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SOME PROPERTIES OF FERTILIZERS IN RELATION TO PARTICLE MOTION IN THE HOPPER AND ON THE DISTRIBUTOR DISC

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ABSTRACT

The quality of fertilizer distribution pattern for the rotary distributer depend on the physical and mechanical properties of fertilizers that used by the rotary distributer. The effect of physical and mechanical properties on the particle motion in the hopper and on the disc was discussed.

Five important properties were measured, namely particle shape, particles size distribution, coefficient of dynamic friction, angle of repose, and particle density. Methods to determine the physical and mechanical properties, and tests results were discussed.

The particle density was 1297 and 1791kg/m^3 for Urea and Ammonium Sulfate fertilizer. The largest repose angle of Urea was 38^0 and the smallest angle was 34^0, while the largest repose angle of Ammonium Sulfate fertilizer was 41^0, and the smallest angle was 35^0.

Keywords: Fertilizers properties, Urea and Ammonium Sulfate fertilizers, Particle motion.

INTRODUCTION

Solid chemical fertilizers are one of important sources for plant nutrition, due to its low price compared to liquid chemical fertilizers, they provide the plant with important nutrients needed for growth during the periods of its life, and also it works to improve the properties of soil (soil structure and the acidity degree) **(Troeh and Thompson, 1993).**

Brinsifeld and Hummel (1975) stated that there are many types of distribution machines of solid chemical fertilizers, but the most famous one is the centrifugal distribution machine, and this was due to its advantages, low cost, low power necessary, simplicity of mechanical

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design, ease of maintenance, its high performance, and its wide operation width, but the disadvantage of this type of distribution machines is the lack of distribution accuracy of fertilizers at the rate desired. **Olieslagers et al (1996)** said that the low price, easy maintenance and large working width could explain the success of centrifugal spreaders.

Csizmazia (2000) explained that the evenness of the spread pattern depends to a large extent on the physical properties of the fertilizer. **Parish and Chaney (1986)** mentioned that variables affecting the distribution pattern include particle size, particle density, particles shape, and coefficient of friction of the particle on the impeller, critical relative humidity of the fertilizer, ambient relative humidity, impeller speed and ground speed of the machine.

Consequently, enhancing the distribution patterns of the rotary distributor was the target of many research projects.

This work was carried out to measure some of important physical and mechanical properties of Urea and Ammonium Sulfate fertilizers, affecting on the quality of fertilizer distribution pattern for the rotary distributer machines.

MATERIALS AND METHODS

Physical and mechanical properties of the tested fertilizers were estimated according to the following procedures:

1. Particle shape

A random sample of 100 particles was taken from each fertilizer type. The shape of each type was studied in terms of maximum diameter (d_c) and sphere diameter of the same volume as the object (d_e). These dimensions were determined using a caliper with an accuracy of ±0.01mm, as shown in Fig. (1). The measured data were used to calculate the sphericity of each sample for fertilizer types, using the next formula according to Curray (1951) as follows.

$$sphericity = \frac{d_e}{d_c}$$

$$d_e = \sqrt[3]{\frac{6}{\pi}\cdot\frac{m}{\rho}}$$

Where: d_e = Sphere diameter of the same volume as the object, mm.
d_c = Maximum diameter of the fertilizer particle, mm.
m = Mass of the fertilizer particle, g.
? = Particle density, g/mm^3.

According to Curray formula, the particle sphericity values of (equal to 1), (less than 1, but very near to 1), and (less than 1, but far from 1) are totally spherical, very near to spherical, and far from spherical shapes respectively. The estimated sphericity data of fertilizer particles were statistically analyzed to get each of the mean values, maximum values, minimum values, standard deviation (SD), and coefficient of variation (CV).

2- The particles size distribution

Also, a random sample of 4 kg was taken from each fertilizer type, and mixed together in very well method. The particles size distribution was measured and replicated for 10 times for every kind of fertilizers, and every sample mass were 0.2 kg, to get the mean particles size distribution.

Sieves group was used to determine the particles size distribution. The numbers and mesh diameters of the sieves were as follows: 4 (4.75 mm), 8 (2.38 mm), 10 (2.00 mm), 12 (1.70 mm), and 20 (0.85 mm), as shown in Fig. (2). The particles size distribution was calculated from the following equation:

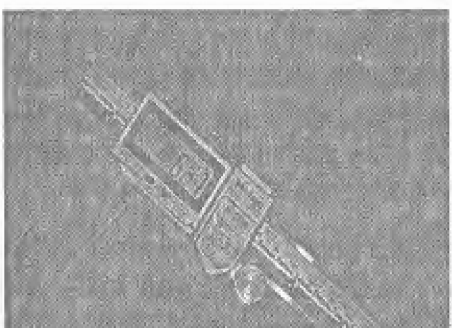

Fig. (1): Accurate caliper to measure the fertilizer particles dimensions.

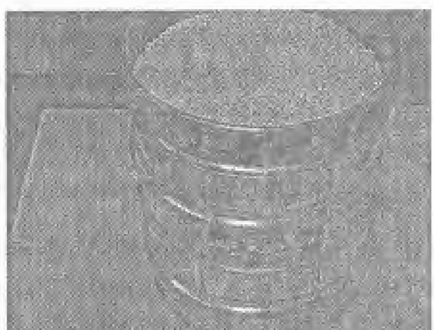

Fig. (2): Sieves group, that used to get the particles size distribution of fertilizers

$$P_{S(n)} = \frac{P_{SW(n)}}{P_{TW}} \times 100$$

Where:

$P_{S(n)}$ = The percentage of fertilizer particles on sieve number (n), %.

$P_{SW(n)}$ = The mass of fertilizer particles on sieve number (n), g.

P_{TW} = The sample mass of fertilizer particles, g.

3. Coefficient of dynamic friction

The coefficient of dynamic friction was measured using the force gauge Fig. (3) and a nylon wire, which connects the force gauge and the plate of fertilizer particles. After fixing the flat friction disc Fig. (4) on the vertical electrical motor, a plate of glued fertilizer particles Fig. (5) has to be set on friction surface then, the electrical motor switched on, and the flat metal disc start to rotate. Due to the flat disc motion, the horizontally pulling force on the plate is gradually increased start from value of zero and after that, it takes the direction of decreasing and it comes constant at the end. At this moment, the force gauge reading was taken. Thus the coefficient of dynamic friction is calculated using the following general equation:

$$\mu = \frac{N}{W}$$

Where: μ = Coefficient of dynamic friction, dimensionless.

N = Horizontal pulling force on the fertilizer particles plate, N.

W= Weight of fertilizer particles plate, N.

It should be denoted that, the coefficient of dynamic friction for fertilizer particles was determined versus painted iron material, and it was measured under four different disk rotation speeds of 100, 200, 300, and 400 rpm. The disk rotation speed was measured by the tachometer as shown in Fig. (6).

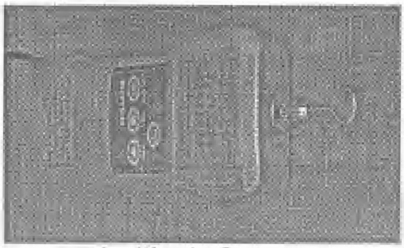

Fig. (3): The force gauge

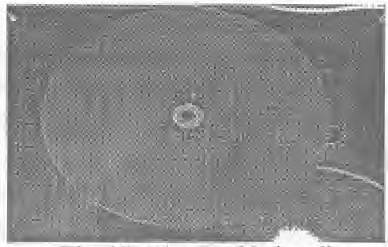

Fig. (4): The flat friction disc

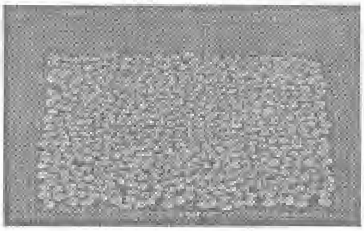

Fig. (5): A plate of glued fertilizer particles

Fig. (6): The tachometer

4. Angle of repose

The repose angle of fertilizer particles was laboratory measured using the digital photography as a new technique, to get the highest possible accuracy of the results. At first, the funnel supported with the holder was used to get a regular stack of fertilizer particles, and after that, many pictures for the fertilizer particles stack was taken with the digital camera (CASIO, Model EX-F1) so, the pictures were printed on the paper and the repose angle was determined using the protractor.

5. Particle density

According to Aphale et al. (2003), the volume and mass of fertilizer sample were determined by using 10 ml graduated cylinder with water and accurate digital balance of ± 0.001 gram accuracy, respectively. The particle density was calculated from the following equation:

$$\rho = \frac{M}{V}$$

Where: ? = Particle density, kg/m^3.,

M = Mass of fertilizer sample, kg.

V= Volume of fertilizer sample, m^3.

The obtained data for physical and mechanical properties were analyzed using program of Microsoft Excel.

RESULTS AND DISCUSSION

The following results were taken under the air conditions of 25 C°, and 29% for temperature, and relative humidity, respectively.

1. Particle shape

The maximum diameter and mass of the particles were measured for random sample of 100 particles of the two fertilizers types. The data for each of maximum diameter, the mass, and the sphericity of fertilizer particles were statistically analyzed to get each of the mean values, maximum values, minimum values, standard deviation, and coefficient of variation (Table 1). The average values of particles sphericity index were 87.58 and 77.22 for Urea and Ammonium Sulfate respectively.

Table (1): The statistical analysis of the fertilizers particles

	Fertilizers types									
	Urea					Ammonium Sulfate				
	Max.	Min.	Av.	SD	CV,%	Max.	Min.	Av.	SD	CV,%
Max. dia., mm	4.77	3.06	3.88	0.32	8.35	6.19	3.46	4.65	0.60	12.9
Mass, gram	0.037	0.014	0.027	.005	18.9	0.074	0.026	0.043	0.009	21.1
Sphericity index	98.2	77.3	87.6	4.39	5.01	89.7	60.1	77.2	6.73	8.71

From table (1), it is cleared that, Urea particles are more spherical than Ammonium Sulfate particles, consequently under the same conditions, if Urea and Ammonium Sulfate particles have the same physical properties except the particle shape property, the Urea particles will travel horizontal distances in the air more adjacent than Ammonium Sulfate particles, because the variance coefficient value of Urea particles is smaller than the variance coefficient value of Ammonium Sulfate particles.

In other words, under the same conditions, if Urea and Ammonium Sulfate particles have the same volume, the Urea particles frontal area will be more adjacent than Ammonium Sulfate particles frontal area, so the drag forces on Urea particles surface will be more nearby than the drag forces on Ammonium Sulfate particles surface. The drag force on the fertilizers particles equation is as the following:

$$F_D = \frac{1}{2} \rho V^2 C_D A$$

Where: F_D = Force of drag, N.

? = Density of the air, Kg/m^3.

V = Velocity of the particle, m/s.
A = Frontal area of the particle, m^2.
C_D = Drag coefficient, dimensionless.

2- The particles size distribution

On the other hand, particles size distribution was measured, and many sieves were used, numbers of the sieves were 4 (4.75 mm), 8 (2.38 mm), 10 (2.00 mm), 12 (1.70 mm), and 20 (0.85 mm). The results of particles size distribution for Urea on the sieves 4, 8, 10, 12, 20, under the sieve number 20 were as follows: 0%, 62.4%, 28.9%, 5.9%, 2.2%, 0.6%, respectively, while the results of particles size distribution for Ammonium Sulfate fertilizer on the same sieves were 0.0%, 85.8%, 9.3%, 2.6%, 2.1%, 0.2%, respectively.

The values of particles size distribution for the two fertilizers types (Urea and Ammonium Sulfate) were shown in Fig (7). From this Figure, it can be noticed that, the largest percentage of particles size was 62.4%, while it was 85.8% on sieve no. 8 (2.38 mm) for both of Urea and Ammonium Sulfate fertilizers, respectively. So, under the same conditions, if Urea and Ammonium Sulfate particles have the same physical properties except the particles size distribution property, most of Ammonium Sulfate particles will travel horizontal distances in the air greater than the traveled horizontal distances of urea particles in the air, because the centrifugal force on the Ammonium Sulfate particles will be greater than the centrifugal force on the Urea particles. The centrifugal force on the fertilizers particles equation is as the following:

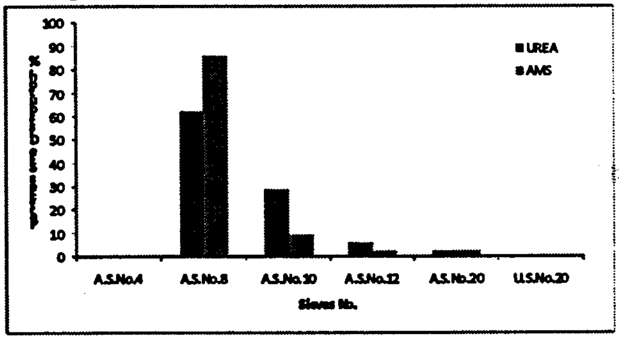

Fig. (7): The values of particles size distribution for fertilizers particles types (Urea and Ammonium Sulfate).

$$F = m\, r\, \omega^{2}$$

Where: F = Centrifugal force, N.

m = Mass of the particle, Kg.

r = Radius of the disc, m.

? = angular velocity of the disc, rad/s.

3. Coefficient of dynamic friction

The dynamic friction plays an important role in most fields of agricultural mechanics, especially during the movement of agricultural materials. The average values of dynamic friction coefficient (μ) for the tested fertilizers types (Urea and Ammonium Sulfate) on paint iron surface, and using different speeds (0.8, 1.6, 2.4, and 3.2 m/sec) were measured and plotted in Fig (8).

Generally, increasing the disc speed for both of two fertilizers particles types decreases the dynamic friction coefficient. But, the dynamic friction coefficient of Urea particles was greater than the dynamic friction coefficient of Ammonium Sulfate particles at the same speed levels.

Results of the dynamic friction coefficient for Urea particles at the speeds of 0.8, 1.6, 2.4, and 3.2 m/s were 0.570, 0.532, 0.508, 0.496, respectively, while the corresponding results of the dynamic friction coefficient for Ammonium Sulfate particles at the same speeds were 0.510, 0.411, 0.359, 0.335, respectively.

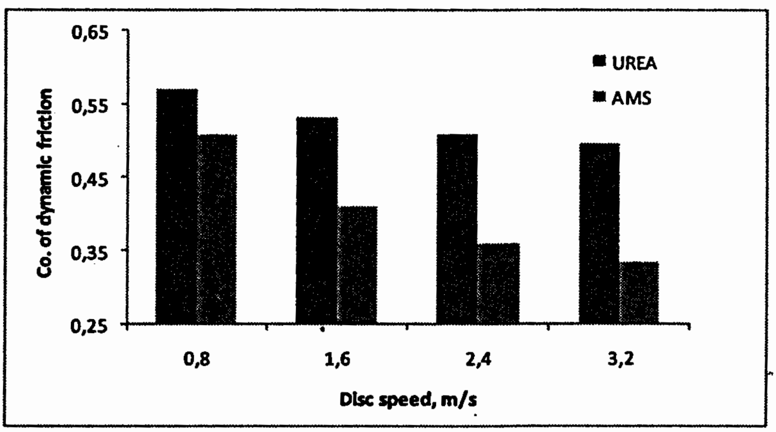

Fig. (8): The average values of dynamic friction coefficient for both tested fertilizers particles

Consequently, the Urea particles will remain on the disc surface for longer time than Ammonium Sulfate particles. That result trend means, the staying angle of Urea particles on the disc surface will be greater than staying angle of Ammonium Sulfate particles.

For fertilizers types under the study, (Urea and Ammonium Sulfate) the mathematical relationships between the dynamic friction coefficient and the disc speed may be represented by the following equations:

$\mu = 0.5572\ S^{-0.102}$ $R^2 = 0.998$ For Urea fertilizer

$\mu = 0.4751\ S^{-0.308}$ $R^2 = 0.998$ For Ammonium Sulfate fertilizer

Where: μ = The dynamic friction coefficient.

S = The disc speed, m/s.

4. Angle of repose

The average values of repose angle for the different fertilizer types were determined. The data presented in table (2) indicate the values of repose angle were 0.624 rad. (36 deg), and 0.652 rad. (37 deg) for fertilizer types (Urea and Ammonium Sulfate), respectively. On the other hand, the results illustrated in Fig (9) show that, the highest frequencies of particles repose angle were recorded at 0.624 Rad. (36 deg), and 0.663 Rad. (38 deg) for fertilizers types Urea and Ammonium Sulfate, respectively. So, to have continues flow of fertilizer particles under this study through the hopper orifice to the rotary disc, the inclined angle of hopper walls should be more than 41^0.

Table (2): Maximum, minimum, average, standard deviation and coefficient of variance of repose angle

	Fertilizers types									
	Urea					Ammonium Sulfate				
	Max.	Min.	Av.	SD	CV,%	Max.	Min.	Av.	SD	CV,%
Repose angle (deg)	38	34	36	.94	2.6	41	35	37	1.56	4.2
Repose angle (rad.)	.663	.593	.624	.016		.716	.611	.652	.027	

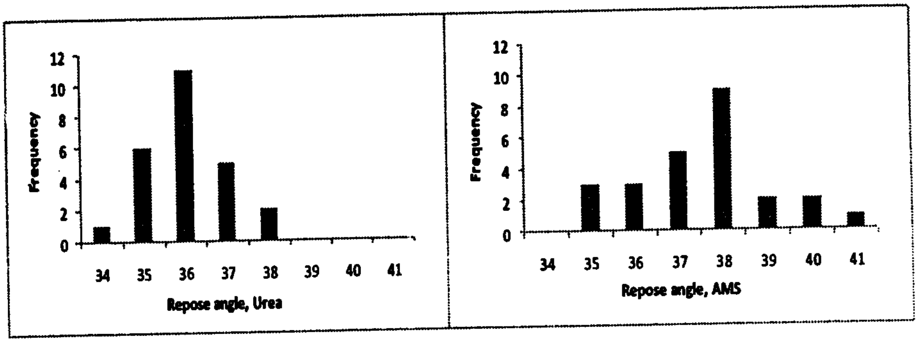

Fig (9): The frequency distribution curves for repose angle of fertilizers types

5. Particle density

Density of the fertilizer particle, play an important role in the particle movement through the air (from the disc edge until the impact surface). The particle density was measured for two fertilizers types, and the average values of particle density for the two fertilizers types were determined. As presented in table (3). The recorded values of particle density were 1297, and 1791 kg/m^3 for fertilizer types (Urea and Ammonium Sulfate), respectively.

From the previous table, it is cleared that, Urea particle density is smaller than Ammonium Sulfate particle density, so if we supposed that Urea and Ammonium Sulfate particles have the same physical properties except the particle density property; the Urea particles will travel horizontal distance in the air smaller than the travelled horizontal distance of Ammonium Sulfate fertilizer particles, because the centrifugal force on the Urea particles will be smaller than the centrifugal force on the Ammonium Sulfate particles.

Table (3): The statistical analysis of the particle density for the tested fertilizers types.

	Fertilizers types									
	Urea					Ammonium Sulfate				
	Max.	Min.	Av.	SD	CV, %	Max.	Min.	Av.	SD	CV, %
Particle density, kg/m3	1340	1241	1297	21.7	1.7	1844	1739	1791	27.7	1.5

CONCLUSION

The main results of this study could be summarized and listed as follows:

1. The particle density was 1297 and 1791kg/m^3 for Urea and Ammonium Sulfate fertilizer.
2. It's advised to use the digital photography technique, to get the highest possible accuracy results of the repose angle. The largest repose angle of Urea was 38^0 and the smallest angle was 34^0, while the largest repose angle of Ammonium Sulfate fertilizer was 41^0, and the smallest angle was 35^0.
3. The dynamic friction coefficients for Urea particles at test speeds of 0.8, 1.6, 2.4, and 3.2 m/sec were as follows: 0.570, 0.532, 0.508, 0.496, respectively, while the corresponding values of the dynamic friction coefficients for Ammonium Sulfate particles using the same speeds were as follows: 0.510, 0.411, 0.359, 0.335, respectively.

REFERENCES

Aphale A; N Bolander; J Park; L Shaw; J Svec; C Wassgren (2003). Granular fertilizer particle dynamics on and off a spinner spreader. Biosystems Engineering, 85 (3), 319-329

Brinsifeld R B; J W Hummel (1975). Simulation of a new centrifugal distribution design. Transactions of the ASAE, 18 (12), 213-220

Csizmazia Z (2000). Some physical properties of fertilizer particles. Aspects of Applied Biology, 61, 219-226

Curray J K (1951). Analysis of sphericity and roundness of quartz grains. MSc. Thesis in Mineralogy, The Pennsylvania State Uni., University Park, Pa.

Davis J B; C E Rice (1973). Distribution of granular fertilizer and wheat seed by centrifugal distributors. Transactions of the ASAE, 16 (5), 867-868

Olieslargers R; H Ramon; J De Baerdemaeker (1996). Design of a centrifugal spreader for site-specific fertilizer application. Precision agriculture. Proceedings of the 3rd international conference, Minneapolis, Minnesota, USA, 23-26 June 1996, pp. 745-756

Parish R L; P P Chaney (1986). Pattern sensitivity of location of fertilizer drop point on a rotary spreader. Transactions of the ASAE, 29 (2), 374-377

Reints R E; R R Yoerger (1967). Trajectories of and granular fertilizer. Transactions of the ASAE, 10 (2), 213-216

Troeh; F R; L M Thompson (1993). Soil and soil fertility. 5th Edition, Oxford University Press, New York, Oxford.

الملخص العربي

بعض خصائص الأسمدة المتعلقة بحركة حبيباتها داخل صندوق آلة النثر وعلى قرص التوزيع

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تعتمد جودة نمط توزيع السماد على العديد من الخصائص الطبيعية والميكانيكية للسماد المستخدم مع آلة نثر السماد بالطرد المركزى. ولقد تم اجراء هذا البحث فى معامل قسم هندسة النظم الحيوية بكلية الزراعة وعلوم الأغذية فى جامعة مانيتوبا بكندا، وفيه تم دراسة تأثير خمس خصائص طبيعية وميكانيكية (شكل حبيبة السماد، التوزيع الحجمى لحبيبات السماد، معامل الاحتكاك الديناميكى، زاوية التكويم، الكثافة الحقيقية للسماد) لنوعين من الاسمدة الصلبة (اليوريا، وسلفات النشادر) على حركة حبيباتها داخل صندوق الة النثر وعلى قرص التوزيع.

ويمكن تلخيص النتائج فيما يلى:

١- كانت قيمة دليل تكور الحبيبات لسماد اليوريا ٨٧,٥٨ بينما كانت ٧٧,٢٢ بالنسبة لسماد سلفات النشادر.

٢- كانت نتائج التوزيع الحجمى لحبيبات سماد اليوريا على غربال ٤، ٨، ١٠ ، ١٢، ٢٠، تحت غربال ٢٠ كالتالى: ٠%، ٦٢,٤%، ٢٨,٩%، ٥,٩%، ٢,٢%، ٠,٦% على التوالى، بينما كانت نتائج التوزيع الحجمى لحبيبات سماد سلفات النشادر على نفس الغرابيل كالتالى: ٠%، ٨٥,٨%، ٩,٣%، ٢,٦%، ٢,١%، ٠,٢% على التوالى.

٣- تم قياس معامل الاحتكاك الديناميكى لحبيبات الأسمدة تحت الدراسة مع سرعات ٠,٨، ١,٦، ٢,٤، ٣,٢ م/ث ، فكانت قيمته بالنسبة لسماد اليوريا كالتالى: ٠,٥٧٠، ٠,٥٣٢، ٠,٥٠٨، ٠,٤٩٦ على التوالى، بينما كانت لسماد سلفات النشادر كالتالى: ٠,٥١٠، ٠,٤١١، ٠,٣٥٩، ٠,٣٣٥ على التوالى.

٤- تم تقدير زاوية التكويم بالاستعانة بالتصوير الرقمى للحصول على اعلى دقة ممكنة للنتائج وكانت قيمة اكبر زاوية تكويم لسماد اليوريا هى ٣٨° وقيمة اصغر زاوية هى ٣٤° بينما كانت قيمة اكبر زاوية تكويم لسماد سلفات النشادر هى ٤١° وقيمة اصغر زاوية هى ٣٥° .

٥- كانت الكثافة الحقيقية لسماد اليوريا ١٢٩٧ كجم/م^{3}، أما بالنسبة لسماد سلفات النشادر فكانت ١٧٩١ كجم/ م^{3}.

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