Optimization of a CAN Granulation Process with INCA Advanced Process Control

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Introduction

This paper describes the application of Advanced Process Control (APC) with INCA Model Predictive Control (MPC) technology to a Calcium Ammonium Nitrate (CAN) granulation process. Although APC is a common tool in many process industries, like refining and petro-chemical, the technology is less introduced and common in fertilizer industry and only very few applications can be found for granulation processes. The production of solid material is often more difficult to control compared to liquid or gas plants. The limited amount of measurements available and the fact that they are not always reliable due to heavy production circumstances, make the application of Advanced Process Control even more challenging.

Process Description

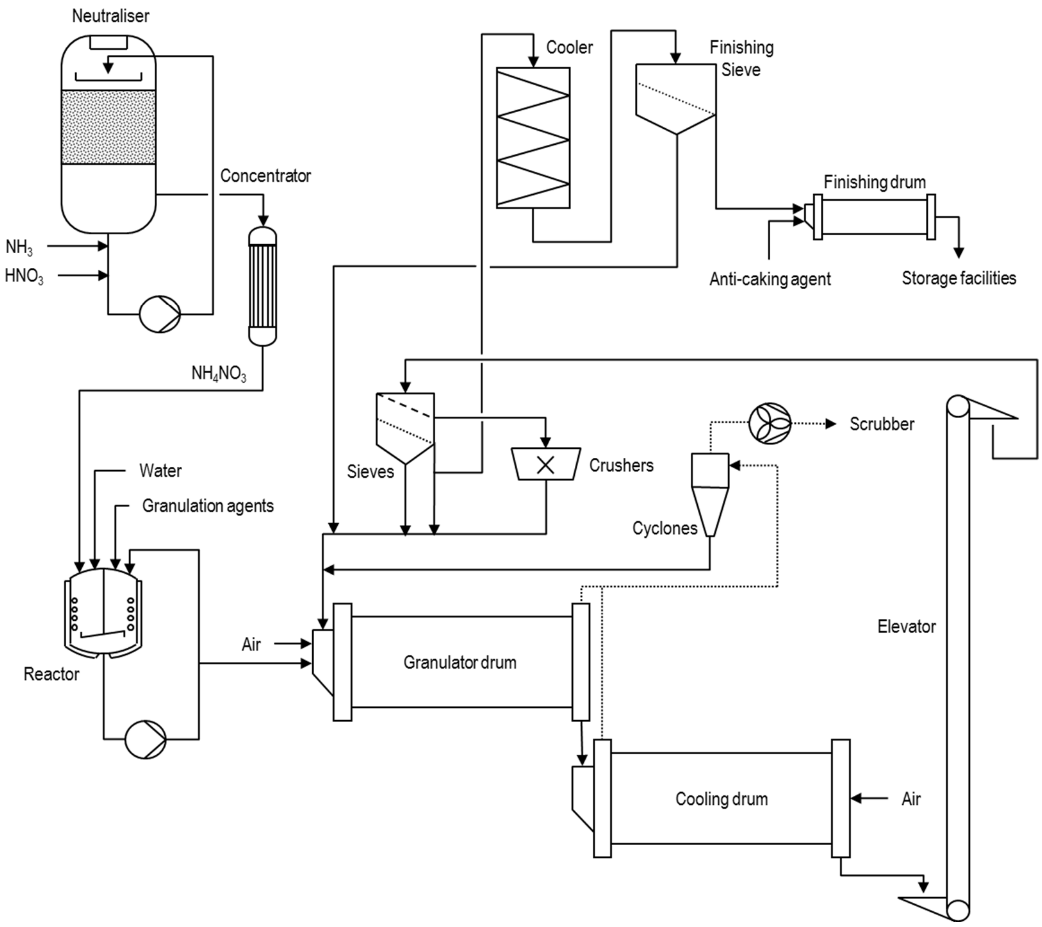

Fig. 1: Schematic overview of the granulation process.

Fig.1 shows a schematic overview of the granulation process. A modern granulation process consists typically of a reaction and concentration section, a granulation loop, a product and process air treatment section and the necessary transport equipment.

The feed to the granulation loop is composed of highly concentrated Ammonium Nitrate (AN) melt where granulation agents and water are added. The AN melt is sprayed on the reflux, consisting of fines, a small fraction of recycled good product and crushed oversized material. After further cooling and anti-caking treatment, the final product is sent to storage facilities.

Challenges

The granulation process consists of a complex chemistry determined by the chemical molecules and reactions. Physical properties are influenced by operating conditions in addition to chemical composition and state of raw materials. Stops for cleaning and other maintenance activities are required on a regular basis. Blockages in chutes and other equipment may influence the process. Measurements can be less reliable or require more frequent re-calibration due to process conditions.

An optimal granulation results in a constant distribution of granule size. Growth is realized mainly through layering with fresh AN melt and partially also due to agglomeration. Removed good product must be replaced by growth of the small fraction. The small fraction itself must be maintained by crushing oversized material. The growth of the granules is a very slow, nearly integrating process which is largely determined by the moisture content. The moisture added to the process is defined by the AN concentration of the feed and the added water. The moisture in the process must be removed again by the drying air to realize product (average granule size (D50), fines content) and storage (hardness) qualities.

The moisture content in the AN melt determines the granulation process. Less moisture results in more fine material and an overload of the system. More moisture causes granular growth and stimulates caking in the equipment, reducing the length of a production run. The integrating process behaviour can change direction due to the selection mechanism of the sieves and the crunching of oversized material into fines by the crushers. Therefore, typical process behaviour of a granulation process is characterized by a continuous, increasing and decreasing amount of fine and oversized material with a period of several hours.

Operation of the process by operators is not only based on process knowledge, but also dependent on experience and partially also influenced by personal preference. Exact timing of process changes is difficult to define but important for stability due to the integrating process behaviour. Acting early in rather small compensation steps is often sufficient to stabilize the process, where late responses may require larger steps to compensate the drift in the granulation process.

Study

Before starting the APC project, a benefit study was executed to investigate the feasibility of applying Advanced Process Control and to determine the benefits. Based on historic data over a period of one year, benefits in the range of 1.1 – 1.4% production increase have been estimated. In addition, some minor DCS control changes were recommended together with an extra weight measurement for the fines.

Control Design

The INCA MPC control design includes the most important process inputs that will be manipulated by the controller (MVs), while continuously monitoring the key process variables that need to be controlled/optimized (CVs). The reflux valve (MV) is included to maintain the reflux (CV) at a desired level to ensure that the AN melt is sprayed on sufficient reflux material. The AN feed (MV) is required to maximize production and used as a secondary handle to control the crushers (CV) in case of over-granulation. The vacuum (AN concentration) is the main process input to influence the moisture added to the granulation process. The ventilator (MV) is used to remove moisture and is further related to quality (which is not measured online). Overloading the crushers can be observed by a steep rise of the motor amperages which needs to be controlled quickly to prevent automatic process shutdown (high limit protecting equipment). Additionally the elevator is included as CV to control extreme process conditions. Granulation processes with frequent cleaning stops show a slowly changing process behaviour during a production run due to caking of material to equipment. Therefore it is difficult to define optimal settings for many process parameters due to drifting process behaviour. To include stabilizing control behaviour in the INCA controller, the derivatives of fines and crushers have been added as CVs to the APC design.

Results

The full implementation of the APC project required more time than initially estimated because controlling the wide range of process conditions turned out to be more difficult, the different strategies and preferences of operators had to be aligned into a single APC control strategy and scepticism of operators had to be transformed into acceptance of APC as a support tool for their daily work by showing good control performance, providing intensive training and having detailed discussions of control behaviour not only for normal/stable conditions but especially for the more extreme process conditions and disturbances. During the project the fines measurement broke down and had to be replaced. Fortunately, this could be done during the yearly maintenance stop, which was also used to improve the conditioning of the measurement.

Fig. 2 shows operator and APC control for a representative period of 3 weeks. The amount of marked areas show the regular maintenance and sometimes frequent unexpected short stops which are typical for a granulation process. The difference between operator and APC control can be observed best by comparing the control moves of vacuum and ventilator. An operator applies typical discontinuous larger changes where the INCA controller calculates continuously changes which are typically much smaller. The significant improvement in stability is seen best when comparing the fines and reflux. Before APC, the reflux was regularly out of control (study using historical one year data indicated 33% of time), resulting in a less stable process operation.

The caking (pollution) effect within a granulation process can be seen by the crushers showing a continuous increasing trend during a production run. Limits within the INCA controller are adapted with production time.

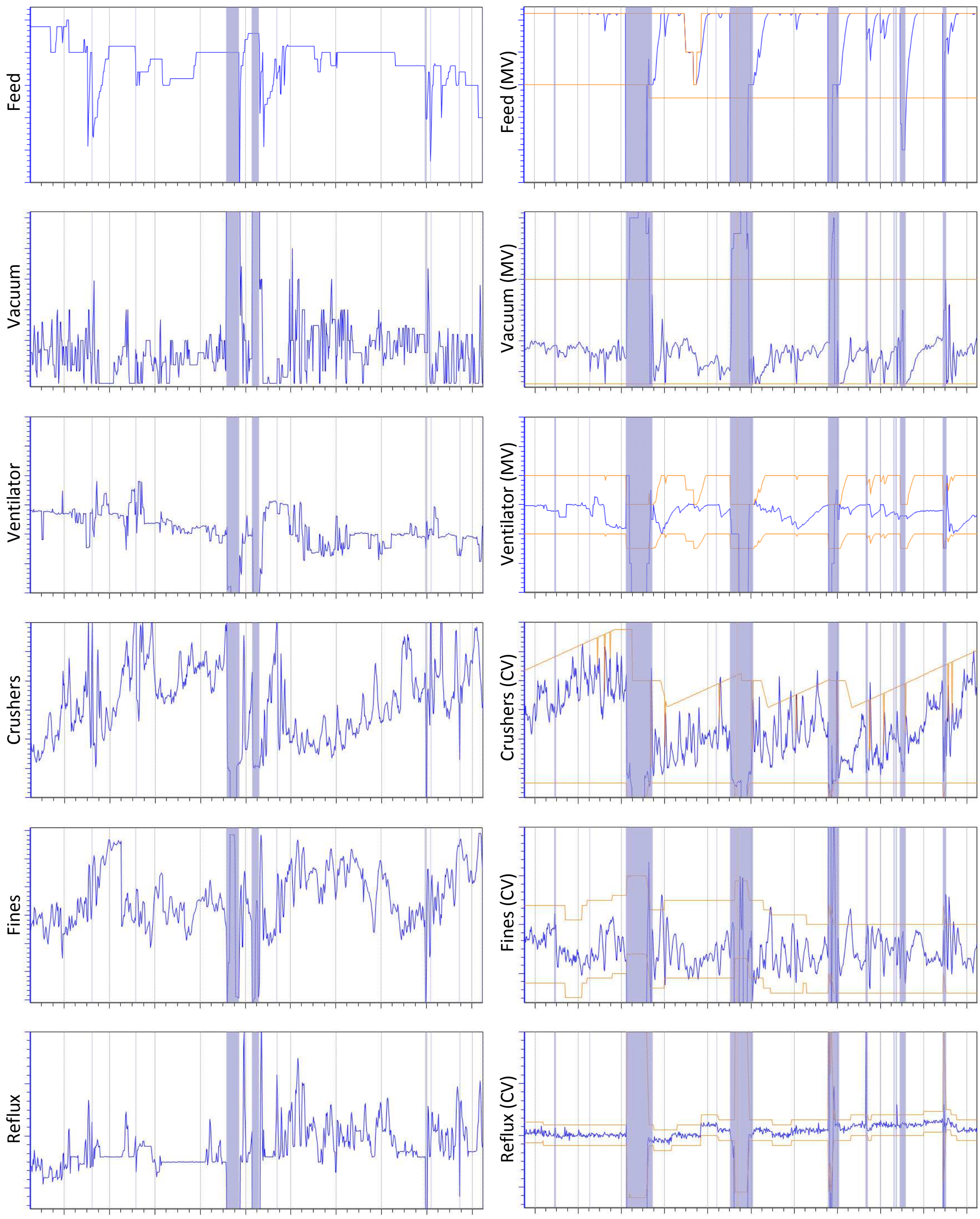

Fig. 2: Granulation operation (3 weeks); Operator (left) & APC (right) – Maintenance/short stops and APC off marked; APC lower/upper limits orange.

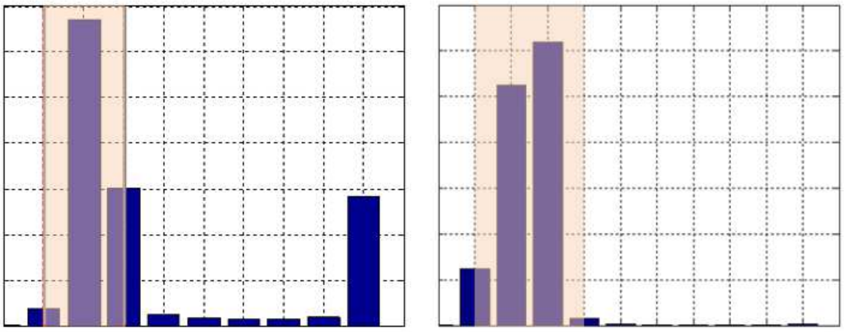

Fig. 3: Distribution of the reflux valve; PID (left) & APC (right) - Improved process stability by keeping reflux valve in control (with typical operating range marked).

The improved stability of the process is even better shown in Fig. 3 illustrating the distribution of the reflux valve. Historically the reflux valve was during 33% of the time out of control. With APC the reflux stays in control for almost 100% of the time.

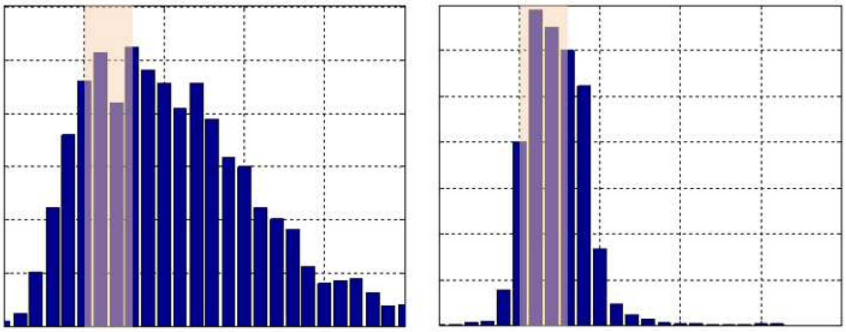

Fig. 4: Distribution of the fines flow; Operator + Old measurement (left) & APC + New measurement (right) - Improved process quality by reducing variation in fines (with quality range marked).

How much the stability of the granulation process improved, is clearly illustrated by the distribution of the fines flow in Fig. 4. The distribution of fines has become much smaller and variations outside the operating range have reduced significantly, improving of course the product quality. The distribution curve at the left (Operator) is probably influenced by a failing measurement (replaced during the yearly stop) and dust deposition during a production run, resulting in a partially overestimation of the high values.

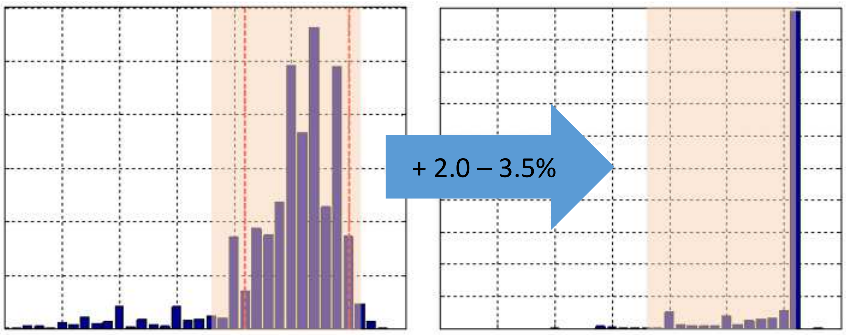

Fig. 5: Distribution of the production quantities; Operator (left) & APC (right) - Increased granulation production by pushing continuously to production limit (with production range marked).

Although process stabilization and improved product quality are nice, the benefits of these improvements are often difficult to quantify. Increasing production makes the benefit quantification much easier. Comparing the feed in Fig. 2 and the distribution of the production in Fig. 5 illustrates that with the improved stability, production can be increased faster and kept over a longer time at the high production limit. Experience gained during the APC project has also triggered the improvement of the start-up procedure. The granulation process is started up manually to the low limit of the APC control range for the feed and then APC is switched on to handle the remaining 20% of the operating range. Fig. 6 shows a comparison of a typical start-up by operators and APC. The 20% feed increase is handled by APC not only more stable but also in a shorter time.

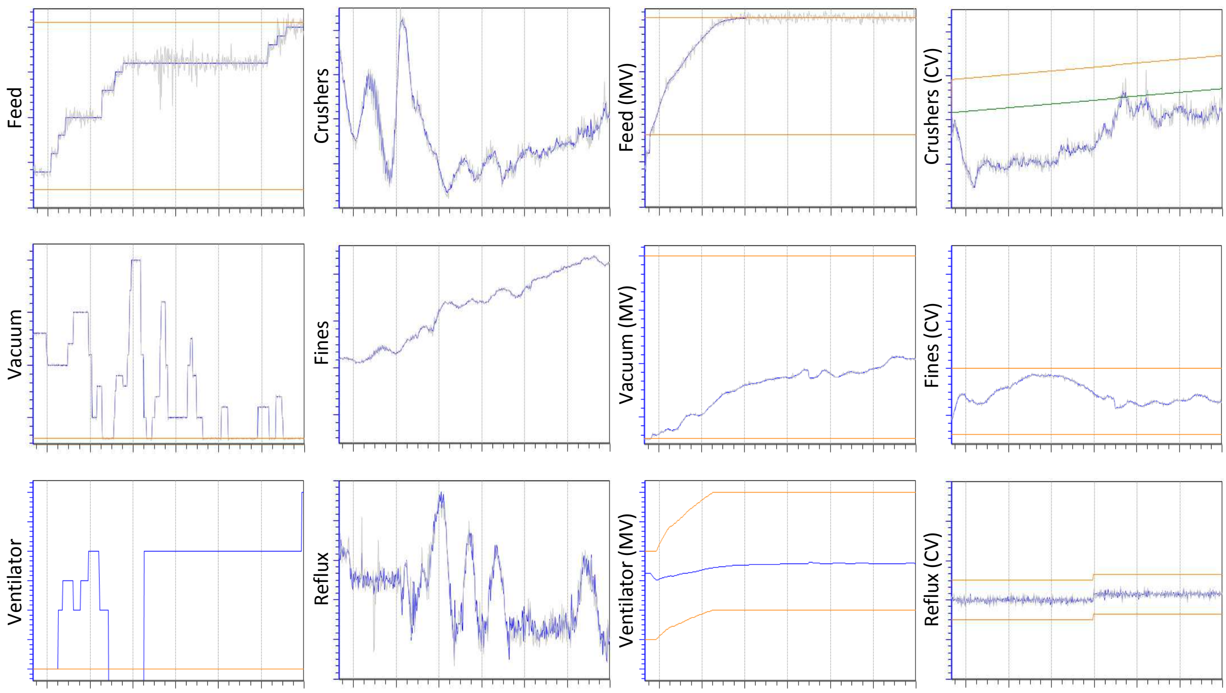

Fig. 6: Startup of the granulation process (38 hrs); Operator (left) & APC (right) - Feed ramp-up +20%.

Overall benefits of increased production based on a first (30 days) production period with APC are estimated on 2.0 – 3.5%. The range depends on how conservative or progressive the production period with APC is compared with the reference data from the study. Nevertheless, the realized benefits are twice as high compared to the study resulting from the fact that the study assumed improvements with APC for 25% of the production time and after implementation of APC production improvements have been realized for more than 60% of the production time. The long term effects (e.g. raw material properties) on the behaviour of the APC controller have to be further evaluated.

Conclusions

Although granulation is a very difficult process to control, APC can be implemented successfully providing significant benefits. Detailed and intensive discussions are required with operators and management to align and optimize the granulation production. The consistent and stable daily operation allows now the next level of further improvements by comparing properties of raw materials, production settings and caking to increase production runs. Acknowledgements must be made to all operators and management of EuroChem Antwerpen NV for their constant support during the project with open discussions.