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PRODUCT DESIGN OF SOLID FERTILIZERS

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Annual fertilizer production shows an increasing trend due to improved performance through product design. The product profile includes chemical and physical properties, environmentally friendliness and stability with respect to mechanical stress and temperature. Product design of solid fertilizers is commonly used to increase handling property by reducing dust formation and caking. Latest developments focus on the decrease of the decomposition of NH_4^+-nitrogen. Owing to nitrification inhibitors, the bacterial oxidation of NH_4^+ to NO_2^- in the soil will be delayed for a certain period of time. A stable formulation containing a nitrification inhibitor therefore increases the bioavailability of NH_4^+. The application of a controlled release effect on fertilizer granules reduces the labour of the farmer and the annual amount of fertilizer needed. This requires a release effect lasting over several months, ensuring the delivery of mineral nutrients as needed by the plants. Product design of solid fertilizers generally results in surface-treated and/or coated fertilizer granules.

Keywords: fertilizer; product design; coating; controlled release.

INTRODUCTION

The world consumption of nitrogen fertilizer (Figure 1) amounts to 80 million tons. The basics of fertilizer production are described in *Ullmann's Encyclopedia of Industrial Chemistry* (1987) and Marshall (1979). In Western Europe a slight decrease in fertilizer consumption over the last decade has been noticed. Conversely an annually increasing part of this bulk product shows improved performance due to product design (Ranney, 1978; Zerulla *et al.*, 2001). Product design affects, among others chemical and physical properties, environmental friendliness, stability with respect to mechanical stress, and temperature. The driving force of product design can be found in modifying the product properties without changing the chemical structure of the active component. As a result of product design, the life cycle of the product can be increased and new markets may be developed. Additionally, consumer relations improve due to a product development in line with consumer demand.

With respect to fertilizer, the product design may: (i) improve handling properties due to reduced dust formation and caking; (ii) reduce decomposition of NH_4^+-nitrogen; and (iii) show a controlled release effect up to more than a year (Anonymous, 2000). Means of increasing the handling properties of solid fertilizers are common knowledge (Diwani *et al.*, 1994; Rutland, 1991). Added value can be achieved when considering reduced decomposition of NH_4^+ and a controlled release effect.

In general, additives can be incorporated in the solid matrix or concentrated on the surface. If a surface modification is intended, it is obviously best to locate the additive only on the surface of the fertilizer. This results in a minimum amount needed. However, at least one additional process step has to be taken into account.

METHODS

Depending on the purpose of the coating, three grades of shell qualities can be distinguished (Figure 2a–c). Where

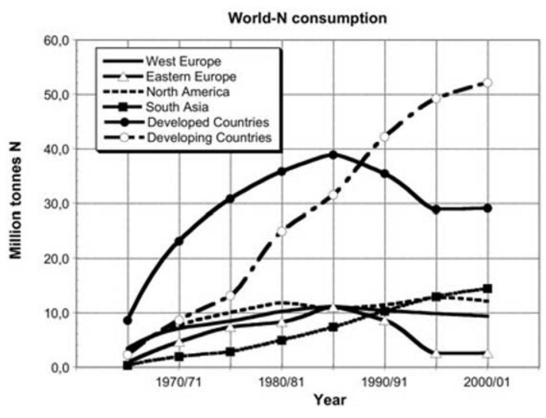

Figure 1. World nitrogen consumption (Int. Fertilizer Industry Association, 2004; www.fertilizers.org).

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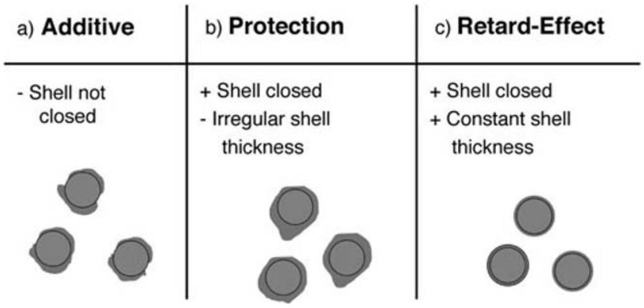

Figure 2. Grades of shell qualities.

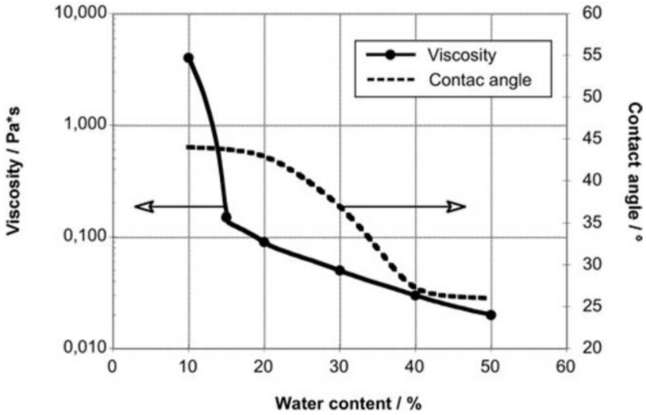

Figure 3. Effect of water content on viscosity and contact angle.

the additive is an active substance, it is sufficient that the additive adheres to the granule (Figure 2a). There is no need for a closed shell. If protection is required, the shell must be closed. The thickness of the shell might be irregular (Figure 2b). A closed shell and a constant shell thickness are required for a controlled retard effect (Figure 2c).

The additive/coating can be applied on fertilizer granules as a solution, a suspension, an emulsion or a melt. The additive should adhere well on the surface of the granules. Therefore wetting properties such as interfacial tension and contact angle play an important role.

Product Design of a Stabilized Fertilizer

Most fertilizers contain nitrogen as ammonium (NH_4^+) and nitrate (NO_3^-), whereas the latter is subject to leaching. Stabilized fertilizers aim to reduce NO_3^- leaching by increasing the lifetime of NH_4^+-N in the soil from less than 1 week under normal conditions to 6–10 weeks. A substance named 3,4-dimethylpyrazole (DMP) shows highly favourable properties as a nitrification inhibitor (Pasda *et al.*, 2001). The use of DMP on fertilizer granules poses three problems: (i) DMP is not stable on fertilizer granules; (ii) the odour of DMP is noticeable; and (iii) DMP is colourless and thus its application cannot easily be detected. Therefore a formulation has to be developed in order to avoid these disadvantages. Research showed that a reaction between phosphoric acid and DMP forms 3,4-dimethylpyrazole-phosphate (DMPP) (Zerulla *et al.*, 2001). The DMPP is soluble in concentrated phosphoric acid and stable on the fertilizer surface. The odour of DMPP is agreeable and hardly noticeable. Together with an acid resistant colour, it forms the liquid formulation called 'ENTEC®'. The colour acts as an indicator in production and shows the consumer that the fertilizer is stabilized.

The advantages of DMPP are:

- DMPP is not subject to leaching;
- DMPP is completely biodegradable;
- N_2O-release is reduced by ~50%;
- the amount of applied fertilizer possible can be reduced;
- production of biomass is increased (Pasda *et al.*, 2001).

The amount of the formulation needing to be applied to the fertilizer depends on the fertilizer's content of ammonium-nitrogen. The density of the formulation liquid is about 1.5 kg l^{-1}. The best distribution can be obtained by using 2–7 l t^{-1} of the formulation on the fertilizer granules. Despite this small volume, every granule has to be coated with the formulation liquid. In order to avoid caking, minimum water must be used in the formulation. Figure 3 shows the effect of the water content on viscosity and wetting properties.

The ENTEC formulation shows a contact angle of 45° at 10% water. It declines at a water content higher than 20%. With 40% water the contact angle is only 27°. Coating experiments showed no significant difference with respect to quality when using a formulation liquid with a contact angle of 45° or 27°. Contrary to this result, strong caking of the coated fertilizer occured at water contents of 20% or above. Therefore the maximum water content should not exceed 20%. Viscosity proved to be another parameter with respect to a homogeneous coating. Experiments showed that a viscosity smaller than 200 mPa s is optimum. Higher viscosities result in a spotted product and lower viscosities contain too much water. According to these findings, it was decided to use 16% water in the formulation. A water content of 16% resulted in a viscosity of 150 mPa s at room temperature. Since a huge amount of fertilizer production takes place during winter, it is necessary to keep the formulation, which normally is kept in storage takes outside production buildings, at an adequate temperature (Figure 4).

In Figure 4 the effect of temperature on the viscosity of the formulation liquid at low temperatures can be seen.

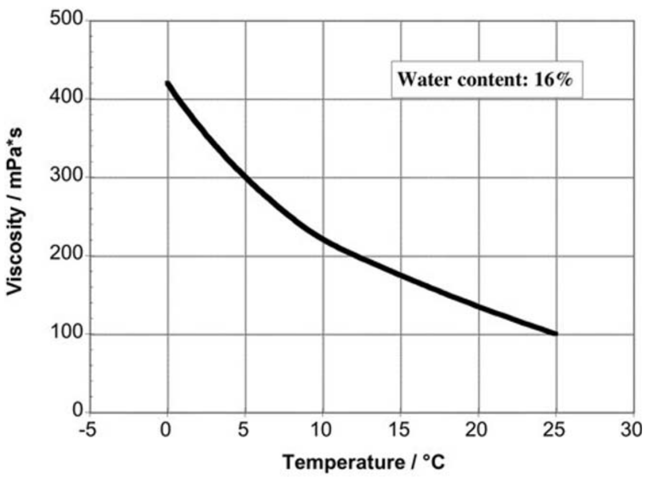

Figure 4. Effect of temperature on viscosity.

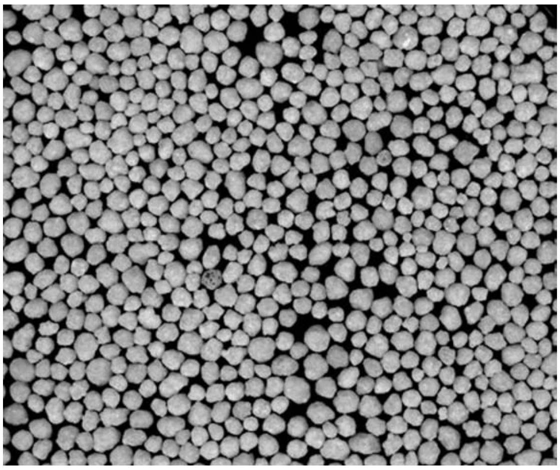

Figure 5. Stabilized fertilizer.

According to this diagram the temperature of the formulation liquid in storage tank should not fall below 15°C. After adjusting the water content, the final formulation shows the expected performance, such as homogeneous coating, adequate wetting properties and no increased tendency to cake. A product sample (Figure 5) from a production site with a throughput of 30–40 t h^{-1} shows a homogenous appearance of the stabilized fertilizer.

Fertilizer with Controlled Release Effect

A controlled release effect of fertilizers aims for delivery of mineral nutrients depending on the demand of the plants. The delivery time is expected to last between several months and over one year. Requirements with respect to coating properties of fertilizers are: constant shell thickness, elasticity of the shell, mechanical stability at low temperatures, and nutrient delivery depending on soil temperature (Anonymous, 2003). A high-quality coating is based on several requirements with respect to the core particle and coating materials. The core particles should show a smooth surface without edges. The coating material should provide a low viscosity, good wetting and film formation properties. Droplet formation or the favoured atomization is based on the Ohnesorge diagram (Figure 6).

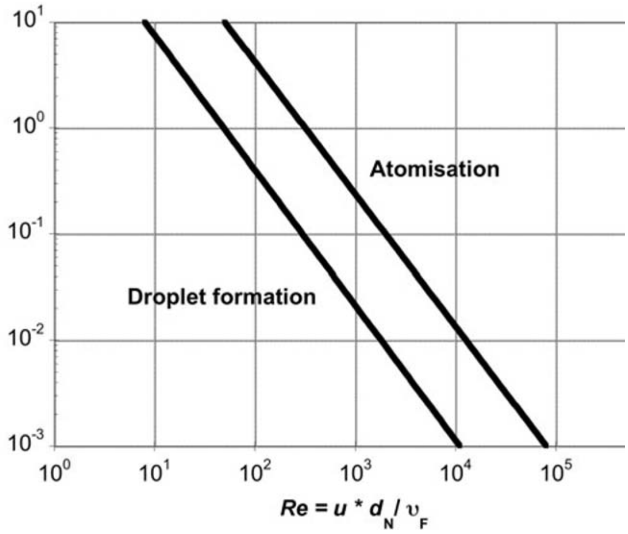

Figure 6. Ohnesorge diagram (Schegk, 1985).

The flow velocity, u, through a nozzle with diameter, d_N, resulting in atomization can be calculated based the Ohnesorge number, *Oh*, and the Reynolds number, *Re.* After the drying process the shell should adhere well to the core particle. The coating also has to be designed with respect to transport and application of the fertilizer. The coating also has to be applicable on a throughput of up to several tons per hour. This kind of coating is carried out in a continuous fluidized bed consisting of several separated zones. The drying conditions affect the shell quality greatly, as can be seen in Figure 7.

Slow drying conditions result in a quite porous shell. The core particle is partially dissolved. Although sufficient shell material is available, a closed shell cannot be achieved. When drying at high temperatures the core particle is stable, the shell is closed and only some pores can be detected. However, the shell does not adhere to the core particle. During transport it is to be expected that this shell will break. A film-forming formulation based on Poligen®, a polyethylene wax emulsion, was designed that meets all the requirements mentioned above. In general the following additives are part of a film forming formulation:

- film formers (providing a coherent layer);
- fillers (providing volume, modifying tensile strength and permeability);
- plasticizers (modifying brittleness and surface smoothness);
- surfactants (minimizing surface roughness and 'orange peel aspect');
- lubricants (minimizing stickiness during production);
- colours and dyes (if product identification is requested); and
- anti-caking agents (avoiding caking during storage).

Depending on the thickness of the shell, the number and diameter of the pores and the conditions during the coating process, the nutrients will be released over a period of 3–12 months (Anonymous, 2003). Latest developments offer a time frame of 15 months. As shown in Figure 8(a), a closed shell with constant thickness adhering on the fertilizer granule is the basis for a constant leaching of mineral nutrients. The effect of an irregular shell thickness results in a nitrogen release of 80% in 7 days, while it releases 30% with a constant shell thickness.

Figure 8(b) shows a shell with a constant thickness adhering well on the core particle. It has to be taken

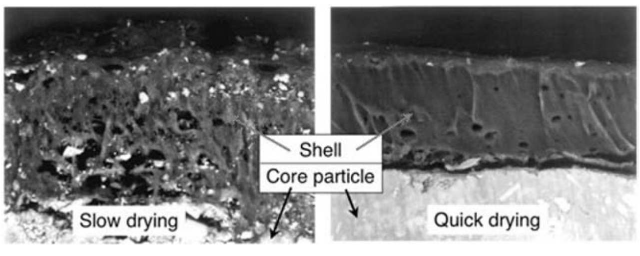

Figure 7. Shell quality depending on drying conditions.

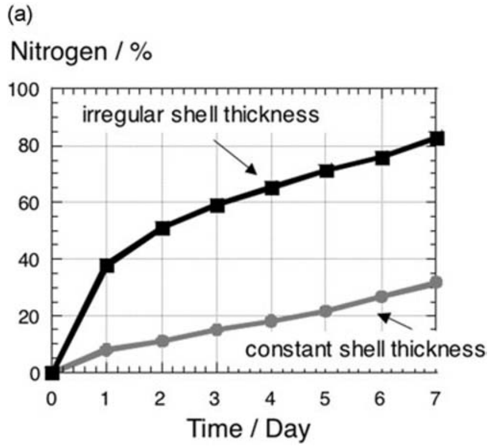

Figure 8. (a) Effect of shell quality on nitrogen release. (b) REM picture.

into account that the coating substance is expected to be environmentally friendly. Bio-degradation of the shell is expected to start at the end of the time-release effect (Figure 9). Therefore the shell has to be stabilized for between 3 and 15 months depending on the fertilizer type before bio-degradation starts. Plants grow faster at higher temperatures, and this also has to be considered. Increased activity of plants demands a higher nutrients delivery.

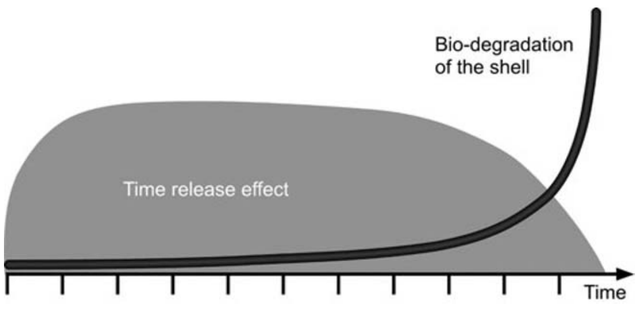

Figure 9. Time release effect and the bio-degradation plotted vs time (Anonymous, 1999).

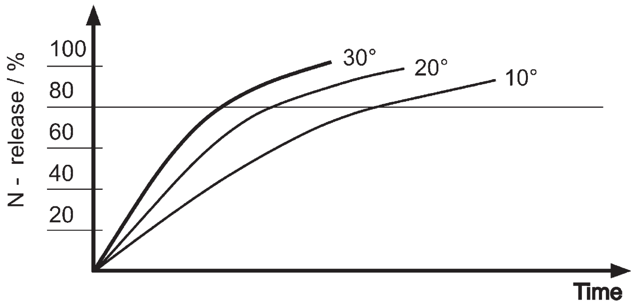

Figure 10. Nutrient delivery depending on soil temperature (Anonymous, 2003).

According to this, the release effect should increase with soil temperature. A special design of the shell improves the performance of the nitrogen per unit time (Figure 10).

CONCLUSION

The development of designed fertilizers through product design may transform a commodity to a highly functional product. It could also be stated that product design is applicable to products with a throughput up to several tens of tons per hour (Personal communication, Compo GmbH, 2004). Still, many trial-and-error experiments are necessary when designing a formulation or a coating material. The components of these formulations are expected to be cheap, environmentally friendly and should show the required performance. Interactions between components, such as chemical reaction, flocculation and aggregation, have to be taken into account in the early laboratory phase.

Designed fertilizers show a consumer-added value, increased nutrient uptake efficiency and therefore avoid contamination of the soil with unabsorbed fertilizer. In future an increasing market share of formulated fertilizers is to be expected.

NOMENCLATURE

Oh	Ohnesorge number
Re	Reynolds number
u	velocity, m s^{-1}
x	particle diameter, m

Greek symbols

ν	viscosity, m^2 s^{-1}
ρ	density, kg m^{-3}
σ	surface tension

Subscripts

F	fluid
N	nozzle
P	particle
T	droplet

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