



The Uhde Pugmill Granulation
The Process for Safe and Reliable Production of
CAN and Other
AN Based Fertilisers

by

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Abstract

Nowadays many granulation processes for AN/CAN are available which have certain advantages over the 'old' prilling process.

One of these processes is the Uhde Pugmill granulation process. Compared to other granulation processes it has many advantages like low power & steam consumption, inherent process safety, high reliability and the production of a high quality product.

Especially for CAN, preferred today to AN because of safety considerations, the Uhde Pugmill granulation process proves to be advantageous.

This paper describes the principles of the process, developments carried out to improve the Uhde Pugmill process and its product quality making it an attractive, well-proven and reliable choice for the modern fertiliser industry.

Uhde's technology is based on over 50 years of experience in the designing of neutralisation and granulation plants. This technology is continually being reviewed to keep abreast of current developments in equipment, materials, environmental and safety requirements, as well as trends in the marketing and application of Nitrogen fertilisers.



1. CAN as the straight AN fertiliser of the future

1.1 Safety Issues in AN and CAN Granulation Units

Not only since the Toulouse accident ammonium nitrate as fertiliser is again under a close safety review. Some countries even prohibited any import of straight AN fertiliser. The safety aspect therefore is not only an issue during the production process, but especially also during storage, transport and distribution.

In large parts of the European Community the production and sale of AN fertiliser with a Nitrogen content of more than 28% is either banned or subject to strict regulations. Therefore CAN, the mixture of ammonium nitrate and limestone or dolomite, is not subject to transport regulation described in UN 2067 or UN 2071 for ADR purposes. Thus it is widely used in Western Europe and will become more popular in Eastern Europe as well.

The critical issues when producing and handling ammonium nitrate are:

- high or excessive temperature
- confinement (while heating)
- contamination

High temperatures are mostly an issue during the production and will be addressed later in this paper. Confinement and heating under confinement is also a subject to be regarded during the detail design of a plant.

However, contamination can take place in any location where feedstocks or products are handled. Critical contaminants are:

- nitric acid (low pH)
- chlorides
- metal ions (e.g. Cu, Zn, Cr)
- organic (combustible) carbon

No.	Reaction	Heat release * kcal/mol	starting at °C	significant from °C
1	$\text{NH}_4\text{NO}_3 \rightleftharpoons \text{NH}_3 + \text{HNO}_3$	+ 44,6	169	250
2	$\text{NH}_4\text{NO}_3 \rightarrow \text{N}_2\text{O} + 2 \text{H}_2\text{O}$	– 8,8	200	200
3	$2 \text{NH}_4\text{NO}_3 \rightarrow 2 \text{N}_2 + \text{O}_2 + 4 \text{H}_2\text{O}$	– 28,2		300
4	$2 \text{NH}_4\text{NO}_3 \rightarrow \text{N}_2 + 2 \text{NO} + 4 \text{H}_2\text{O}$	– 6,6		300
5	$3 \text{NH}_4\text{NO}_3 \rightarrow 2 \text{N}_2 + \text{N}_2\text{O}_3 + 6 \text{H}_2\text{O}$			300
6	$4 \text{NH}_4\text{NO}_3 \rightarrow 3 \text{N}_2 + 2 \text{NO}_2 + 8 \text{H}_2\text{O}$	– 22,2	230	300
7	$5 \text{NH}_4\text{NO}_3 \rightarrow 4 \text{N}_2 + 2 \text{HNO}_3 + 9 \text{H}_2\text{O}$	– 29,4	only under presence of spongy platinum and gaseous HNO_3	
* at constant p, 25° C; calculated from heat of formation data; all products gaseous				
<u>Reaction with organics:</u>				
$2 \text{NH}_4\text{NO}_3 + \text{C} \rightarrow 2 \text{N}_2 + \text{CO}_2 + 4 \text{H}_2\text{O} + \Delta\text{H} ; \quad \Delta\text{H} = -75.2 \text{ kcal/mol at } 25^\circ \text{ C}$				

Figure 1: Decomposition reactions of AN



A special case of contamination is the contamination by nitric acid, because this does not have to be induced from the outside but happens just by itself in the product.

In Figure 1 the main decomposition reactions of ammonium nitrate are shown. The first reaction into ammonia and nitric acid already starts at low temperatures, though at very slow rates. The ammonia gas escapes and leaves behind an excess of nitric acid, resulting in a drop of the pH value. The nitric acid catalysis the decomposition reaction, thus enhancing the acidifying effect.

This reaction can be suppressed by an acid binding additive (or filler material), thus stabilising the pH in the product. The calcium carbonate contained in limestone or dolomite serves as such a pH stabiliser, not only in the product, but also in the soil after application.

Another effect of the limestone/dolomite addition is the resistance to detonation, which makes CAN practically useless for any use or misuse as explosive.

1.2 The effect of limestone/dolomite on CAN safety

Ammonium nitrate and calcium ammonium nitrate fertilisers are produced from ammonium nitrate and an admixed filler material. To this filler other additives can be added to supply further nutrients to produce the required fertiliser grade.

Granulation is a two step process: First the melt is mixed with the required filler and/or additives then the mixture is granulated.

For the production of calcium ammonium nitrate or ammonium nitrate fertilisers dolomite or limestone is usually used as filler material. The reason is that calcium carbonate and magnesium carbonate reduce the rate of decomposition of ammonium nitrate. This improves the safety of the production process and the stability of the fertilisers during storage and transport. It also serves as pH buffer in the soil after application of the fertiliser.

Dolomite is a naturally occurring mixture of CaCO_3 and MgCO_3 . Limestone can be from natural sources or synthetic CaCO_3 from a nitrophosphate plant. Natural limestone and dolomite ores can be broadly classified as shown in the following table.

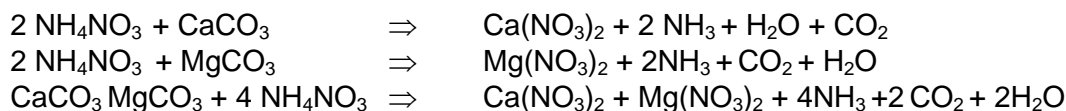
Type	MgO Content wt. %	Ca $\text{Mg}(\text{CO}_3)_2$ content [wt. %]
Limestone	0 – 1,5	0 – 7
Dolomitic limestone I	1,5 – 5,5	7 – 25
Dolomitic Limestone II	5,5 – 11,0	25 – 50
Limestonic Dolomite I	11,0 – 16,5	50 – 75
Limestonic Dolomite II	16,5 – 20,5	75 – 95
Dolomite	0,5 – 21,8	95 – 100



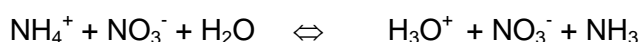
Some other additives, which can be added, are:

Compound	Formula	Use
Iron sulphate	FeSO ₄	Granulation aid, micronutrients
Aluminium sulphate	Al ₂ (SO ₄) ₃	Granulation aid, Stabiliser
Gypsum	CaSO ₄	S Fertiliser
Ammonium Sulphate	NH ₄ (SO ₄) ₂	S Fertiliser
Epsom salt	MgSO ₄ 7H ₂ O	micronutrients
Kieserite	MgSO ₄ H ₂ O	micronutrients

The main chemical reactions occurring during the granulation process are:



All reactions can only occur if water is present, e.g. dissolution of ammonium nitrate



The reactivity of the filler is a measure of the intensity of the reactions between ammonium nitrate and the carbonate compounds of the filler. It is expressed as the total weight percent of nitrate in the form of Ca(NO₃)₂ and Mg(NO₃)₂ in the granules or in a laboratory test. A high reactivity means that more Ca(NO₃)₂ and Mg(NO₃)₂ is formed according to reactions (I) and (II).

In general, the reactivity of a filler decreases with the CaO content of the filler - with pure CaCO₃ at the highest, followed by limestone, then dolomite and finally magnesite.

The following diagram demonstrates this behaviour by showing the influence of CaO content on pH from a mixture of ammonium nitrate and different fillers at 160°C. At this temperature the conversion reactions described above occur and gaseous CO₂, H₂O and NH₃ are released. Due to the good reactivity of pure CaCO₃ exhibits the quickest and largest release of NH₃. The addition of a filler containing dolomitic carbonate reduces the NH₃ loss significantly with the lowest mass loss occurring with the addition of magnesite. The loss of NH₃ from pure ammonium nitrate derives from the low temperature decomposition of AN into NH₃ and HNO₃.

The most pronounced drop of pH occurs in pure ammonium nitrate sample. The drop in pH is reduced by adding the different fillers with a carbonate component. The conversion reactions consume any nitric acid surplus generated by the normal decomposition of the ammonium nitrate, thus stabilising the AN fertiliser for pH. This is one reason for calcium ammonium nitrate fertilisers with an N content of below 28% to be considered safe and exempting them from many of the strict regulations pertaining to straight AN fertilisers on the EC market.

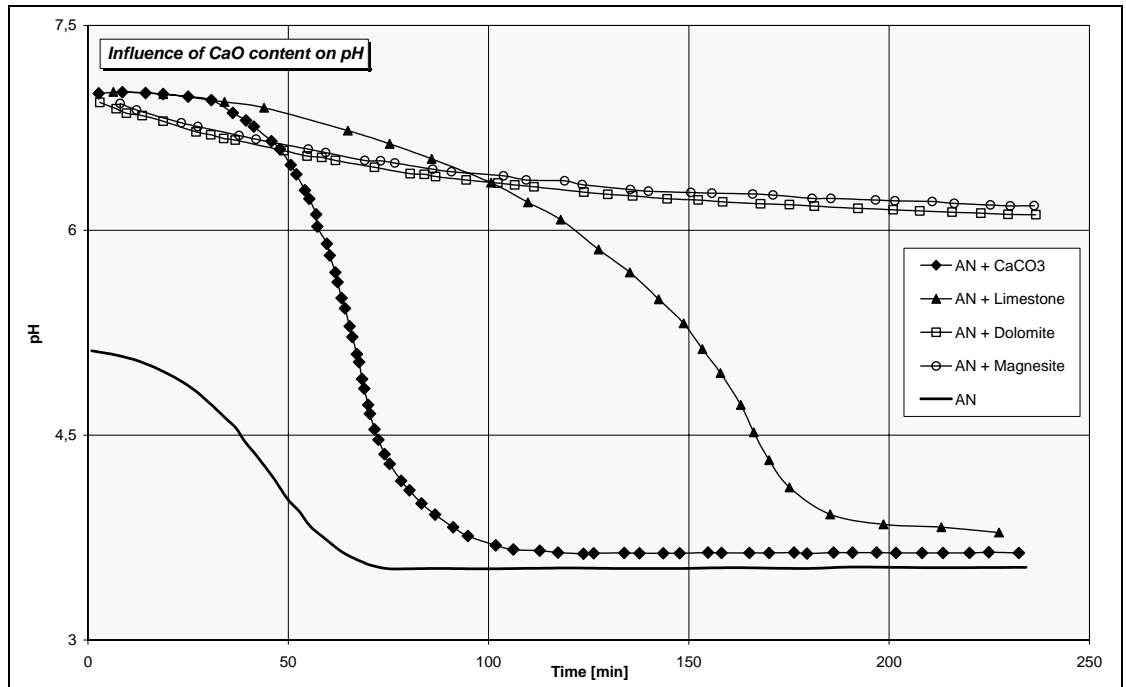


Figure 2: pH stabilisation of AN with different fillers at 160°C

The rate of reaction can be influenced by:

- pH of granules
- filler type
- drying and grinding conditions for the filler
- granulation temperature
- granulation moisture
- product moisture

While a certain low amount of $\text{Ca}(\text{NO}_3)_2$ and $\text{Mg}(\text{NO}_3)_2$ improves granulation conditions by helping to form well-bound and round granules, a high content leads to products with a low critical humidity and a tendency to cake in storage. If the reactivity of the filler is too high then the rate of reaction must be limited. This can be done by changing the pH, the residence time or by blending fillers with high and low reactivity. Addition of additives like ammonium sulfate also suppress the conversion reaction.



2. Ammonium Nitrate Granulation Processes

Prilling used to be the favoured process to produce AN fertilisers. However, prilling has largely been superseded by the granulation processes which nowadays produce the majority of AN and CAN products. In fact, many prilling plants have been replaced by granulation units, mainly because of environmental problems of the prilling towers but also due to the superior product quality (hardness, size, storage properties) of the granules. Currently AN prilling plants are exclusively being built for technical and explosive grade AN production.

2.1 Common AN/CAN Granulation Processes

The granulation processes can be divided into high solid recycle processes, e.g.

- Pugmill,
- Spherodizer,
- Drum.

and low solid recycle processes:

- Fluidised bed,
- Pan,
- Fluidised Drum.

"Recycle" in this case is defined as the amount of solid material going back to the granulator in relation to the amount of product being produced. A high recycle process will have a recycle of 1.5 - 2, whereas a low recycle process will usually stay below 1.

These differences result in the different AN concentrations or amount of liquid phase required by the granulation process. A high solid recycle granulation process usually requires a lower AN concentration (94 - 96.5%) than a low solid recycle process (98 - 99.5%). This correspondingly means that the amount of water to be removed from the product by drying is higher for a high recycle process. Some low recycle processes operate with such a low water content so that a dryer is not required.

These differences in operating conditions of the two granulation routes have important consequences with regard to safety, production and maintenance.

- A high recycle process operates with lower ammonium nitrate concentrations, therefore the melt temperatures are significantly lower. Lower temperatures significantly decrease the risk of ammonium nitrate decomposition. Also, the filler material can be admixed to this AN solution without the risk, that natural or induced impurities in the filler material bear a safety issue.
- In a high solid recycle process fines, oversize and off-spec material produced during granulation can be returned directly to the granulator. In a low recycle process these streams have to be dissolved, which usually requires a large agitated tank. From this tank the solution is sent to the concentration section to reduce the water content. This means that potentially contaminated material is introduced into hot AN solution at high temperature which presents a safety issue.



- If the low solid recycle plant operates without a dryer, the amount of material which can be dissolved and returned to the process is limited by the water balance. Under upset conditions this can become a problem if too much over- or undersize material must be reprocessed. In this case the plant has to be equipped with an off spec storage system to buffer this material until it can be reintroduced into the process. A high recycle process is usually designed with enough capacity to handle such upsets. As it contains a dryer the plant is not that limited by the water balance. As a rule of thumb, a high recycle process runs more constant and reacts better-natured on process fluctuations.
- In a high solid recycle process the filler can be introduced into the granulator without any heating. Due to the low AN concentration (= high water content) in the melt, this is even possible for grades with low N contents which require large amount of filler (up to 15-20% of production). In a low recycle processes producing low CAN grades with low N contents is difficult as the filler must be mixed with the AN solution before it enters the granulator. This requires a heated and agitated mixing vessel.
- A high solid content in the melt leads to an increase in the amount of erosion occurring in the spray nozzles. This in turn causes the spray pattern to deteriorate. As this usually leads to bigger droplets more coarse and lumpy particles are formed. Therefore the spray nozzles have to be replaced regularly. The spray nozzles, in combination with a very hot AN solution, do also cause the formation of AN aerosols, which can only be removed in special expensive scrubber systems.
- Low recycle processes have the advantage of being able to add $Mg(NO_3)_2$ to produce granular ammonium nitrate. This is a very effective method of stabilising ammonium nitrate as it changes the phase change temperature. It reduces caking and dust formation during storage and transport due to thermal cycling which, however, is no issue in moderate climates and of minor significance in hot climates. The great disadvantage is the considerably increased moisture pick-up of the product, which is a particular problem for plants operating in or exporting to humid climate regions. This is also the reason why $Mg(NO_3)_2$ cannot be easily used in a high recycle process due to the higher liquid phase in the granulator. For CAN production the addition of magnesium nitrate is only of minor importance, if at all.

2.2 Uhde's State of the Art Pugmill Granulation Process

In the course of this time period the industry has faced many major changes. Broadly these changes are shown in the following diagram. It shows the increase in capacity of a typical granulation plant for AN/ CAN fertiliser. Also indicated are various developments due to financial or environmental influence that had a marked influence on the design of a modern AN/CAN granulation plant.

The inherent flexibility of the Pugmill granulation plant design enabled it to meet all these challenges which lead to the modern plant concept outlined in the next section.

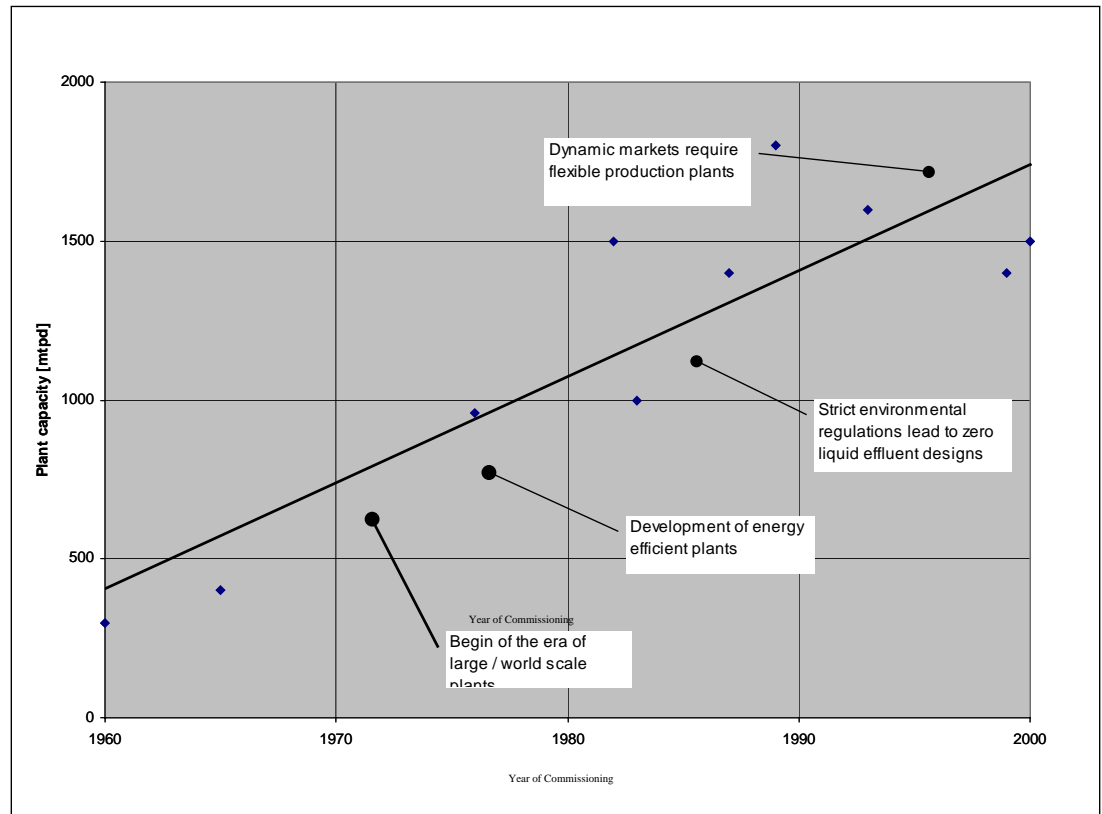


Figure 3: Development of Plants in the Change of Time

2.3 Details of a Modern Pugmill Granulation Process

A modern granulation plant consists of the following units:

- Granulation loop
- Product treatment
- Process air treatment
- Process water treatment
- Wash water treatment system

The granulation loop forms the actual product from AN melt, the required additives and the filler to adjust the N content. The main equipment of the loop contains of the granulator and a dryer, screens, crushers and the necessary transport equipment.

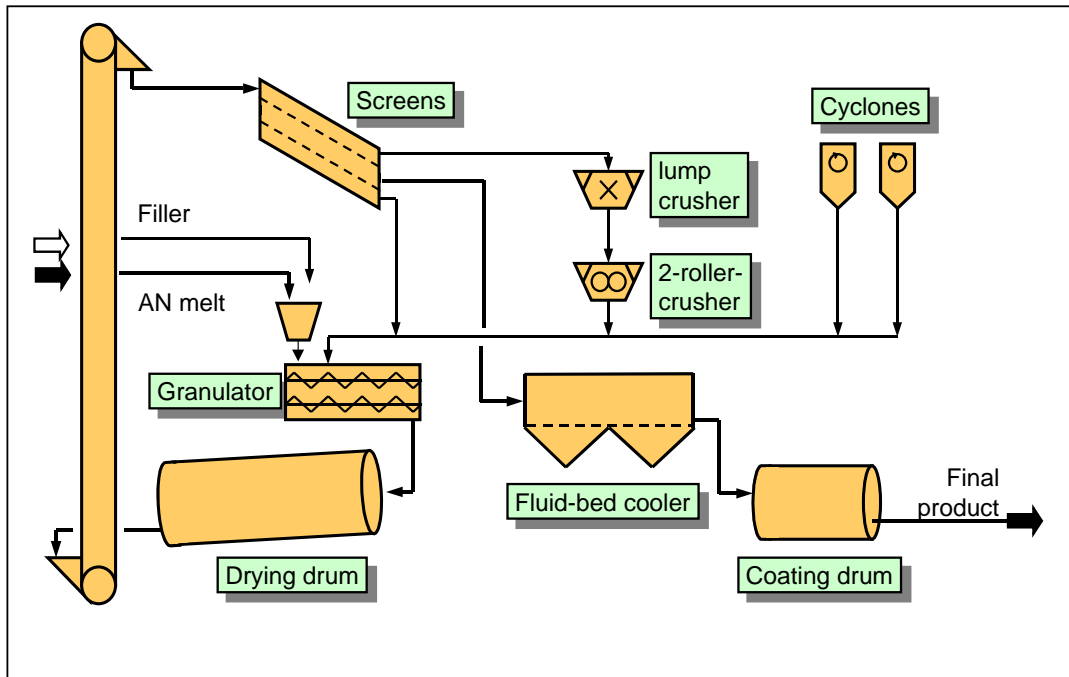


Figure 4: Granulation and Recycle System

The product treatment section cools the product to the temperature required for storage. Subsequently, the product is usually treated with an anti-caking agent and optionally with a coating agent.

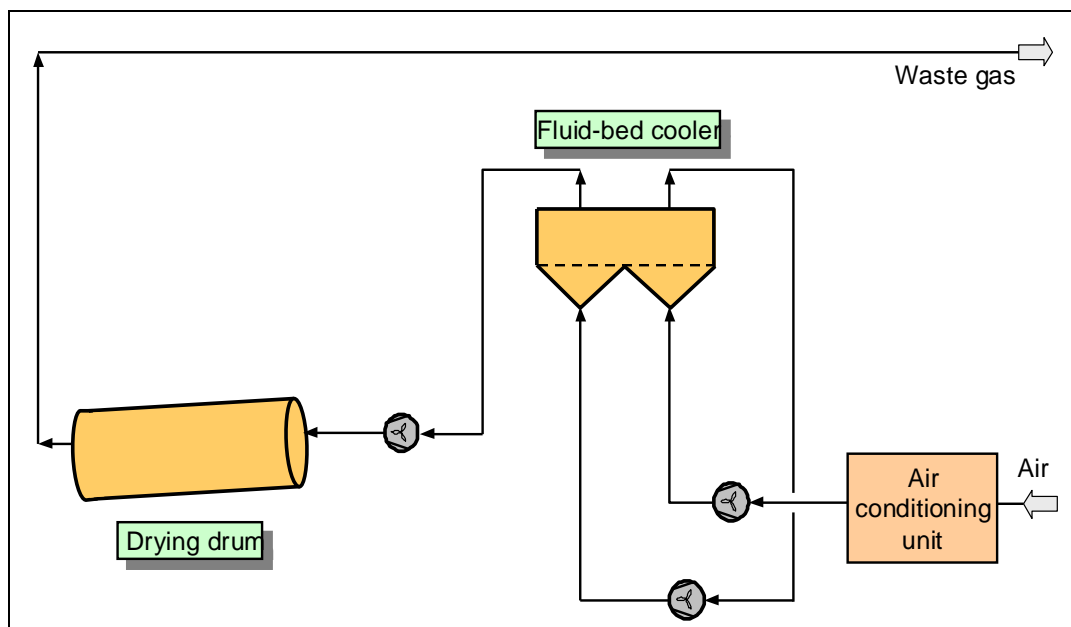


Figure 5: Combined cooling / drying air System

A significant feature of the Uhde process is the re-use of the offgas from the fluid bed cooler for the drying of the product in the dryer. This is a significant energy saving feature and enables the plant to run autothermally for nearly all CAN grades.



This feature also effectively halves the amount of air that must be processed in the air treatment section.

Process air comes from the dryer and cooler and has to be treated to reduce the amount of NH_3 and dust. A combination of cyclones and a wet scrubber are used to reduce the emissions. The cyclones remove most of the dust, whilst the scrubber takes care of the ammonia gases and the remaining dust.

The combination of cyclones and scrubber has the advantage that more than 95% of the dust is recycled as dry matter and serves as seed material for the granulation. Only a small fraction of the dust is dissolved in the scrubber solution and is returned as a liquid suspension.

The dust consists of ammonium nitrate and filler. The calcium carbonate in the filler reacts with the acidic scrubbing solution to produce calcium nitrate according to the following reaction:



By reducing the amount of dust fed into the scrubber the amount of calcium nitrate formed is therefore significantly reduced. A high calcium nitrate content greatly increases the moisture pick-up of the granules and decreases their hardness.

All vapours from the concentration section are also treated in the wet scrubber. The scrubber consists of a packed bed section with an additional tray or wetted demister section to effectively eliminate dust and ammonia.

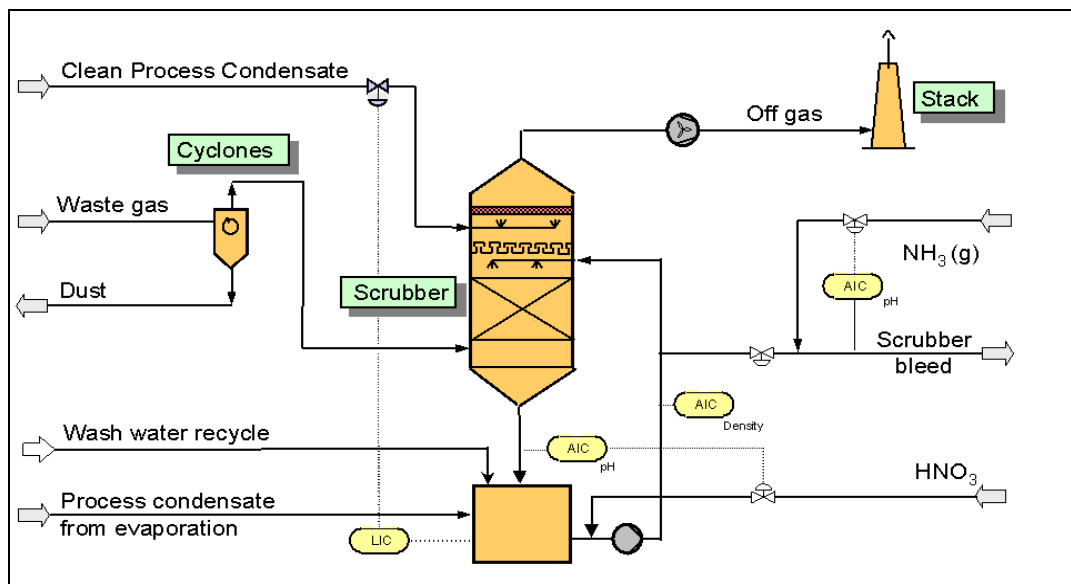


Figure 6: Process Air treatment

To achieve 'zero liquid effluent' operation all process water streams, e.g. the scrubber bleed, are collected and sent to a dedicated concentration section in the granulation plant.



All granulation plants must be cleaned from time to time. Due to the high solubility of AN the most efficient way is to use water. This discontinuous effluent stream can be discharged to a wastewater treatment plant, if such is available and has sufficient capacity. A better way is to collect the 'clean' wash water in a pit or tank and reintroducing it into the granulation unit when the plant has resumed operation. From the pit the wash water is sent to the scrubber as make up water.

As the waste liquids contain large amounts of N in the form of AN, they can alternatively be used by local farmers to be sprayed on their fields (in case the market and infrastructure allows for this) or to be processed in nearby NPK plants.

2.4 Characteristics of the Pugmill Process

All of the above features are incorporated into the design of a modern Pugmill plant.

It is Uhde's opinion that the Pugmill process is still the best option for producing CAN and related fertilisers:

- One Pugmill plant is capable of producing the whole range of N contents from 22 - 33.5 %N. The switching from AN \leftrightarrow CAN is done quickly.
- The Pugmill process is very tolerant regarding the filler materials and additives. Most natural dolomites and limestone can be used. It can also process synthetic limestone from nitrophosphate plants.
- The addition of additives to achieve desired levels of sulphur or micronutrient is straightforward. These do not have to be added as solutions, but can be fed directly into the granulator.
- The process is inherently safer because it operates at low temperatures throughout the system (max. AN temperature is below 160°C) and low concentration (max. 96.5%)
- The high solid recycle makes the plant very stable and self-regulatory. All disturbances will balance over the time and minor disturbances rarely require operator action.
- The kneading action of the Pugmill produces a hard and uniform product. Scalping screens or a sophisticated seed preparation system is not required.
- With very few exceptions easily obtainable standard equipment is used in the plant design. The amount of proprietary equipment is very low, spare parts can normally be obtained or produced locally.
- The Pugmill plant is able to produce most CAN grades autothermally (i.e. no external heating required).
- The electrical power consumption is lower than for other granulation processes.
- The reuse of cooler off-gas for drying considerably reduces the air flows that must be treated in the scrubbing section. This reduces the investment and operating costs.
- The emissions in the offgas from the scrubber are below 'Best Available Technology' (BAT) levels. No aerosols are generated throughout the process.
- There are no liquid emissions during normal operation. All wash water solutions are collected and reprocessed (except for contaminated floor spillage).
- The total plant cost are comparable or even lower than for other granulation processes.



3. Further Improvement of the Uhde Pugmill Granulation

3.1 Dolomite / Limestone Assessment

An important part of the design of a new plant is the evaluation of the available raw materials, in particular the locally available filler material.

Many parameters play an important role for the selection of the filler and the subsequent design of the plant. Some of these are :

- The reactivity of the filler with AN and the amount of $\text{Ca}(\text{NO}_3)_2$ formed during production.
- Its influence on the phase changes of AN, particularly the phase changes below 60°C , i.e. the resistance against thermal cycling.
- The influence of SiO_2 and other components on the product hardness.
- The effect on AN decomposition during production and storage.
- The effect on porosity and oil absorption.

To be better able to assess these parameters a laboratory programme has been set up to assess all filler material used in existing Uhde plants, but also potential material from previous and current projects. This knowledge has enabled us to generate a database, which currently contains the results of about 20 types of fillers from all over the world. As this programme is a continuous effort the number of tested materials will increase continually.

With this knowledge we are in a position to assess available filler materials and to comment on their suitability during very early phases of the project. It also gives us an excellent reference base for the design of new plants.

3.2 Additives and their Effect on Granule Properties and Thermostability

Ammonium Nitrate is polymorphic and can assume at least at ordinary pressure five crystalline forms with different enthalpies and densities. Each form has a Latin figure from I to V. The stable form at ambient temperature is form IV. The change in crystal shape is combined with a change of volume and heat of transition. Each phase change (thermocycling) can result in a change of hardness, increase of porosity and dust formation so that the aptitude to detonation becomes apparent.

The phase change between crystal structures IV and III is extremely critical as pure ammonium nitrate cycles around 32°C , which is close to subtropical and tropical ambient temperatures.



Possible methods to stabilise AN are:

Deep Drying

The transition from form III \Rightarrow IV must take place in connection with dissolution and re-crystallisation of the solid.

If the AN is exhaustively dried this transition is shifted to 50 - 55°C. Drying of the AN fertiliser below 0.03% H₂O content can therefore be a method of stabilising against thermocycles, but is extremely difficult to achieve and to maintain.

Addition of additives binding crystal water

Some inorganic additives bind reversibly crystal water. During the granulation process these salts can lose partly their crystal water to pick it up again during storage. This behaviour is shown e.g. by Al₂(SO₄)₃ x 17 H₂O and Mg(NO₃)₂ x (4-6) H₂O. But the addition of aluminium sulphate to the melt requires a levelling of the pH by adding NH₃ and using Magnesium Nitrate may generate a hygroscopic product because the critical relative humidity of AN granules can decrease below 10%.

Adding Ca(NO₃)₂ x 2H₂O moves the transition point up to max. 50°C but granules containing CN show a very hygroscopic behaviour.

Combined additives:

A mixture of the above mentioned additives is used to achieve the highest degree of stabilisation. The transition temperature at 32.2°C is relocated to 43 – 45°C. It is also claimed to reduce water absorption.

Other possibilities:

Addition of cations that replace the NH₄⁺ and block the transition.

The NH₄⁺ ion can be replaced by ions having similar ion radius like K, Rb, Ti, Ca. If the radius of the substitute is smaller than the ammonium ion (like K), the transition temperature will be lowered. If the radius is bigger (like Ca, Ti) the transition temperature will be increased.

The optimum additive shall meet the following requirements:

- prevent thermal shock,
- be efficient at low amounts,
- reasonable costs,
- simply to apply,
- improve the physical properties.

Considering all the above mentioned requirements there are three additives remaining: Al-sulphate, potassium-sulphate and a mixture of boric acid, phosphate and Ammonium sulphate.

These additives were tested by Uhde in laboratory tests with the results being implemented in actual projects.



3.3 Control of Filler Reactivity

In most pugmill plants the ammonium nitrate melt and the filler are added directly to the granulator. This results in a relatively short and fixed residence time - i.e. the time period between initial mixing and crystallisation in the granulator - at a fairly low temperature. With this system the residence time can only be optimised for one combination of product grade and filler. Adapting the process variables to changes in reactivity is difficult and limited, forcing the plants to operate more or less with the original filler specification.

In order to achieve a better process control a mixing device has been developed and installed in an Uhde pugmill granulation plant in Romania. This enables the producer to increase or decrease the residence time of AN melt and filler prior to feeding it to the granulator. This additional degree of freedom results in a flexibility to adapt the plant to changing filler reactivity (e.g. when using a different filler) or different products.

The device was proven to be very successful, enabling the plant to change from one type of filler to a totally different type without any noticeable change or upset in process conditions. The AN granulation improved considerably, allowing the plant to manipulate the product size simply by changing the recycle ratio. Shape and surface of the granules were improved to a clearly visible extend.

3.4 Fertiliser with Sulphur

In recent years many soils have been showing a deficiency in sulphur. This has many causes, the most important being the switch from sulphur containing fertilisers like AS, SSP and TSP to straight N Fertilisers AN and Urea. Another factor are the reduced sulphur emissions from electric power plants, as large-scale de-sulphurisation projects are showing an unexpected side effect.

This has spurred the recent demand for fertilisers containing sulphur. Despite the marketing efforts of some companies, elemental sulphur is not a good substance for plant nutrition. It takes at least 6 months before any effect is seen. Therefore various manufacturers have developed fertilisers with sulphur components. Some additives, which have been used, are Kieserite or Epsom salt ($\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$) or even Bentonite. Another alternative is the use of gypsum.

A pugmill plant can produce S-fertilisers, when one replaces part of the filler with a sulphur containing substance e.g. gypsum. To optimise this plant trials were conducted. Using anhydrite gypsum the plant easily produced fertilisers with up to 6% S at full capacity. No changes to plant equipment or any significant changes to the process conditions were necessary. Currently development work is being undertaken to switch from anhydrite to the cheaper dihydrate gypsum.

Ammonium Sulfate (AS) forms with AN 2 double salts having different molar ratio of nitrate to sulfate, AN : AS can be 2:1 and 3:1. An addition of < 3% AS means that the transition point IV \Rightarrow III increases from 32°C to 51°C. However, the double salt formation has to be completed before granulation.



4. Conclusion

Though Ammonium Nitrate has an excellent fertilising effect it has been banned or is subject of strict safety regulations. Therefore CAN, the mixture of Ammonium Nitrate and a calcium carbonate containing filler like limestone or dolomite, is considered to be inherently safe. Thus CAN is widely used in Western Europe and becomes more popular in Eastern Europe as well as an up to date fertiliser.

The Uhde pugmill is the ideal granulation process for the production of CAN because

- of its capability to produce the whole range of N-content,
- it is tolerant regarding filler material and additives
- of its high degree of safety also compared to low recycle processes
- of the high product quality
- emissions are well below BAT-level
- investment, energy and maintenance costs are reasonably low



References

1. Keleti C., 'Nitric Acid and Fertilizer Nitrates', Marcel Dekker, New York, 1985
2. Kiiski H., 'Self sustaining decomposition of Ammonium Nitrate containing Fertilisers, IFA Technical Conference, 2000
3. Vuori A., Tähtinen I., Saijonmaa T., Prediction of decomposition behaviour of fertilizers containing ammonium nitrate', IFA Technical Conference, 1998
4. Parker A.B., Watchorn N., 'Self-propagating decomposition in inorganic fertilisers containing ammonium nitrate', J. Sci. Fd. Agric., 16(1965)6,355f
5. Shah K.D., 'Safety of ammonium nitrate fertilisers' Proceedings of the Fertilizer Society No. 384
6. Antonus R., 'Production of Ammonium Nitrate - Environmental, Energy and Safety aspects', Proceedings of the Fertilizer Society No. 414
7. N.N., 'Keeping it safe', Nitrogen & Methanol, 247(2000)5,37f
8. EFMA, 'BAT Booklet No. 6 : Production of Ammonium Nitrate and Calcium Ammonium Nitrate', 2000
9. Ando J., 'Caking and Degradation of granular compound fertilizers containing nitrates and sulfates', ISMA Conference, 1974
10. Erben A., 'The Krupp Uhde Ammonium Nitrate Process: An Advanced Safe Technology', Krupp Uhde Fertiliser Symposium, 1998
11. Erben A., 'Safety Aspects in AN/CAN Production', ANNA 2003
12. Franzrahe H., 'CAN and other Ammonium Nitrate based Fertilisers: Production, Handling and Safety 'Uhde Fertiliser Symposium, 2002
13. Liptay G. (ed.), 'Atlas of thermo-analytical curves', Heyden, London
14. Laurent B., 'Straight Ammonium Nitrate Fertilizer Granule-Prill Stabilization: Theroretical Possibilities', Kemira S.A., Belgium