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PHYSICAL MEASUREMENTS APPLIED TO "ON LINE" QUALITY CONTROL IN FEED MANUFACTURING

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A b s t r a c t. On line control provides real time measurement of the feed quality as it is being manufactured. Real time measurement may contribute to a better information of the quality. It allows to detect eventual disturbances of processing and to make the equipment self-running. Numerous methods are available for each step of feed processing: near infra-red spectroscopy for proximate analysis (proportioning), laser diffraction for particle size (grinding/classifying), abrasion test (pelleting). A particular attention has to be paid to sampling methodology and to the validity of the relationships between the considered quality criteria and process variables.

K e y w o r d s: feed processing, on-line control, particle size, composition, durability, near infra-red spectroscopy, laser diffraction

INTRODUCTION

As process production rates continue to improve, the delay between laboratory analysis and process correction of the product stream becomes more significant and costly in many applications. Elimination of sample handling and operator manipulations are now possible for most materials or products flows using various methods which are properly interfaced with the process stream.

On-line quality control may refer to two main purposes. The first objective can be to follow the quality of the final product according to time in order to collect data for statistical analysis of the plant production or to detect eventual disturbances and derivations with reference to a process «finger print». The second objective is to control accurately each process itself in order to optimise it and to make the equipment self-running. The process monitoring (Fig. 1) has to be adapted to «open loop» conditions (it is operator's decision) or to «closed loop» conditions (it is host computer decision).

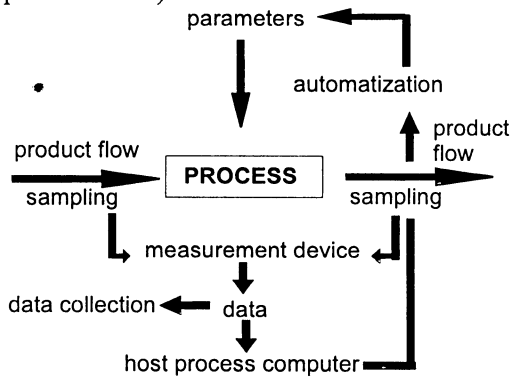

Fig. 1. Utilisation of process monitoring.

WHAT TO MEASURE ?

A feed production flow sheet can be divided into different steps (or key-processes), i.e., grinding, proportioning, mixing, pelleting and cooling, extrusion-cooking. Each of them depend on numerous parameters. In a first approach, the required optimisation of the quality of the product as well as the yield of the process needs a precise definition and control of both influencing parameters and system variables, including energy, time, shear etc. (Fig. 2).

The « yield » means output or specific energy consumption. The measurements of the feed flow, of the electrical intensity, electrical power and mechanical torque are important for the feed manufacturer and for a good management of the feed mill.

The «quality» is somewhat larger: it could mean physical properties which are of importance in processing control according to each processing step : particle size of the meals, moisture and temperature, apparent viscosity, colour. Moreover, quality could be related to commercial aspects (i.e., hardness, durability of the pellets, fine particles into the pelleted feed), and mainly to nutritional aspects (i.e., material composition, proximate analysis or substantial modifications of one specific component such as starch).

HOW TO MEASURE THE QUALITY ?

Numerous methods are available. One family of methods is based on rapid and non destructive analysis using different types of lights and wave lengths (infra-red, visible and/or laser lights). A second family uses destructive analysis based mainly on behavioural and rheological measurements.

Sampling

Prior to measurements, attention has to be paid [5] to sampling which ensures the accuracy and the liability of the on-line quality control. Sampling has to be adapted to:

- the product variability which could be from natural origin or from industrial origin,
- the sampling frequency (i.e., the sampling accuracy),
- the sampler design (i.e., the representa- tivity of the sample),
- the position of the sampler within the flow sheet in order to reduce the lag time, i.e., the time required by the machine to react to the measurement.

On-line sample conditioning requires generally several steps according to the relevant processes. An example is given in Fig. 3 for on-line pellet durability control.

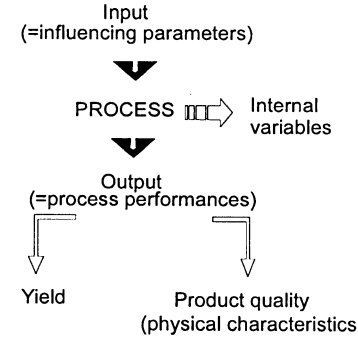

Fig. 2. Definition of influencing parameters on the yield and the quality of a key-process.

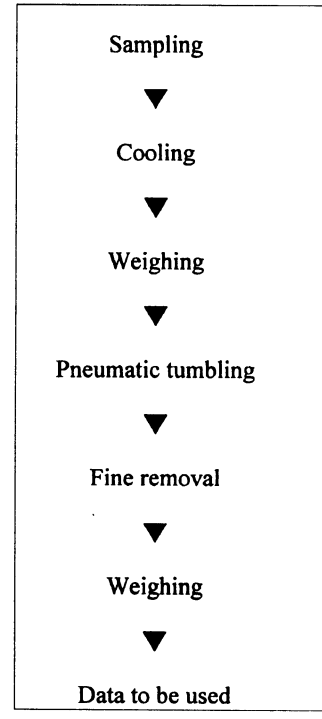

Fig. 3. Successive steps of on-line durability measurement.

Proximate analysis of the materials

Control of the receiving and proportioning step

Due to its robust character and its speed of analysis, Near Infra Red Spectroscopy (NIRS) has proven potential as an on line analyser method. New on line analysers have been developed, some of which perform in the liquid and other in the solid mode [10]. NIRS is well adapted to analyse pure raw materials but not

adapted to analyse pure raw materials but not feed mixtures, in a short range of mixtures compositions excepted. NIR system can be equipped with remote sensors mounted at any point of the process to monitor product composition. It can be interfaced with an on line grinder or non contact optics, automatic sample introduction (to the optics), computer software, connection with the process flow sheet (proportioning process) through a computer and so forth. NIR data contribute first to a better information of the proximate analysis of the raw materials. In addition, from sample analysis data, the computer is able to adjust the feed composition in real time by acting the feed proportioning (Fig. 4). The scope of these methods goes far beyond the number of installations, probably because of the price threshold [8].

Several principles of NIRS are available or presently under testing:

- the diffuse transmission into which energy is transmitted through and between particles with multiple refractions, diffractions and reflections occurring. Transmitted energy is diffused through the sample exiting at all angles and the detector needs to be positioned at the exit surface of the sample. The technique is applied to feed pellets, whole seeds or wheat kernels or powders for protein or moisture content, but the success of this method is hampered by the small light yield passing through the sample, resulting in a low signal/background noise ratio;
- with diffuse bulk reflection (reflectance: Fig. 5), the sample is illuminated and the energy returning from the sample at all wavelengths is collected by a detector positioned on the same side of the sample as the source. Some energy going through the particles is absorbed, by some energy is reflected

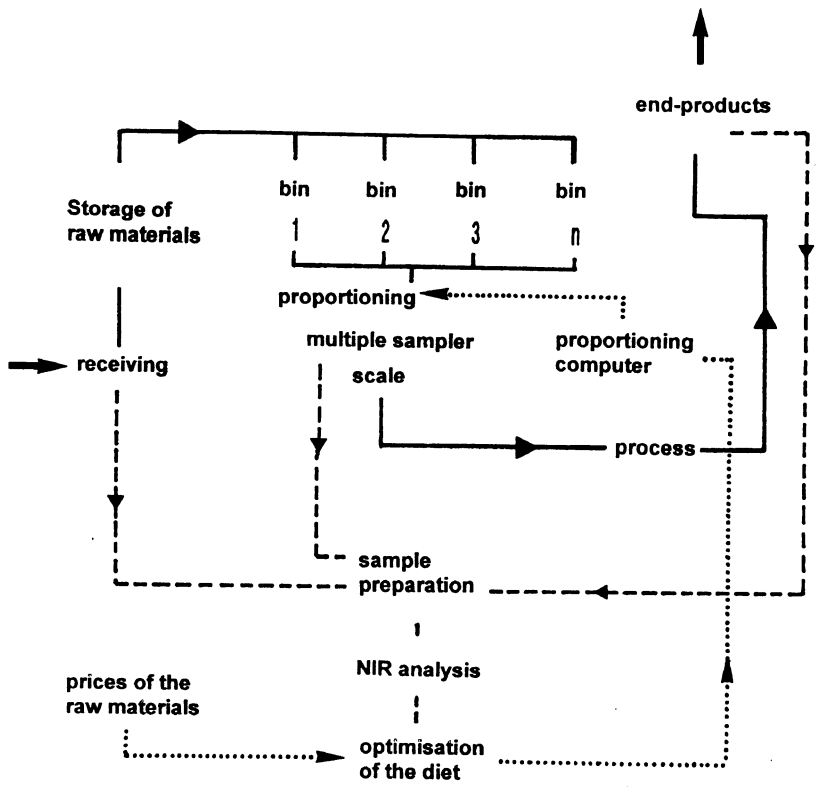

Fig. 4. Proportioning and formulation control with NIR on-line (from Prinacon documentation).

flected from the sample surface - this is the specular component - that escape without interaction with the sample and thus carries no information about the sample composition. Refraction and particle shape combine to diffuse energy;

- interactance measurement associates diffuse reflection with lateral diffuse transmission. Energy enters the sample, undergoes diffuse reflection combined with lateral diffuse transmission and then exit to the detector. This principle is applicable with by means of coaxial optical fibers into which the external coat (the cladding) is used for incident illumination and the central part of the fiber (the core) for collection the resulting light returning to the detector.

NIR measurement are in a 1000 to 2500 nm range of wave lengths. There is a potential for the use of very near infrared (800-1100 nm) because of a deeper penetration of the material.

Sampling has to be achieved directly from the flow of raw materials in a by-pass of the main conveying line. If reflection is used, there is need for grinding the sample without loss of moisture. To prevent unnecessary delays of measurement, the gravity pipe from the branch-off of the main line to the inlet of the measuring section should be as short as practicable. The data provided by NIRS devices can be moisture, protein, fiber and/or fat content, but there is a need for a permanent calibration of the device with off-line measurements, according to the variability of the ingredients which are included into a feed.

Potential control of extrusion cooking

Near Infra Red Spectroscopy was recently [9] evaluated as a mean of following physical and chemical changes in starch during the extrusion cooking of the wheat flour. With the use of principal component analysis, samples could be classified according to the severity of the extrusion cooking conditions, i.e., the Specific Mechanical Energy (SME) consumption. SME is known to be correlated to water (and heat) addition. On line measurement of starch damage by NIRS using optical fibers within the extruder may be of potential interest and is presently under experimentation.

Particle size measurement

Grinding/classification step

In-process measurement of particle size and concentration distributions are achieved by means of optical techniques whose primary benefit is speed. It provides continuous analysis and quality control of a product stream and can be used to monitor particulate emissions.

One optical technique is the laser diffraction method which is based on measuring the scattered light at a number of different angles from a large number of particles. Basically, small particles preferentially scatter light at large angles, while large particles scatter light at small angles. A ring detector is generally

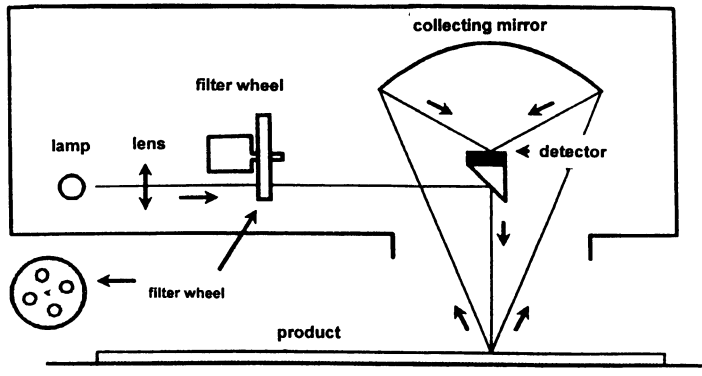

Fig. 5. Schematic of back scatter sensing head of a digital four-wavelength on-line infrared measurement.

used to collect light at 32-64 different angles, which can give a size resolution of 5-10 % of the indicated size. Average size accuracy can be better than 3 %.

Laser light diffraction is used for measurement of the particle size of the meal after grinding/classifying. In-process particle size analysis provides real time measurement of powdered material as it is being manufactured. Distribution update rates are computed and displayed in less than 5 s, considerably faster than grinder/classifier response times of approximately 30 s [7]. The size distribution range of existing apparatus is from 1 mm to 1.5 mm. Real time measurements allowed diagnosis and correction of non-steady feed rates to a classifier-mill [3]. The instruments can diagnose mill feeding problems over a wide range of flow rates and provide a uniform output size distribution.

The powder can be sampled directly on the flow until material speed of 400 m s^{-1}, or on a derivation of the main flow. A real-time by-pass arrangement uses an aspirator to sample a portion of the flow and is useful for high concentration (>1000 g m^{-3}) and multiple line applications (Fig. 6). The type of data provided by the device are usually the average particle size of the distribution, or the percentage of pre-determined fraction. Some correlation can be done between light scattering particle sizing results with sieving results [6].

These data could be used to detect disturbances ensuring alarms systems (holes in screens of a hammer mill for instance), or to provide complete automatic feed back control of grinding/classifiying. Product uniformity is maintained by acting on the process parameters. These parameters have to be flexible enough to ensure significant variations of the average size of the particles (i.e., the gap between rolls in a roller mill, the speed of rotation of the rotor in a hammer mills, the feed rate in classifiers).

Other devices are presently under testing and begin to be proposed by equipment manufacturers such as artificial vision analysis in order to measure particle sizes or shapes of

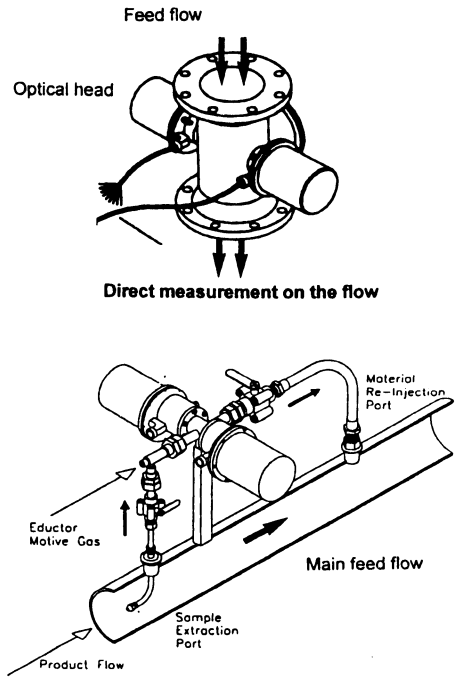

Fig. 6. On-line particle size measurement using laser light diffraction (from Insitec documentation).

meals [4]. Images of the milled products in flow were captured on-line in order to avoid any sample preparation. The image data processing and the classification procedure made it possible to define 4 classes of size. Near Infrared reflectance could be also of potential interest [2].

Measurement of pellet texture and quality

Control of the pelleting step

The purpose of an optimisation system for the pelleting process is to increase production rate and physical pellet quality whilst also facilitating greater flexibility of mill operators. Variation in product mechanical resistance can be detected (and corrected) on-line by means of auto sampling and direct testing - with results and trends continuously displayed.

A great variety of principles can be used: pneumatic handling for durability measurement, shear or flexibility tests for hardness. The elasticity of the pellets, the level of fine particles out of the die, the sounds potentially can be considered as interesting criteria for the measurement of the pellet quality on-line.

The most popular measurement is pneumatic abrasion which is a more flexible technique as the compressive test. In order to decrease the lag time, samples have to be removed directly from the pellet flow at the outlet of the pellet mill. They need to be cooled (0.5 to 1 min) in order to harden the pellet which properties become similar to the ones of the cooled pellet removed from the cooler. The sample is then subjected to air stream which causes them to degrade. Fine particles are then removed by a blower and carried away in the air stream and returned to the feed mill process. The remaining pellets are then weighed, the results are expressed as a percentage of the original weight and recorded by a computer (Fig. 7).

The tester can be integrated with a computerised press controller with the appropriate software in order to ensure that pellet quality is not only measured, but maintained (Holmen documentation). It is used thereafter for the detection of disturbances and for the feed back control of the press through steam addition and feed rate (after proper study of the relationships between these parameters and the durability). The micro-processor of the on-line tester can be programmed to accept sample pellets from more than one press providing each press is producing pellets within either of two diameter ranges (<5 mm and >5mm). The time of response of the device, according mainly to the cooling time, has to be shortened in order to increase the efficiency of the control.

The % of particles generated by abrasion could be calibrated with a manually-operated durability tester (off-line measurements).

On-line fine production measurement after cooling the samples could also have potentiality for pelleting control: unfortunately, it has been demonstrated [1] that there was no correlation between the durability measurement and the percentage of fine particles removed from the hot pellets out of the die.

Control of extrusion-cooking

Apparent viscosity measurements of extruded products are achieved on plastic materials using slip die rheometer. As a potentiality, it can be applied to feed or food flours in order to control the thermo mechanical «history» of the product and then its expansion properties.

Measurement of moisture and material temperature

Cooling drying step

The control on line of the cooling step is performed according to the same principles as

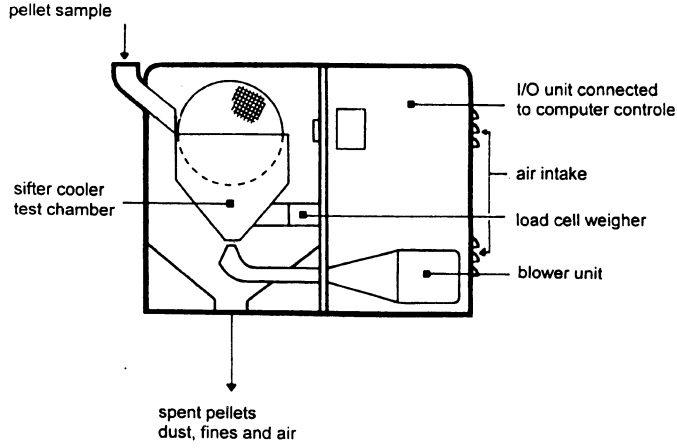

Fig. 7. On-line durability measurement apparatus (from Holmen/Norvidan documentation).

previously: moisture can be measured with NIR (it is a surface moisture), NMR or microwaves. The temperature can be measured by means of infra red radiation (no contact with the feed) or thermocouples (with contact with the material).

After sampling directly out of the feed flow into the cooler or at the outlet, the feed has to be ground in order to be able to measure its moisture. Generally, data are related to local moistures and temperatures. It is not a gradient of temperature and it allow only to control the cooling process, by the regulation of the thickness of the pellet layer, the belt speed and the air flow rate, if the relationships between these parameters and the measured criteria have been studied previously.

CONCLUDING REMARKS

Various measurement principles and devices are to-day available as well as several potential ones for measuring on line feed quality at practically each step of the feed manufacturing flow sheet.

The quality of on-line measurements is related to the accuracy of sampling, sample division and conditioning. The equipment has to be robust enough to be installed into severe industrial environments. The information provided by the different systems need also to be compared and fitted on classical analysis.

A data collection is easy to access, but the automated control of processes is to-day limited by several factors:

- the cost of on-line devices versus the monetary return which has to be estimated accurately before each investment;
- the lack of knowledge in some cases concerning the relationships between the resulting quality data and the process variables. The validity of the algorithms used by the software between resulting data and pre-set values of process variables has also to be checked. In addition one have to pay attention to the delay between measurement and back reaction according to the feed rate;
- sometimes the lack of flexibility of the equipment used in the feed industry. As an example, the screen of a grinder or the die of a press cannot be changed easily.

Generally speaking, there is a need for the improvement of the knowledge in the field by further research on non-destructive and rapid analysis measurement principles, and a better understanding of the processing mechanisms involved in feed technology.

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