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Energy savings for spray dryers in the dairy industry

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ABSTRACT

The Research and Innovation Division of GDF SUEZ, in partnership with INRA (French National Institute for Agricultural Research) and with the financial support of ADEME (French Environment and Energy Management Agency), is conducting a project to evaluate the possibilities of energy savings for spray dryers in the dairy industry. The approach is based on the use of the SD2P® software (Spray Drying Parameters Simulation & Determination) developed by INRA which allows to predict the thermodynamic parameters for spray drying based on the physico-chemical characteristics of the dairy concentrate to be dried.

At first, using the software, a parametric study involving different types of dairy concentrates as well as the spray dryer operating parameters reveals that an increase of the spray dryer evaporative capacity can lead to a 5 to 12% saving in specific energy consumption. Likewise, heat recovery on the exhaust air enables for a 4 to 15% saving in specific energy consumption.

Testing on the Bionov pilot spray dryer at INRA confirms those potentialities. Technical equipments allowing for these optimizations to be performed are then identified and evaluated, both technically and economically.

Lastly, it is shown that while dehumidification of the inlet drying air is of no interest in terms of energy savings, it enables for a decrease of powder stickiness at the drying chamber base. It therefore facilitates the production continuity regardless of the outside weather conditions and air moisture.

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1. INTRODUCTION

The most frequently used technique for dehydration of dairy products is spray drying. There are more than 75 spray dryers in the French dairy industry producing around 990,000 tons of dairy products with an energy consumption of 3.10^{12} Wh. Manufacturers have always followed empirical approaches when producing concentrates powders in industrial spray dryers. Indeed, the current state-of-the-art and knowledge do not allow for a determination of spray drying parameters beforehand. This is even more problematic nowadays with the increasing variety and complexity of the concentrates to be dried. Thus, the only way to determine spray drying parameters is to perform several expensive experiments on spray dryer pilots. This approach is complex and costly. A rigorous understanding of spray drying has therefore become necessary. INRA (French National Institute for Agricultural Research) has developed the SD2P® (Spray Drying Parameters Simulation & Determination) software in order to determine beforehand spray drying thermodynamic parameters of dairy products based on their physicochemical properties [1].

Besides, natural gas is the first energy used when producing concentrates powders in the French dairy industry standing for 47% of the total energy consumption of the sector. In particular, large amounts of energy are expended in the spray drying process with a drying air heated at around 453 to 473 K by steam or direct or indirect combustion of natural gas. Energy costs are therefore crucial in the powder production total cost so that energy efficiency in spray drying is a key concern for dairy manufacturers, clients of GDF SUEZ group. It is in this context that the Research and Innovation Division of GDF SUEZ, in partnership with INRA and with the financial support of ADEME (French Environment and Energy Management Agency, contract n°0874C0056), are conducting a project on energy savings for spray dryers with the use of the SD2P® software and the Bionov pilot spray dryer, partner of INRA. This article presents the main results obtained in the framework of this project.

2. ENERGY SAVINGS PREDICTED BY THE SD2P® SOFTWARE

- **Presentation of the SD2P® software**

The SD2P® software is a decision-making tool for dairy manufacturers to determine the main spray drying parameters beforehand. Unlike the expert monitoring systems they use at present, this method can anticipate the temperatures required to dry a given dairy product, based on its desorption drying characteristics that allows to determine a drying kinetics in given conditions.

The preliminary phase consists in the evaluation of the rate of bound water and free water present in a given dairy product using the method of drying by desorption. Few grams of the product are placed on a zeolite layer in a protective shield, thus reproducing drying conditions. A sensor monitors water activity (a_w) and the temperature in order to follow water transfers from product to ambient air.

These monitored data are integrated in the SD2P® software. The variation of a_w (or the relative humidity RH) over time results in the determination of the drying parameters of a given product: this is the drying kinetics.

The software then displays the desorption curve versus time that first comprises a constant drying rate which is related to evaporation of free water (phase I), then a falling rate of the drying kinetics which is related to evaporation of the bound water (phase II). This curve shows the difficulty of eliminating water during the spray drying process. During phase I, water can be easily eliminated from the product while during phase 2, water is bounded to the product and is therefore more difficult to eliminate.

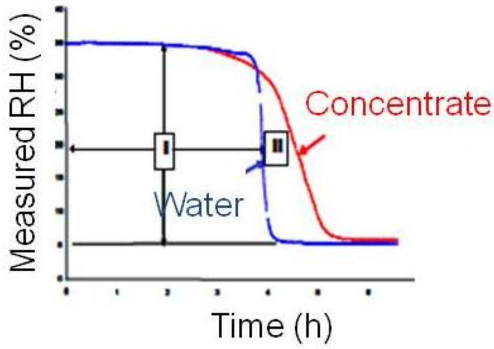

Figure 1: Desorption curve versus time

Inlet and outlet air temperatures of the spray dryer are then determined by using the thermodynamic laws for air. The following assumption is made: if the drying kinetics decreases by half, then two times more energy must be provided to the system to evaporate the same quantity of water. Therefore, it becomes possible to determine the value of the drying parameters beforehand taking into account the own characteristics of the drying system (e.g.: losses at walls, evaporative capacity of the system, absolute moisture content air, etc.), and the product characteristics (temperature, relative final moisture).The enthalpic Mollier diagram is then visualized with inlet and outlet air temperatures.

Finally, the SD2P® software enables for the validation of these calculated theoretical parameters using a database of results obtained from experiments performed on the Bionov pilot spray dryer on more than 30 dairy concentrates.

- **Types of spray dryers considered**

The SD2P® software can consider single or two-stage spray dryers (including an air inlet at the level of the internal fluidized bed). External vibro-fluidizer is not taken into account as the percentage of drying at that level remains negligible. Thus, only single and two-stage spray dryers have been studied in the framework of this project.

- **Quantification of energy savings by calculation**

A parametric study using the SD2P® software has been conducted in order to identify operating parameters of a given spray dryer that can lead to significant savings in specific energy consumption (energy consumed per kg of final product). Considering that many different types of concentrates can be dried in the same dryer, 7 different products have been selected, some being easy, some being less easy to dry. Their desorption characteristics have been analyzed. The parametric study has then consisted, for each of the concentrate, to make vary one by one each of the operating parameters of the spray dryer in order to precise its potential influence on the energy cost of the produced powder when compared to a standard reference case. Mean characteristics of the French climate have been taken into account. The 13 operating parameters for a two-stage spray dryer are presented on Figure 2.

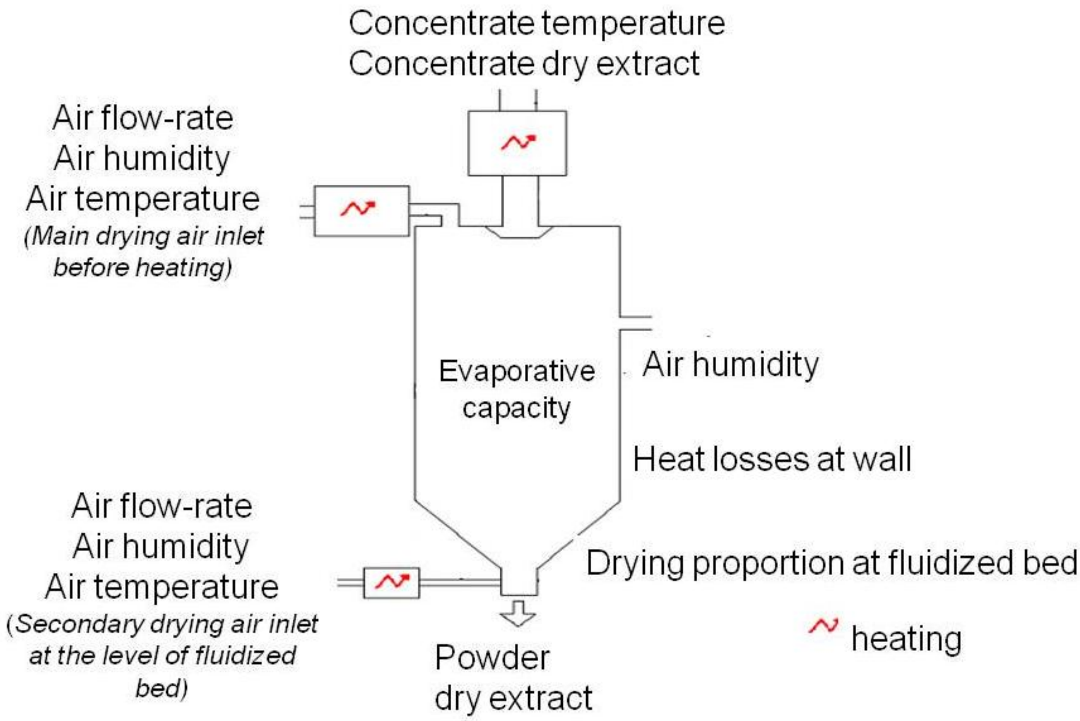

Figure 2: SD2P® operating parameters for a two-stage spray dryer

Note that an increase in the evaporative capacity corresponds to an increase in the drying capacity of the spray dryer. It is measured as the mass of evaporated water per mass of dry air and expressed in g/kg of dry air. The evaporative capacity can be increased for example by increasing the main drying air temperature after heating hereafter referred to as “inlet drying air temperature”.

Finally, the parametric study involving different types of concentrates has shown that **two significant parameters** allow for savings in specific energy consumption:

- An **increase in the main inlet drying air temperature before heating** (“preheating of the upstream air”) can lead to **4 to 15% saving in specific energy consumption**;
- An **increase in the spray dryer evaporative capacity** can lead to a **5 to 12% saving**.

3. EXPERIMENTAL VALIDATION

Testing on the Bionov pilot spray dryer, partner of INRA, has been made in order to validate this theoretical approach. This is a MSD ("Multi-Stage Dryer") type spray dryer which evaporates 80 kg of water per hour. Two different types of concentrates have been used:

- Skim milk concentrate at 40% of total solids, robust and easy to dry;
- A mixture of skim milk (16%), maltodextrin (68%) and sorbitol concentrates for an overall 40% of total solids. This is a very hygroscopic mixture and therefore difficult to dry.

Several experiments and measures on Bionov spray dryer have qualitatively confirmed the possibilities for energy savings as previously identified through SD2P® simulations:

- Preheating of the upstream air can be performed by heat recovery on the exhaust air thanks to the use of a heat exchanger. This leads to a saving in specific energy consumption up to 9%;
- Increase in the spray dryer evaporative capacity has also been validated as a parameter allowing for a saving in specific energy consumption up to 31%.

However, increasing the evaporative capacity by increasing of the "inlet drying air temperature" remains a delicate approach. It must be efficiently controlled because if a powder layer is formed and sustained inside the drying chamber, this layer may ignite as the auto-ignition temperature of a milk powder layer is estimated at 473 K. There is therefore potentially a risk of an explosion inside the chamber.

4. ROLE OF THE INLET DRYING AIR DEHUMIDIFICATION

Simulations using the SD2P® software have shown that dehumidification of the inlet drying air, while widely used by dairy manufacturers, is of no interest in terms of energy savings. However, lowering the drying air absolute humidity enables for a decrease in the maximum product temperature inside the drying chamber. This helps to decrease the risks of powder stickiness at the drying chamber base which are particularly high for hygroscopic products. As powder stickiness results in the interruption of the drying process and the need for additional time for cleaning, avoiding stickiness is key to achieve a drying operation with a good economic performance.

Thus, dehumidification of the inlet drying air facilitates the production continuity all along the year regardless the outside weather conditions and air moisture. It has also been verified that for a two-stage spray dryer, dehumidification of the secondary inlet air at the level of the fluidized bed is often sufficient to limit the product temperature inside the drying chamber.

For a two-stage spray dryer, an ideal optimization leading to energy savings and limiting the risks of powder stickiness therefore consists in preheating the main inlet drying air ("upstream air") thanks to heat recovery on the exhaust air as well as increasing the evaporative capacity by increasing the "inlet drying air temperature" of the upstream air and dehumidifying the drying air at the level of the internal fluidized bed. This is represented on Figure 3.

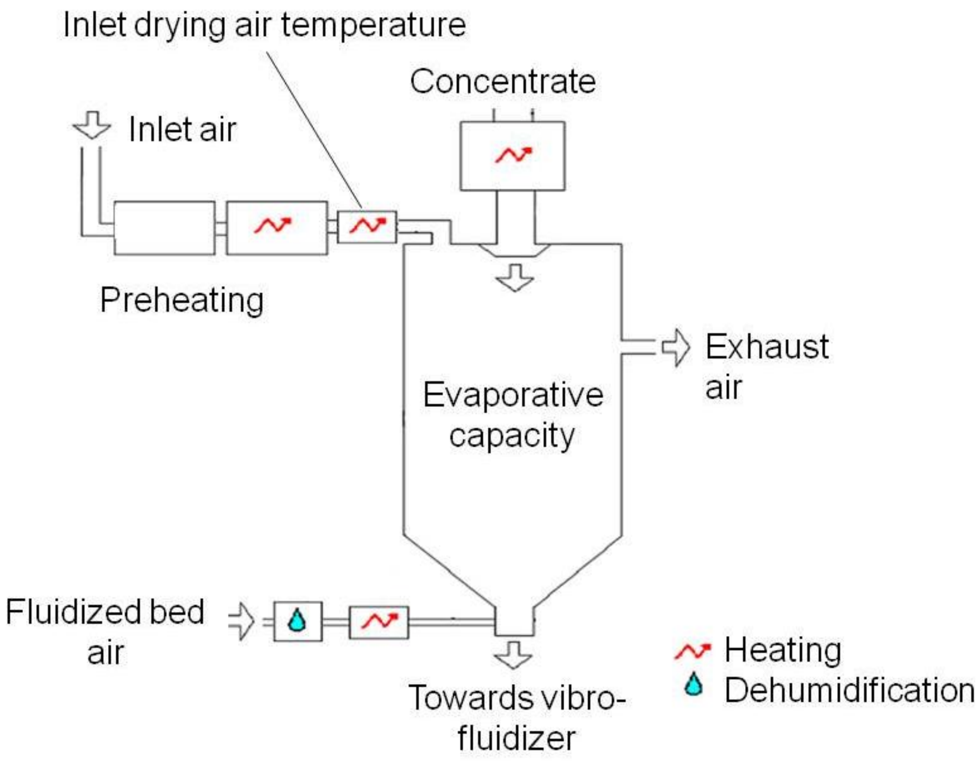

Figure 3: Ideal optimization for a two-stage spray dryer

5. IDENTIFICATION OF TECHNICAL SOLUTIONS

Technical equipments allowing for the proposed optimizations to be performed have been identified and evaluated. In order to **preheat the main inlet drying air**, heat recovery on the exhaust air can be performed using the two following technical options:

- An **air-to-air plate heat exchanger** with a high exchanged power, a saving in specific energy consumption ranging from 16 to 23% and a return on investment from 8 months to 6 years depending on manufacturers and models considered;

- A system based on **indirect thermal exchange:** a first heat exchanger allows for a heat transfer between the hot spray dryer exhaust air and a cold heat-carrying fluid. When heated, this fluid circulates in an intermediary circuit thanks to a pump and in turns preheat the cold drying air circulating in a second heat exchanger, upstream to the spray dryer. The exchanged power is lower and with this technical solution, a 11% saving in specific energy consumption can be obtained with return on investments ranging from 9 to 17 months depending on the model considered.

Which of the two options will be selected will depend on the space available to install the whole heat recovery system around the spray dryer.

In order to **reduce the inlet drying air humidity**, choice of a desiccant rotor has been made (Figure 4): air is blown through the rotor structure and the humidity in the air is absorbed by the desiccant. The air leaves the rotor as dry air. The use of a desiccant rotor is accompanied by an increase in the process air temperature equivalent to a preheating of the drying air without a supply of additional energy. The choice of this equipment corresponds to a big investment. It can be designed to dehumidify both main and secondary inlets drying airs.

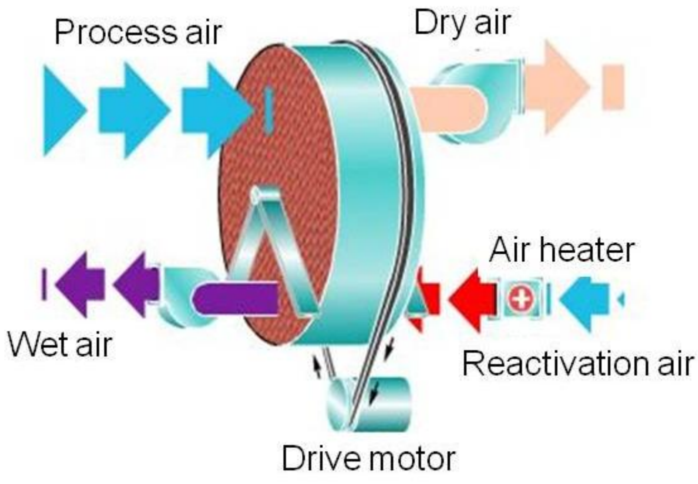

Figure 4: Desiccant rotor principle

Lastly, in order to **increase the spray dryer evaporative capacity** by an increase of the “inlet drying air temperature”, several types of equipments have been studied. They are either designed to increase the total air heating power by adding an additional heating system or to completely replace the existing system. The equipment must be able to provide a drop in “inlet drying air temperature” from 483 K, the usual temperature, to 573 K, the targeted temperature. The following solutions have been identified:

- Indirect air heaters operating with natural gas can both provide an additional heating power or replace the whole existing heating system. For a 6.5% saving in specific energy consumption, the return on investment is around 40 months;
- Boilers cannot attain a temperature of 573 K and need to be complemented by an additional heating system downstream. An electric battery can be a solution with a return on investment of around 15 months for a saving in specific energy consumption of 6.5%.

6. CONCLUSION

This project on energy savings for spray dryers in the dairy industry has proved that an increase in the spray dryer evaporative capacity or the use of heat recovery on the exhaust air to preheat the main inlet drying air are two ways to reduce energy consumption of a spray dryer. These optimizations have been confirmed by both theoretical and experimental approaches. Many technical solutions have been identified and can be implemented to perform these optimizations. Nevertheless, conducting an analysis on energy efficiency of a spray dryer has to be done on a case-by-case basis by considering the diversity of dairy concentrates, the configuration of the production site as well as the potential security problems related to a modification of some of the operational parameters or the installation of new equipments.

Beyond dairy products, spray drying is widely used in many other industrial applications such as the production of chemical powders (ceramics, detergents, …) or food powders (coffee, egg, carbohydrates such as maltodextrin, …). Extending the current approach to those sectors will be of primary interest.

Further to this project, GDF SUEZ will evaluate the possibility to develop a service offer in Europe related to energy savings for spray dryers dedicated to its clients, in order to allow them to decrease their energy consumption, their CO_2 emissions and improve the quality and productivity of their production.

References

[1] Schuck P., Dolivet A., Méjean S., Zhu P., Blanchard E., Jeantet R. 2009. Drying by desorption: A tool to determine spray drying parameters, Journal of Food Engineering 94: 199-204.

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