20

CONTROL OF THE MOISTURE CONTENT OF MILK POWDER BY THE FRALCOMP METHOD

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ABSTRACT

The variations in the moisture content of milk powder produced in a spray-dryer are mainly caused by disturbances in the dry-matter content of the concentrated milk. Measurement of these disturbances offers the possibility of compensating for the variations in moisture content of the milk powder almost completely. The level of the moisture content and that of the variations which remain are controlled by using a feed-back control loop. Compensation of the disturbances in dry-matter content and control of the moisture content level of the milk powder are realized by the Fralcomp control method. The moisture content of the milk powder is measured by an IR-reflectance measurement method.

An evaluation of the Fralcomp control method in two industrial milk powder plants (4000 kg powder/h) showed that variations in moisture content obtained by the conventional control method are about ±0·2%, whereas use of the Fralcomp control method will lead to variations of less than ±0·05%.

INTRODUCTION

The production of milk powder takes place in two phases. In the first phase the milk is concentrated in a multiple-effect falling-film evaporator. In this phase the dry-matter content increases from approximately 10 to 50%. The second phase is the actual drying process which takes place in a spray-dryer (see Fig. 1). The viscous concentrate leaving the evaporator is atomized (by wheel or nozzle) in a hot air flow. The concentrate droplets fall down and

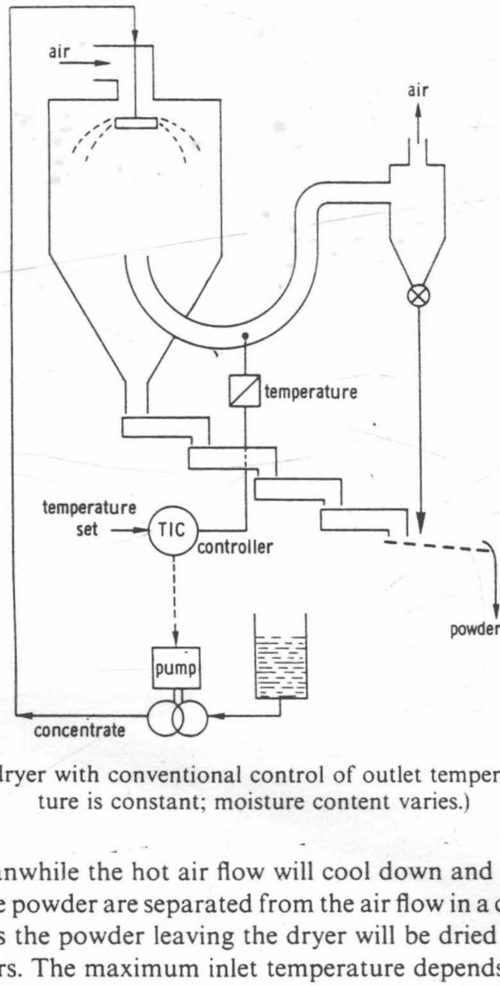

Fig. 1. Spray-dryer with conventional control of outlet temperature. (Temperature is constant; moisture content varies.)

are dried. Meanwhile the hot air flow will cool down and leave the dryer. The fines of the powder are separated from the air flow in a cyclone. In most drying systems the powder leaving the dryer will be dried in one or more fluid-bed dryers. The maximum inlet temperature depends on the type of milk powder produced. The temperature is usually 240°C for skim milk powder and approximately 180°C for whole milk powder. Generally this temperature is kept constant during a production run to avoid changes in milk powder properties such as the solubility index.

The moisture content of milk powder is one of its most important properties. In The Netherlands heavy penalties are attached to the production of milk powder with a too high moisture content. A low moisture content limits the production efficiency (high energy costs, low product yield). Minimizing the variations in moisture content will lead to optimal production efficiency. For these reasons a new control method has been developed.[3]

CONVENTIONAL CONTROL OF A SPRAY-DRYER

When using the conventional control method it is assumed that there is a relation between the moisture in the milk powder and the outlet temperature. Therefore the outlet temperature is fixed at a setpoint value. However, at the production of different products or when variations in concentrate properties occur, the relation between outlet temperature and moisture content changes. To correct these changes the process operator will take a sample of the milk powder from time to time. In the laboratory the moisture content of the sample is determined and the result is sent back to the process operator. When the result deviates from the desired value of the moisture content, the operator adjusts the setpoint of the outlet temperature so that a correction of the concentrate input flow is obtained.

The analysis made at the laboratory, when using the official methods (e.g. IDF 26), takes at least 4 h. This delay time is too long to achieve good controllability. For this reason many dairies are using rapid methods of analysis. Though these are less accurate, controllability can be improved. Nevertheless, more accurate and more rapid methods are to be preferred.

IN-LINE MEASUREMENT OF MILK POWDER MOISTURE CONTENT

As mentioned before the controllability of the moisture content of the powder during production is poor. An in-line analysing system would improve it considerably. One way to realize this is the application of a near-infrared reflectance measuring method. The principle that underlies this method is the property of water to absorb radiations of specific wavelengths, for instance 1·9 μm. Accordingly, the amount of radiation at this specific wavelength reflected by milk powder is dependent on the amount of water in the powder. The amount of infrared reflection is also influenced by other powder properties, such as chemical composition, colour, powder density, particle size distribution, distance between sample and measurement system, and, last but not least, the surface condition of the powder sample.

Figure 2 shows a schematic drawing of an IR-reflectance system. In this

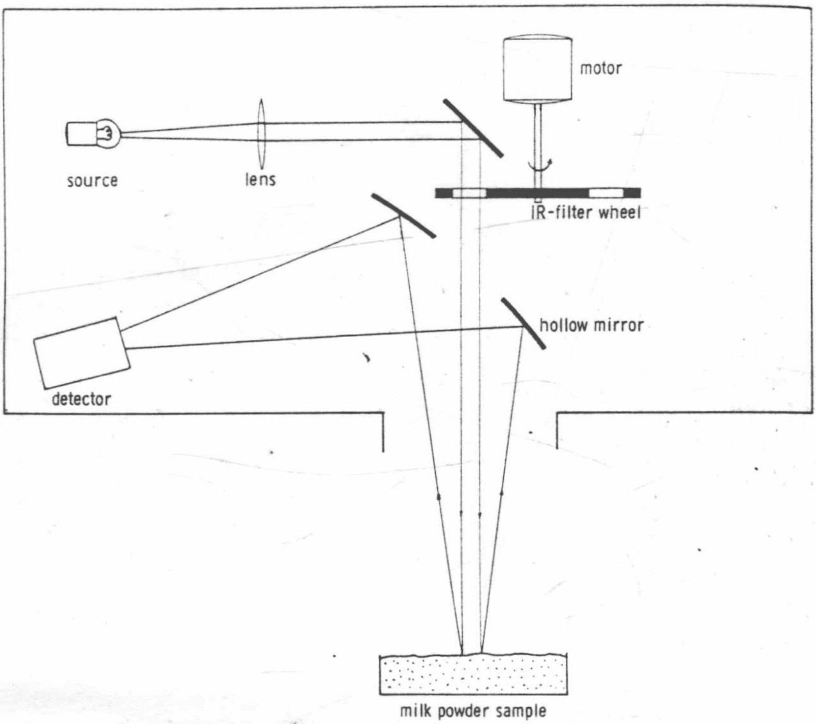

Fig. 2. Schematic representation of IR-reflectance measuring method.

system the reflected value at the absorption wavelength is compared with the reflected value at a reference wavelength just outside the absorption band for water (e.g. 1·7 or 1·8 μm). To achieve this a scanning wheel with two infrared filters is used. The moisture content of the sample is calculated from the differences in intensity between the two reflected beams as they reach the detector. The reference beam compensation for differences in powder properties turned out to be insufficient to obtain the required accuracy in moisture determination of milk powder. A sampling system (see Figs 3 and 4) offered the possibility of excluding the effects of surface condition, distance between sample and sensor, and powder density on the accuracy of the measuring method.

Changes in chemical composition, colour and particle size distribution can only be compensated by calibrating the system for every type of powder. As measurement systems are provided with memories, calibration curves can be stored and recalled when necessary.

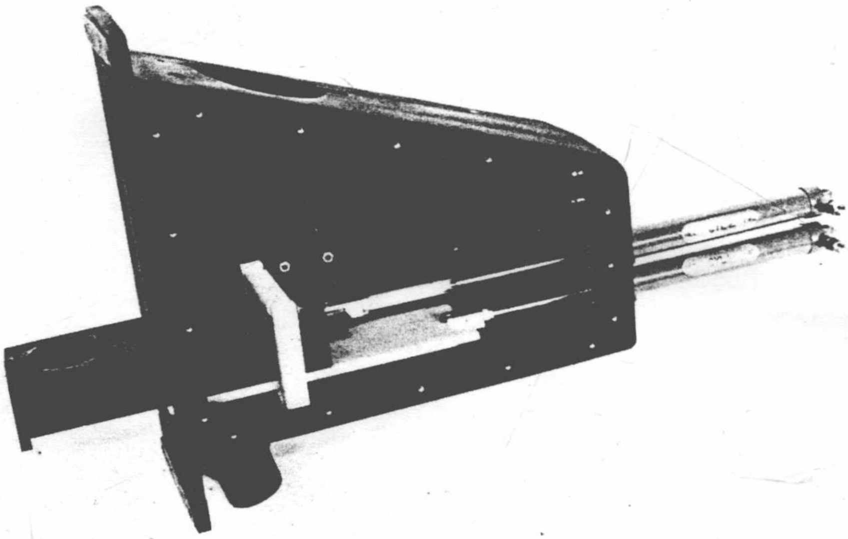

Fig. 3. Sampling system.

With this in-line system good repeatability (±0·03% of moisture) and also good accuracy (±0·05% of moisture) were achieved. So the system could be used to improve the controllability of the moisture content of milk powder.

Over the years the systems have been improved still further. Now in-line systems with up to five infrared beams are available which have a greater accuracy and make less stringent demands on sample preparation.

FRALCOMP CONTROL METHOD

Changes in dry-matter content of the concentrate result in changes of product viscosity and also in a varying size of the atomized droplets. The drying time of the droplets depends on their size. So to obtain a powder with a constant moisture content it is necessary to adjust the drying conditions as soon as changes in the dry-matter content of the concentrate occur. As has been shown,[1,2] the following relationship between parameters exists:

$$\Delta T_{out} = C_1 * \Delta DM + C_2 * \Delta X_p + C_3 * \Delta T_{in}$$

Fig. 4. IR-reflectance measuring system and sampling system. (Temperature varies; moisture content is constant.)

in which ΔT_{out} = changes in outlet air temperature (K)
ΔT_{in} = changes in inlet air temperature (K)
ΔDM = changes in concentrate dry matter (%)
ΔX_p = changes in moisture content (%)
C_1, C_2, C_3 = constants

The constant parameters C_1, C_2 and C_3 are product- and installation-dependent. Because of constraints on powder qualities (such as solubility index, etc.), T_{in} is kept constant in most dryers so in the given relation ΔT_{in} is equal to zero.

The relation shows that, to obtain a constant moisture content of the milk powder, disturbances in the dry-matter content can be compensated by adjusting the outlet air temperature. This compensation is one part of the Fralcomp control method. Disturbances in the dry-matter content are detected by using an in-line density transmitter in the concentrate flow (the density is proportional to the dry-matter content). When a disturbance in the dry-matter content occurs, the setpoint of the outlet temperature is adjusted in a ratio determined for the spray-dryer (see Fig. 5). In most cases the density meter has to be built-in some distance before the wheel or the nozzle. Therefore a delay time (τ_v) between the detection of the disturbance and the adjustment of the outlet temperature setpoint is necessary. The delay time corresponds to the time necessary to transport the fluid from the density meter to the wheel or the nozzle.

Adjustment of the setpoint of the outlet air temperature results in a nearly constant moisture content. Low-frequency deviations will remain. To control these changes and to fix the level of the moisture content a master-slave control loop, based on moisture measurement, is incorporated. First, moisture measurement results are filtered and a moving average is calculated; deviations from the setpoint will also result in adjustment of the outlet temperature setpoint (see Fig. 5). In the control scheme all the adjustments of the outlet temperature setpoint will result in adjustment of the product feed rate. It might be remarked that the time to

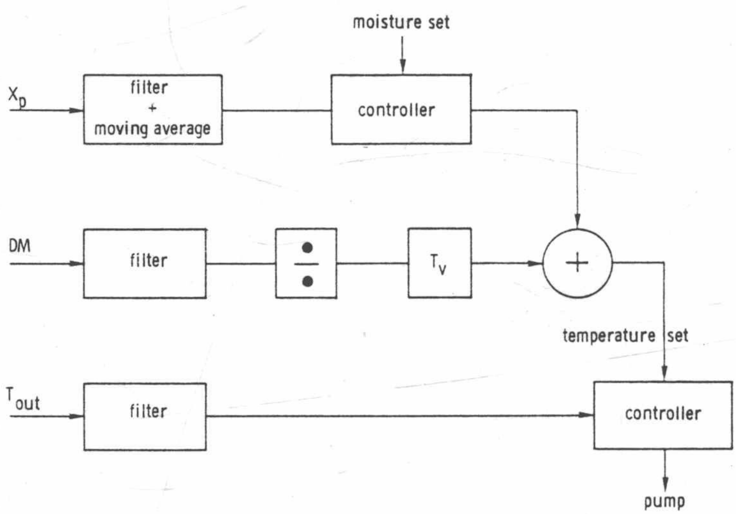

Fig. 5. Fralcomp control scheme.

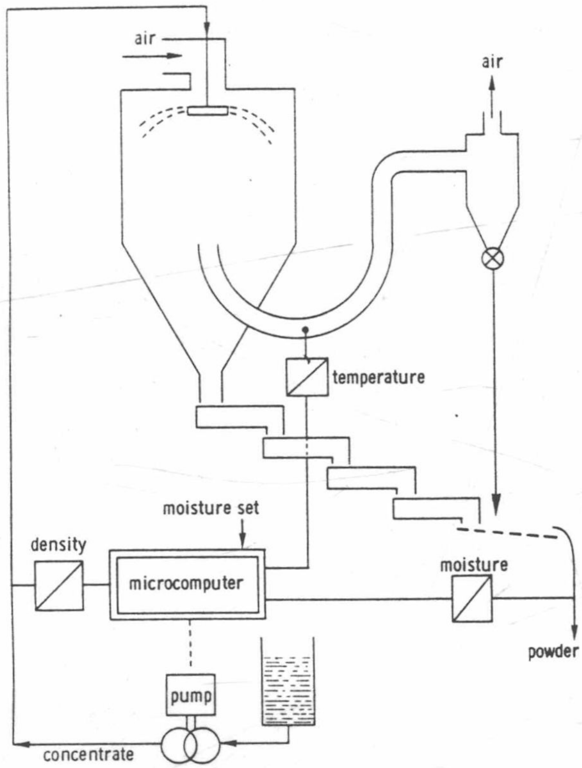

Fig. 6. Spray-dryer with Fralcomp control of moisture content of milk powder.

reach this adjustment is long. That is correct from the point of view of control. But for the operation of the spray-dryer the approach mentioned is to be preferred. With this control it is much easier to start up and to go down. On the other hand, minimum and maximum permitted levels of outlet temperature can be monitored.

In Fig. 6 the application of the method is shown.

THE APPLICATION OF FRALCOMP IN INDUSTRIAL SPRAY-DRYERS

Fralcomp control has been evaluated experimentally in two industrial spray-dryers. The first was a one-stage spray-dryer (without fluid-bed dryers) and the second a two-stage dryer. In both systems the concentrate was atomized by a wheel. Before the Fralcomp system was put into use, conventional control was evaluated for some months. For the evaluation 0·5 h mean values of moisture measurement, obtained by the IR-reflectance method (sampling speed: once a minute), were calculated.

During the course of the months in which the Fralcomp method was used the same values were calculated. For both spray-dryers a great improvement of the moisture content control was achieved. In Fig. 7 the results of this evaluation, in which use was made of conventional and Fralcomp controls, are given. The results concern the production of milk powder with a fat content of 26%.

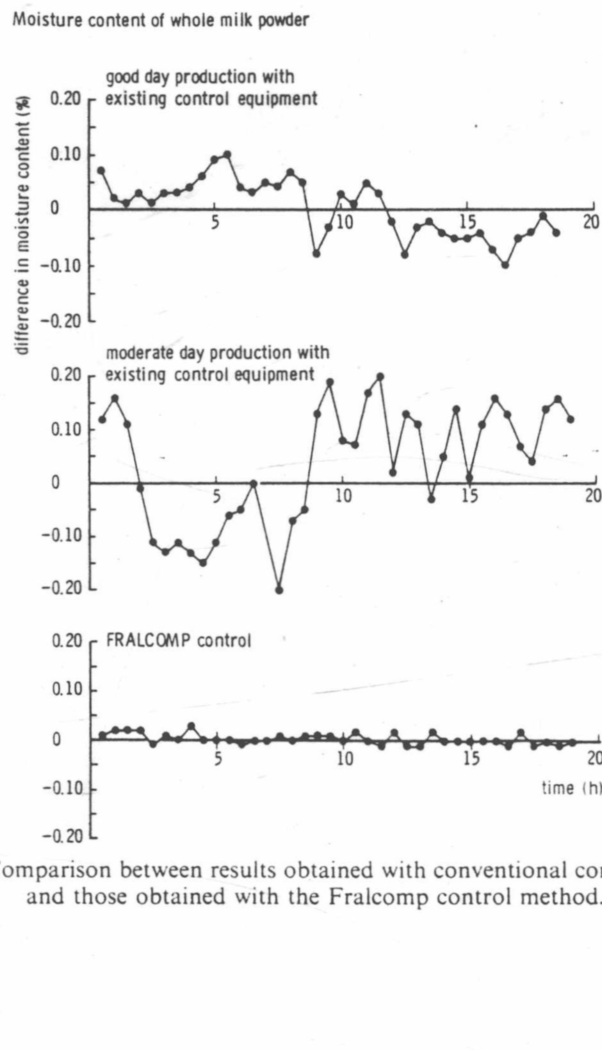

Fig. 7. Comparison between results obtained with conventional control method and those obtained with the Fralcomp control method.

For conventional control a distinction is made between 'good' and 'less good' production days. On 'good' production days deviations of $\pm 0{\cdot}1\%$ of moisture around the desired value are normal, whereas on 'less good' production days deviations of $\pm 0{\cdot}25\%$ moisture around the desired value are quite normal. When use is made of the Fralcomp control method there are no differences between production days in this respect. The deviations in moisture content were found to be less than $\pm 0{\cdot}05\%$ moisture around the desired value. This comes down to an improvement of at least 2·5 times in comparison with the conventional control method. The same results were obtained during the production of milk powder with a fat content of 28% and during the production of skim milk powder.

In applying the control method to industrial spray-dryers, the improvement as regards starting up was evaluated. It has been found that 6 min after the moment at which the first milk powder left the installation the moisture content of the milk powder would be at specification. When the conventional control method was used, it took at least 1 h before the moisture content was at specification.

ECONOMICAL EVALUATION

For the application of the Fralcomp method two new measuring systems have to be installed:

—an IR-reflectance system (moisture); and
—a density transmitter (dry matter).

Further, an intelligent controller or a small process computer is required. This will, of course, involve extra costs for the installation of the Fralcomp method.

The pay-back time depends on the installation and type of milk powder produced. If the new method appears to permit an increment of the mean moisture content of milk powder by, say, a mere 0·1%, the capital outlay for a plant producing 4000 kg powder per hour can be paid back in about 1 year.

Other features of Fralcomp are:

—increase of capacity by 1%;
—as mentioned before Fralcomp can be involved with automatic starting-up and stopping procedures. The milk powder will be at specification at an earlier point of time. This also results in an increase of capacity.

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21

CONTRIBUTION A L'AUTOMATISATION D'UN PROCEDE INDUSTRIEL DE SECHAGE SUR CYLINDRE

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ABSTRACT

After a description of food processes specificities in the field of automatic control, we discuss a simple way for automatic process control design. The methodology begins with a study of steady-state evolution. It is very important to know how the process is working. The consequences of this study are a variable classification: manipulated variables, controlled variables and disturbances. The example of a food drying process is presented to illustrate this methodology. A static model is built and the simulation results are presented. These results are used to define a control strategy which takes into account different working possibilities.

A static study is insufficient to elaborate a good process control system. So a dynamic model, based on an input–output description of the drying process, was built. The validation is made with experiments on a pilot plant and the results are satisfactory. An on-line humidity sensor is used for this validation.

On the basis of the dynamic model a control algorithm is designed and simulation results are presented.

RÉSUMÉ

Après un bref exposé des spécificités de l'automatisation de procédé en industrie alimentaire, on présente dans le cas des procédés continus un démarche classique d'automatisation. Le procédé de séchage sur cylindre illustre cette démarche. Après la modélisation statique du procédé les résultats de simulation sont discutés dans l'optique du contrôle-commande. On conclut

par une classification des variables qui prépare la synthèse de la commande. Sur cette base, une stratégie de conduite est proposée et les résultats de simulation sont présentés.

NOTATION

C_p = capacité thermique massique ($J\,kg^{-1}\,°C^{-1}$)
C_s = charge en matière sèche ($kg\,m^{-2}$)
e = épaisseur du produit sur le cylindre (m)
L_v = chaleur latente de vaporisation ($J\,kg^{-1}$)
$\dot{m}$ = débit ($kg\,s^{-1}$)
t = temps (s)
T = température (°C)
V_r = vitesse de rotation du cylindre ($M\,J^{-1}$)
X = teneur en eau du produit (kg eau/kg m sèche)
α = coefficient global de transfert de chaleur ($W\,m^{-2}\,°C^{-1}$)
λ = conductibilité thermique ($J\,m^{-1}$)
v = vitesse du cylindre ($m\,s^{-1}$)
ρ = masse volumique ($kg\,m^{-3}$)
ϕ_m = flux matière ($kg\,m^{-3}\,s^{-1}$)
ϕ_Q = flux de chaleur ($J\,m^{-3}\,s^{-1}$)

Indices

m = métal
P = produit
v = vapeur

1 INTRODUCTION: LE CONTROLE-COMMANDE DES PROCEDES EN INDUSTRIE ALIMENTAIRE

Les industries alimentaires apparaissent bien souvent comme un secteur difficile du point de vue du contrôle-commande. Plusieurs auteurs[1,2,...] proposent des explications quant à ces difficultés:

—empirisme et méconnaissance des procédés,
—variabilité et caractère 'vivant' des produits,
—instrumentation limitante,
—etc.

Des études bibliographiques récentes nous ont permis de constater un intérêt croissant pour l'automatisation des procédés même si ces spécificités rendent plus difficiles les travaux dans les industries alimentaires, on constate que les actions réussies correspondent à la convergence de quatre facteurs essentiels:

—la connaissance des procédés,
—l'existence des techniques et des outils d'automatisme,
—l'instrumentation,
—la formulation claire des objectifs de conduite.

Ces facteurs se retrouvent aussi bien pour les procédés continus que pour les procédés discontinus. On constate à ce propos, qu'il apparait plus simple de réaliser des systèmes de contrôle-commande de procédés discontinus. Des exemples très performants en brasserie, laiterie, stérilisation, etc., sont fréquents. Le niveau d'automatisation atteint par ces procédés est souvent très élevé même si une instrumentation plus adaptée permettrait d'accroître la qualité des résultats. Il est certain que l'existence d'outils et de méthodes d'automatisation: automate programmable et Grafcet, par exemple, adaptés et bien répandus dans l'industrie est un facteur prépondérant du développement de ces systèmes.

Pour les procédés continus, il n'en est pas de même et les réalisations probantes restent du domaine de la recherche. Or, il nous semble que dans bien des situations les quatre conditions précédemment citées sont remplies sans que les réalisations ne suivent. Les méthodes d'automatisation de procédés continus sont aujourd'hui très bien maîtrisées[3] et ne doivent plus constituer un frein. Il nous paraît possible de rappeler ici la démarche classique visant à constituer un système de contrôle-commande d'un procédé industriel. Cette démarche sera illustrée par l'exemple de l'automatisation du séchage sur cylindre.

La première étape est l'étude du comportement statique du procédé. Si cela est possible sur une base empirique, une modélisation est en général plus riche et donne davantage d'informations, comme l'exemple traité plus avant le démontre. Soulignons que la construction d'un modèle, en vue du contrôle-commande d'un procédé n'est pas nécessairement une étape complexe compte tenu des hypothèses simplificatrices qu'autorisent en général un problème de contrôle-commande. Les avantages d'un modèle sont nombreux, il permet notamment de mieux formaliser le, ou les, objectifs de contrôle et de définir l'instrumentation adéquate.

La phase d'instrumentation reste une étape délicate pour laquelle cependant de nombreux progrès dans le domaine des mesures physiques ont apporté des améliorations très sensibles. Il nous semble également que les méthodes de l'automatique et du traitement du signal peuvent produire de nouvelles solutions à de nombreux problèmes de mesure. Si l'analyse statique est correctement menée, la structure de la commande sera facile à définir, il s'agit là des relations entre les variables commandées et les variables observées. Cette étape très qualitative est fondamentale et représente en partie le savoir-faire des spécialistes du procédé. La mise en oeuvre des techniques d'automatique est alors très simple.

Les deux étapes suivantes consistent à modéliser la dynamique du procédé autour du régime statique choisi et à partir de ce modèle dynamique à faire la synthèse des algorithmes de commande, ce qui peut être réalisé en utilisant de nombreux outils issus de la recherche en automatique.

Ainsi, nous insistons dans cette présentation sur l'importance de l'étape de modélisation statique qui ne doit cependant pas faire négliger les autres aspects du travail. Nous proposons une illustration de ces réflexions en montrant notamment que la modélisation peut être faite sur une base simple et donner des résultats performants.

2 ETUDE DU CONTROLE-COMMANDE D'UN PROCEDE INDUSTRIEL DE SECHAGE

2.1 Description du procédé

Le procédé de séchage sur cylindre consiste à faire sécher le produit en couche mince par contact sur une surface chaude. Un cylindre en fonte, creux, chauffé à l'intérieur par de la vapeur est maintenu en rotation par un moteur à courant continu. Le produit est déposé par l'intermédiaire d'un petit cylindre tournant en sens inverse du cylindre principal (Fig. 1). Après un temps de contact entre le produit et la surface chaude, qui dépend de la vitesse de rotation, le film de produit sec est râclé par l'intermédiaire d'un couteau.

La nature des produits ainsi traités nécessite parfois une cuisson préalable (en présence d'amidons notamment); on utilise alors un échangeur de chaleur à surface râclée dont les fonctions principales sont la stérilisation du produit et la cuisson jusqu'à une température pouvant être supérieure à 100°C sous pression atmosphérique. Le procédé que nous avons étudié présente, comme le montre la Fig. 1, une telle configuration. Le nombre de cylindres satellites applicateurs peut varier selon les produits et les productivités envisagées.