Size Matters

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Abstract
Many urea experts and practitioners know that numerous factors affect fertilizer product quality. They include finishing technology, geographical location (climate) as well as how the final product is stored and transported. In this article, B. George van Bommel of BioTorTech and UreaKnowHow.com highlights one of the most easily overlooked but critical aspect determining fertilizer product quality – the end user.
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Many urea experts and practitioners know that numerous factors affect fertilizer product quality. They include finishing technology, geographical location (climate) as well as how the final product is stored and transported. In this article, **B. George van Bommel** of BioTorTech and UreaKnowHow highlights one of the most easily overlooked but critical aspect determining fertilizer product quality – the end user.

Table 1: **Typical specification sheet: urea granules**

Chemical properties	Typical	Range	Physical properties	Typical	Range
Total nitrogen (N) content, wt-% N	46.2	46.0-46.6	size guide number (SGN)	270	240-320
Biuret content, wt-%	1.0	0.85-1.5	uniformity index (UI), %	52	50-55
Moisture content, wt-% H_2O	0.25	0.1-0.4	bulk density (loose), kg/m³	720	700-740
Formaldehyde (HCHO), wt-% F	0.4	0.2-0.6	bulk density (tapped), kg/m³	810	800-860
Free NH_3, ppm	75	50-150	angle of repose, degree	30	38-32
pH in water solution, 10% wt/wt	7.8	7-9	crushing strength, kgf (N)	3.5	3-4

Table 2: **Typical specification sheet: urea prills**

Chemical properties	Typical	Range	Physical properties	Typical	Range
Total nitrogen (N) content, wt-% N	46.1	46.0-46.6	size guide number (SGN)	190	140-240
Biuret content, wt-%	0.8	0.85-1.5	uniformity index (UI), %	54	50-55
Moisture content, wt-% H_2O	0.35	0.1-0.4	bulk density (loose), kg/m³	740	730-760
Formaldehyde (HCHO), wt-% F	0.2	0.1-0.3	bulk density (tapped), kg/m³	780	760-860
Free NH_3, ppm	125	50-150	angle of repose, degree	28	26-30
pH in water solution, 10% wt/wt	7.8	7-9	crushing strength, kgf (N)	1.2	1-3

Fig. 1: *Typical prill (left) and typical urea granule size (right).*

Many readers will be familiar with the standard specification sheets for urea granules and urea prills shown in Tables 1 and 2 respectively. When comparing the two, a number of physical properties differ due to the different finishing technologies applied.

The granulated product has a much bigger average diameter, 2.7 mm versus 1.9 mm for a prill (d50). The difference in the product is also visible to the naked eye (Fig. 1)[1,2].

In the fertilizer industry, product size[2] is commonly expressed in SGN (size guide number), which is the average particle diameter (d50) multiplied by 100.

The thesis of this article is that size does matter in terms of quality and storage as evidenced when exploring the important impact of different particle size at production sites in locations with (semi)-tropical conditions and high relative humidity.

Like most fertilizer products, urea particles can also adsorb moisture from the environmental atmospheric air conditions. Urea particles are susceptible to moisture absorption, decomposition, and caking even at moisture contents as low as 0.25 wt-% during transportation and storage processes.

In fact there is a strong quality relation between the urea product's total surface, number of contact points when exposed to high humidity air and product load during temperature swings. This is not unsurprising and can be demonstrated using easy

Table 3: **Identification of different fertilizer particles in 1 m³ volume**

Balls/ spheres	Diameter, mm	Volume, mm³	Area, mm²	Perimeter, mm	No. of particles per cu side	No. of particles per m³	No. of possible bonds per m³	Total area of all particles, m²
Ping-pong	40.0	33,510	5.027	126	25	15,625	187,500	8
Prill	1.9	3.59	11.34	5.97	526	145,793,847	1,749,526,170	165
Granule	2.7	10.31	22.90	8.48	370	50,805,263	609,663,161	116
NPK granule	2.2	5.58	15.21	6.91	455	93,914,350	1,126,972,201	143

to understand mathematical examples in Table 3.

In the following simplified example, with "one size" 40 mm diameter ping-pong balls, you can stack 25 balls per side in a 1 x 1 x 1 metre cube (length, width, height of 1 metre = 1000 mm/40 = 25), thus you can fit 25 x 25 x 25 = 15,625 balls into the cube with square close packing layers[3].

Each ball touches 12 other balls, as illustrated in Fig. 2, where the grey balls base, are stacked with the yellow balls. If another layer is added, the total amount of contact points is 12 x 15.625 = 187,500 in this 1 m³ volume and all balls have a total surface area of 8 m².

The total surface area on which interaction can take place is an important factor with regard to the exchange of mass force, moisture or absorption. Even in a typical 50 kg bag urea (approx. 70 litres) of prilled product, the total particle surface is 12 m², with some 10 million contact points, thus exponentially increasing the possible caking bonds.

Take, for example, 1 m³ of prills (of 1.9 mm) comprising about 145 million individual prilled particles, with a joint internal surface of some 165 m² (Table 3). The amount of inter granular contact points, where the caking bridges start for the 145 million prills is about 1,750 million contact points, versus 610 million for urea granules (50 million individual granules, size 2.7 mm).

It can therefore be concluded that prills have roughly 2.8 times more contact points, and 40% more surface area than granules!

It is very clear that large particles are less sensitive to caking or pressure contact bonding, because they have significantly less contact points. The highest theoretical cubic close packing of equal spheres is 74 % of particles, leaving 26% volume for void (empty) area for air.

This void volume forms an additional problem because this 26% volume can be filled with "moist" air, or in bad cases

Fig 2: **Stacking and filling patterns**

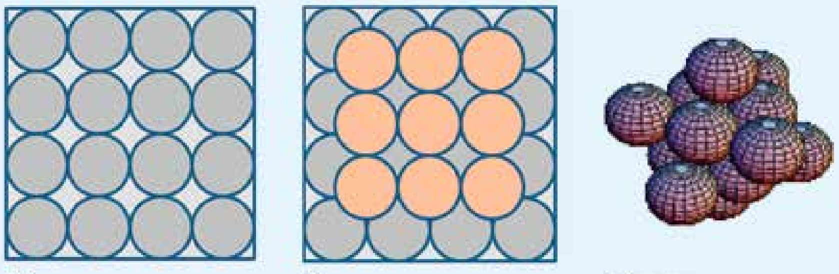

Fig. 3: *Urea lumps (left) and severely caked storage pile (right).*

with ultra-fine, broken and dusty particles. The dusty particles in these void areas can dramatically increase the amount of contact area. This creates a perfect environment for further caking resulting in big lumps and solid piles of product (Fig. 3). It is therefore critical to ensure not only the right size but consistent uniformity of the urea product and to eliminate the risk of dust in the void spaces.

Now that we have covered the impact of size and the risk of dust particles in void spaces let us focus on the additional impact of climatatic conditions.

In tropical climate conditions with temperatures of 30°C and 80% relative humidity (RH), we know that urea can absorb within 72 hours on the exposed pile surface a total of 3,5 kg/m² of water, whilst the air only holds some 21 g/m³. These conditions can therefore create a crust of caked product and lumps.

Bearing in mind that the dew point of the "moist" air is already at 26°C, if the temperature drops from 30°C to 26°C during the night, the "condensing" air will transfer all of its moisture to the warehouse pile. Therefore, reducing fluctuations in the warehouse air temperature and high RH helps to reduce crusting, caking and lumps formation. This is also valid for bulk transshipments when transporting the product to customers.

However, fertilizer products have a certain range of product distribution, depending on accurate sieving, and it is of paramount importance that fines, dust and broken products are removed to prevent void (air) areas from being filled with these off-spec products, thereby increasing the number of contact points and thus cake bridges. These cake bridges need to be eliminated to ensure product consistency and quality.

PHOTO: CUSTOMER OF ROYAL HASKONING DHV

Fig. 4: *Near miss of a truck coming out of dusty cloud with an approaching pay loader at NPK plant in Brazil, South America.*

Larger granules are also stronger than prills (see crushing strength 3.5 versus 1.5 kgf or kg/particle), and cannot be deformed or plasticised (creating more contact points) so easily by stacking or compacting pressure.

The moisture content in the final product is also a very important quality parameter. A high moisture content is an indication of many capillaries that are still filled with moisture. Consequently, during the drying-evaporation-storage of the prill (or granule) additional needles (fine recrystallised salts) are formed which become a dust nuisance during handling actions such as loading and bagging and bulk transport transfers.

Fig. 4 shows that high dust is also a safety factor; appropriate dust removal systems are necessary to prevent incidents and health inhalation problems which can contribute to respiratory illnesses.

After bulk storage, the static pressure when bagging the product for the customer is important. Static pressure, which can occur in bagged and stacked product, also promotes bridging behaviour resulting in caking. In Fig. 5 the result of static pressure promoting the capillary behaviour can be seen. The porous channels of the granule force out the internal moisture, creating a liquid meniscus of new bridging-caking-crystals on the surface. The static pressure of bagged and stacked fertilizer products therefore plays an important role in caking. The IFDC has developed a method S-106 (small bag method) in which 0.3 kg/cm^2 pressure is applied to the bag equivalent to the pressure applied to a bag at the bottom bag of a 20 bag high stack (Fig. 6). The results of this pressure can then be assessed after one, three and six months by checking the caked lumps and hardness in the bag.

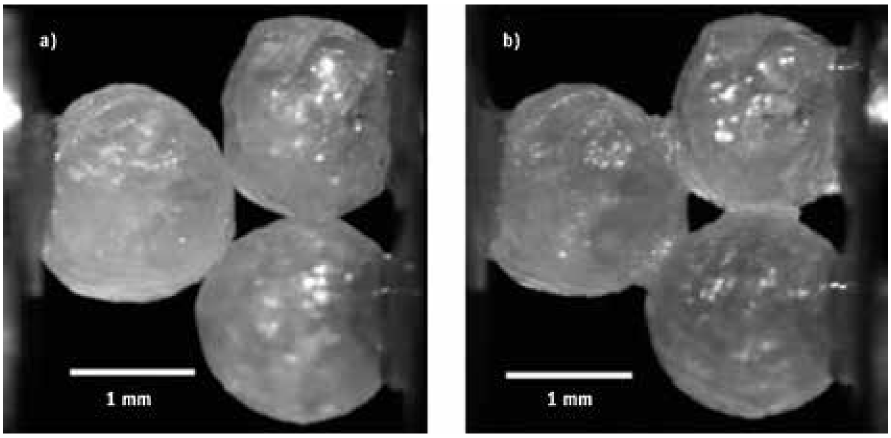

PHOTO: THE FACHSCHULE TRIER, GERMANY

Fig. 5: *Three-particle system of urea prills before (a) and after (b) solid bridge formation*

A promising, faster "company internal" caking tendency method was witnessed at an Asian NPK facility, where 500 ml product sample, was put in a closed bag within a metal cylinder (6 cm diameter and 18 cm length) under a pressure weight of 3 kg/cm^2, for 24 hrs (see Fig. 7).

To assess the caking tendency the two metal cylinder shells were removed carefully, the remaining fertilizer particles

Fig 6: **Storage rack to measure caking tendency of fertilizer by small bag method**

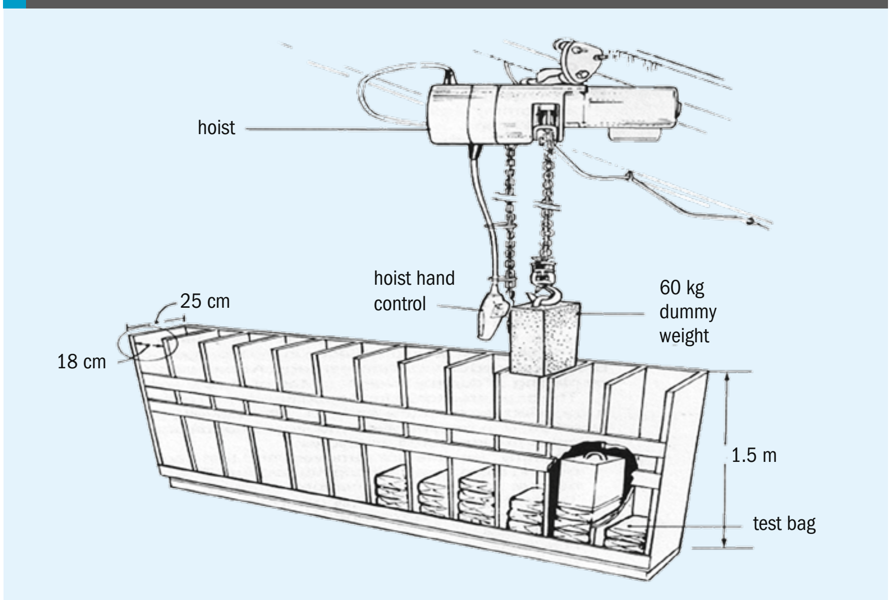

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Fig. 7: *Company internal caking tendency method at an Asian NPK facility.*

cylinder, was put under 1 kg weight. If the tested product has high caking (9-10) the fertilizer cylinder does not collapse, and remains intact. If the product cylinder collapses with the weight medium caking (5-6) was noted. If the cylinder collapses with no weight on it, a very low caking tendency (1-2) is expected.

The size of prills or granules of other common fertilizers (MAP, DAP, MOP, SOP, AN, AS, NPK's etc) are also paramount.

When (steam-physical) drum granulated NPK (17-17-17) is compared to the multi raw material input with all the different chemical properties, the relative end product high moisture of 0.9 wt-% is a very critical factor, as are the size and number of contact points (see Table 4).

Aside from the different chemical composition behaviour (e.g. different salt-out temperatures, moisture absorption sensitivity) the NPK has about 1,121 million contact points per 1 m^3 (see Table 3).

The high number of different NPK chemical formulations, SGNs and UIs make NPKs even more sensitive or susceptible to caking, because they have a lower critical relative humidity (CRH) compared to urea prills-granules. It can therefore be concluded that size does indeed matter in ensuring consistent product quality, as do storage and climate conditions.

Tropical conditions also have a large negative impact on the raw materials applied in the high urea NPK product formulations (Fig. 8). The relative humidity (rainy season) and temperature (day-night) fluctuations of various NPK formulations often surpass the critical relative humidity threshold, initiating water absorption by the product around 50-55% RH.

Bear in mind that if the same 1 m^3 is now filled with this urea based NPK granules, the surface area is capable of absorbing 14.8 % of water in weight after five hours at 25°C and 70% RH as indicated by research figures from Yara (see Fig. 9).

Therefore, compared with urea under the same tropical conditions of 30°C and 80% relative humidity, we know NPK 17-17-17 can absorb some 5,8 kg/m^2 of water (almost twice as a urea granule!) on the exposed surface within 72 hours

Fig. 10 shows a typical pile of high urea NPK after 24 hours in a NPK plant in Asia. A surface crust formation about 5 cm thick and discoloration (darker granules) is clearly visible. This is clear evidence of water absorption evidence (after only 24 hours), even though in this case the NPK (21-7-18) product pile was covered with a PE blanket as a precautionary measure.

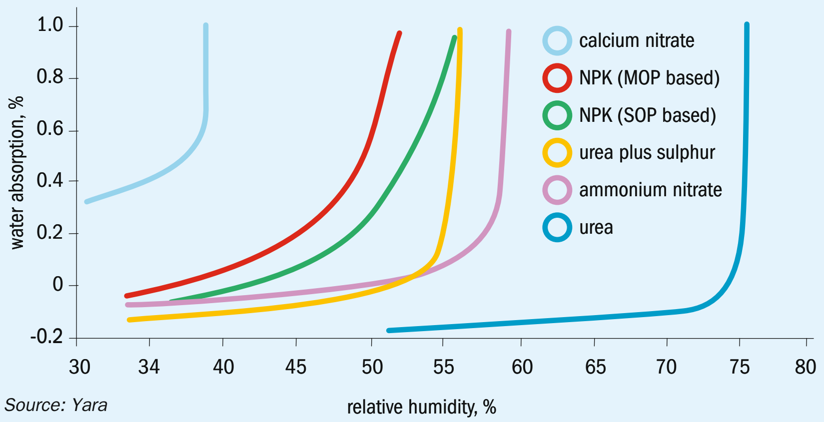
Fig. 11 shows the results of spills and high traffic in a fertilizer plant in the tropics with high relative humidity and temperature fluctuations that has created a lot of mush as a result of the water absorbed and the hygroscopic properties of the fertilizers.

Each production location (and client) is unique with regards to the production process and climatic conditions. BioTorTech clients

Table 4: **Typical specification sheet: NPK 17-17-17 granulated**

Chemical properties	Typical	Range	Physical properties	Typical	Range
Total nitrogen (N) content, wt-% N	17.0	16.5-17.5	size guide number (SGN)	220	140-240
Total phosphate (P) content, wt-% P_2O_5	17.0	16.5-17.5	uniformity index (UI), %	52	50-55
Total potash (PK) content, wt-% K_2O	17.0	16.5-17.5	bulk density (loose), kg/m^3	800	760-840
Total sulphur (S) content, wt-% S	4.7	4-5	bulk density (tapped), kg/m^3	833	800-860
Moisture content, wt-% H_2O	0.9	0.8-1.5	angle of repose, deg	29	27-31
pH in water solution, 10% wt/wt	7.8	7-9	crushing strength, kgf (N)	3.1	2-5

Fig 8: **Critical relative humidity (CRH) of various fertilizers at 25°C**



receive their own detailed report regarding the quick (or hard) wins regarding the production and storage process. Including which ones can have the biggest economic impact for the plant operations and profitability.

Based on the case study, the following non-exhaustive list of general recommendations can be applied to improve product quality:

- large granules, SGN > 250 and 95% between 2-4 mm;
- more uniform size of granules, prills, briquettes, pellets etc, maintain uniformity index > 55;
- low angle of repose <30 degrees, by more and better sieving;
- less Moisture, < 0.8 % moisture content in end product;
- low granule porosity <0.5%;
- hard strong granules, crush test > 3.0 kgf on a 3 mm diameter granule;
- less fines and dust in product, so no < 1mm product;
- allow only limited dT between ambient T and final product to storage pile;
- constant warehouse temperature, prevent moisture migration absorption;
- limit the amount of product formulations, impact and transfers;
- apply first in-first out warehouse principles;
- lower bag stacking of high potential caking products;
- good housekeeping, vacuum clean dusty areas. ■

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Fig 9: **Water absorption in blends**

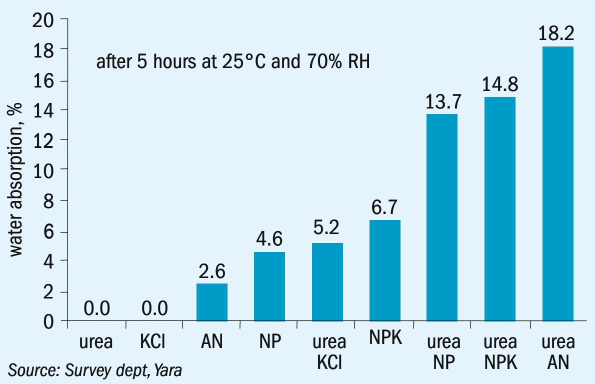

PHOTO: CUSTOMER OF BIOTORTECH

Fig. 10: *21-7-18 NPK with surface crust.*

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Fig. 11: *Results of spills and high traffic in a fertilizer plant in the tropics.*