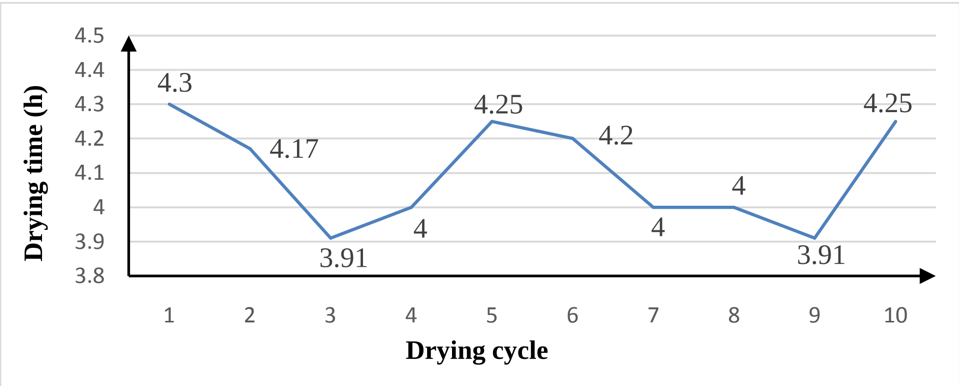

Fig.6 : Drying time for ten drying cycle with manual stirring

The fig. 5 shows that for humid grain arriving with a moisture content on 25%, 03 hours of drying time is necessary and adequate to dry the beans till 12% of moisture content. While the fig. 6 shows clearly that the drying time for coffee beans stirred manually vary between 3.91 h and 4.3h which means it vary between 3h55 minutes and 4h18minutes. Then the mechanisation of the stirring operation will allow to reduce the drying time by 30% in lower valueand 43.3% in upper value, which represent a gain of at least 55 minutes.

4.3 Scraping duration

The obtained values for Ie and Ic are: $Ie = Ic = 0.1$ [12]. The Table 1 below give the results obtained by applying the equation (5) to determine the theoretical scraping duration. It is remarks the theoretical scraping duration is about 30 minutes.

Table 1 : Scraping duration theoretical calculations

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	Data						***Results***
Physical qty	m	Ic	Ie	ρ	v	S	t_r
Unit	kg	/	/	kg/m^3	m/s	m^2	minutes
Value	10000	0.1	0.1	798.9	2	0.344	30,3

On ten drying cycles, the values of the manual scraping duration have been recorded [13] and presented on the following fig. 7.

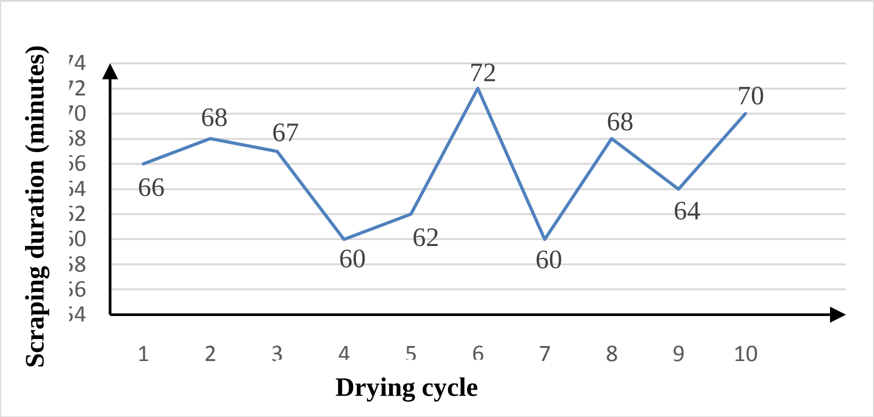

Fig.7 : Manual scraping duration for ten drying cycle

From the fig. 7, it is noticed that the manual scraping duration for each drying cycle vary between 60 and 72 minutes, while the mechanised scraping time equals 30.0 minutes. This signify the scraping duration is reduced by 49.5% to 58%. Then, the mechanised scraping allow to reduce the scraping duration of at least 29.7 minutes.

After analysing and study the three criteria defining the impact of mechanised stirring and scraping on drying, the following conclusions are considerate: the mixing degree is clearly improved and the homogeneity of the drying is also improved. By combining the gains in time on each phase, it comes the mechanisation of the stirring and scraping operations allow to reduce the drying cycle time for at least 01h 24 min 42s which represent a reduction of 28.7% for each drying cycle.

V. CONCLUSION

The work released was about «The impact of mechanised stirring and scraping operations in a coffee and cocoa beans drying unit in Cameroon ». The objective was to study drying cycles in order to evaluate the impact of the mechanisation of the stirring and scraping operations. For an already designed and sized machine to fulfil these functions, it is important to proceed to the evaluation of the contribution of this mechanism for a drying cycle. To reach our objectives, the following steps were completed: the analysis of a drying unit, the description of the stirring and scraping mechanism, the reminder of the sizing methodology and mechanisations' impact study. After evaluation of three (03) performance indicators, the following results were obtained: the mixing degree, which will be include between 0.97 and 0.98 for coffee and cocoa beans stirred continuously during at least 20 minutes, while the mixing degree for manual stirring vary between 0.51 and 0.76. The drying time, theoretically will be three hours (03h) for a drying cycle with mechanical stirring beside of at least three hours and fifty five minutes (03h55min) for manual stirring. The scraping duration for the mechanised scrape will be equal to twenty nine minutes and forty two seconds (29min42s) while this duration for a manual scraping is at least sixty minutes (60min). Then, the designed mechanism will allowedto improve the quality with homogenate dried beans. Also the drying cycle time will be reduce for at least one hour, twenty four minutes and forty two seconds (01h24min42s). This signify the drying cycle duration will be reduced by 28.7% at lower value.

VI. Acknowledgements

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