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Applicability of Simple Mass and Energy Balances in Food Drum Drying

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ABSTRACT

Drum drying is one of the most important drying methods in the production of dried food. Drum dryers are robust in construction and consume huge quantity of energy. Holding the drying process under control can be of high importance for both saving the energy and reducing the costs. Mass and energy balances represent a very good basis towards efficient process control and quick estimation of the process state, as well as are unavoidable step in the design of food processes, respectively. In this work the using of simple mass and energy balances in practical industrial applications is demonstrated.
KEY WORDS: baby food, drum drying, energy balance, mass balance, process calculations

1. INTRODUCTION

Drum drying (Figure 1) has been widely used in food industry for drying of various liquid, semiliquid and paste-like food materials. That way, many dried food products such as milk powder, baby foods, starch, fruit and vegetables pulps, honey, malto-dextrins, yeast creams and many other food and non-food products can be produced [1-6]. The obtained dried product is porous and easy to rehydrate, ready to use [6]. As well, the manufactured dried products can be employed as semi-finished products in milk, drinking, confectionary and other industries [4]. However, the purpose of food drying is to extend shelf life of products with minimum packaging requirements and reduced shipping weights [4].

Drum dryers(Figure 1)are conduction dryers, the drying effect being obtained by the transfer of heat from the condensing steam inside the drums to the film of material covering their external surface [7,8].Commonly, the drum dryer consists of one cylinder rotating about horizontal axis with variable speed control. One of the most important features of the drum drying is a high drying rate [9]. Different methods have been employed to apply the material as a film over the drum surface depending on the drum arrangement, the solid concentration, viscosity and wetting ability of the product. There are roll feeding, nip feeding, dipping, spraying and splashing [5,10]. Figure 1 represents a commonly process scheme of dehydrated baby food production on drum dryers. The food material to be dried is prepared in the mixer by adding the desired components (flour, sugar, vitamins, etc.) and water. After mixing (5-10 min) the liquid or semi-liquid food material is transported by pump to the drum dryer surface and equally distributed along the surface. Applying onto the rotating outer surface of the drum dryer as a thin film the food material is dried. After ¾ of a revolution from the point of feeding the dried product is scrapped off and conveyed to the sifter in order to obtain the uniform size.

The control and optimization of a drum dryer process is rather complicated due to the complex interactions between all operating variables and parameters [11, 12].There are five important variables required to be controlled during the drum drying process: steam pressure, rotation speed of drum, drum clearance, pool level between the drums (by application double drum dryer) and conditions of the feed material (concentration, physical characteristics, temperature) [13].

Major problems in the use of drum drying have to do with a nature of the product to be dried, the drum drying as a heat transfer mechanism, design and construction of the dryer, conditions under which the dryer operates and economies to be affected within the drum dryer itself and in the connection with the manufacturing process in which it is being used [14].

Nevertheless, problems are sometimes encountered with the output product quality because of some perturbations in the drying processes, such as fluctuations in the initial moisture content and thickness of product [15], accumulation of non-condensable gases in the drum with local bad heat transfer [16], etc. These perturbations produce wet zones on the drying film, and unevenness in the moisture content of the final dried product, and can be overcome by over drying the product [6].

Other disadvantages that should be overcome during drum drying operating can be summarized as follows [5, 17]:

- film building on the drum surface,
- difficulties by scrapping off the dried material,
- low throughput compared to spray dryer,
- high investment costs,

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- not able to process salty products due to potential pitting of drum surface,
- possible scorching of the product to impart cooked flavor,
- at times undesirable color changes, etc.

In order to overcome and to deal with the above specified problems the unavoidable first step figures the basic process calculations. In industrial practice the need for process calculations of dryers may arise from the following situations [18]:

1. Selection of suitable dryer type and size for a given product to optimize the investment and operating costs,
2. Finding operating conditions for the ancillary equipment for a selected dryer or a dryer already in use for each new product to be dried,
3. Determination of the optimal operating conditions for a dryer already in operation.

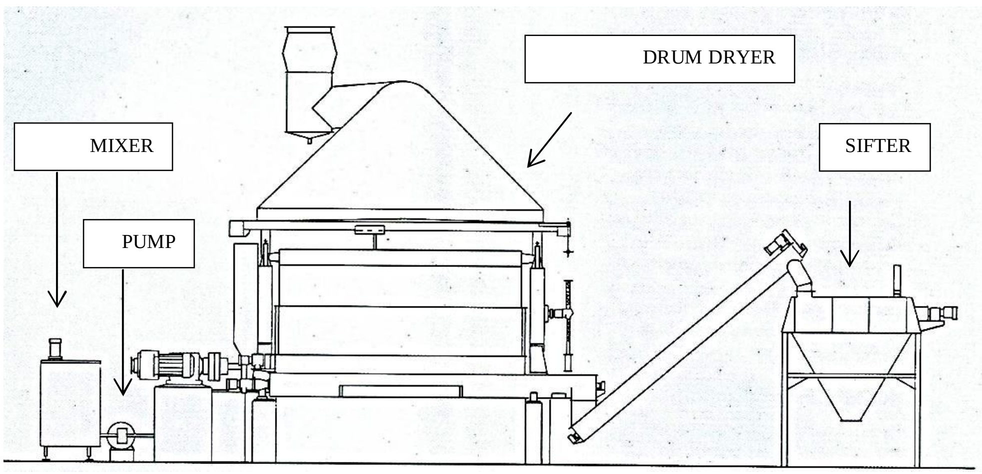

Figure 1 Process scheme of baby food drum drying

All above mentioned problems are solved using a large experimental database and experience [16], including the technical performance factors of dryers, heat and mass balances over dryer and process calculations in externally and internally controlled drying.

2. Motivation for the work

Besides many contemporary drying techniques, the drum drying as a method for dehydrated food production is still of high importance. As mentioned earlier, in the manufacturing process many different problems can appear [6, 14, 15, 16]. These problems can provoke the abandonment of the process causing high costs and long resting time. Very often the production engineers are in doubt of choosing the appropriate approach to the problem understanding and solving. Sometimes, in production practice, because of lack of time and high production demand, is tried to recover the production systems without checking the material or energy parameters, although there is a high possibility that some important material or energy parameters has been changed. In order to check the process state, the simple mass and energy balance can deliver satisfactory results as shown in literature data. The intention of this work is to apply the simple mass and energy balance by daily baby food drum drying production and to indicate their helpfulness by daily operations.

For full process control, it is recommended to conduct further process calculations and to master all crucial variables and parameters, which are not the main topic of this work.

3. Mass and energy balance

Mass and energy balances represent the basis for process control in food industry, and consequently for food drying processes. The mass flow in drying processes can be described by mass balance following the law of conservation of mass. Hence, the energy balance follows the law of conservation of energy, whereas all energy flows may be described by energy balance. Mass and energy balances within food processes require special attention, due to the complexity of food materials, and the importance of minor food components to food quality [19]. Mass and energy balances by drying processes can be very simple [19] or very complex taking into account a large number of process variables and parameters [3,20].

Not only for process control, but also for most process design calculations and equipment sizing mass and energy balances are of high importance. Therefore, mass and energy balances are essential in the design of food processes, processing equipment, process utilities, waste treatment facilities, in process optimization and control, and in cost analysis of the process and the processing plant [19].

In this work I concentrated on very simple mass and energy balance in drum drying process. Namely, there is a need by practical engineering applications for quickly solving of daily process problems connected with material and energy flows.

Figure 2 shows a schematic sketch of a food material and steam flow in a drum dryer requested for properly defining of overall mass and energy balance. Liquid or semiliquid material of mass flow m_i(kg/s dry basis), moisture content X_i (kg/kg dry basis) and temperature T_i (°C) is dried and scrapped off the drum dryer with mass flow m_o (kg/s dry basis), moisture content X_o (kg/kg dry basis) and temperature T_o(°C). Moisture (water) is removed from the material by heating with a mass flow m_w.

Hence, the steam (mass flow m_s (kg/s), temperature T_s (°C) and the heat quantity Q (kW)) is entering the drum dryer transferring the heat to the drum wall, cooling and condensing itself outputting the system as a liquid (condensate).

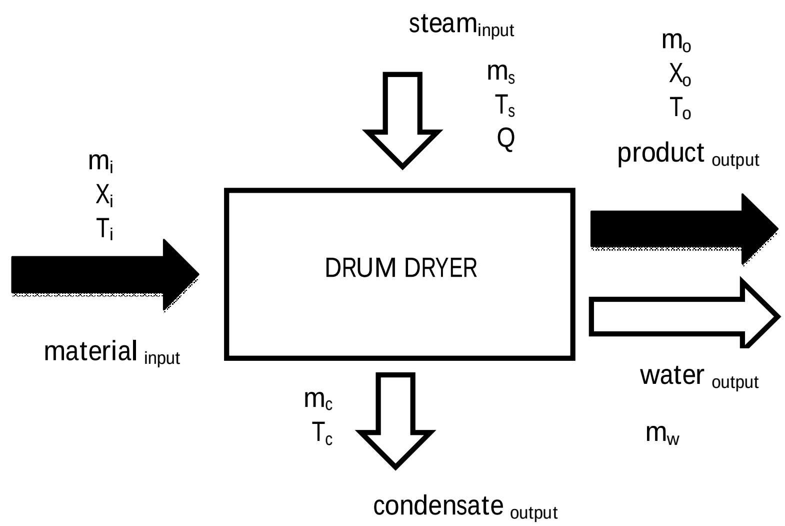

Figure 2 Schematic sketch of food material and steam flow in a drum dryer

3.1. Mass balance equation

Mass balance represents the basis for process control [21]. Mass balances should be in the first order developed theoretically already in early stage of new product development, or should be checked, respectively corrected after experiment performing in pilot plant scale, as well as obtaining the final shape in the industrial conditions. Mass balance should be investigated always by changing of production conditions or recipes for particular product.

A very simple mass balance has the following form [22, 23]:

Input = Output + Accumulation

Thus, for an ideal adiabatic dryer (no mass and heat losses) the mass balance could be:

Input (mass flow of dry matter) = Output (mass flow of dry matter) + Evaporated water (mass flow of dry matter)

$$m_i = m_o + m_w \tag{1}$$

Assuming that in evaporated water no dry matter can be found, $m_w = 0$, consequently the mass balance can be written as follows:

$$m_i = m_o \tag{2}$$

Mass balances are simplified in continuous operations, since the accumulated masses (total and component) are equal to zero. Mass balances can be expressed for one or more food components, also.

3.2. Energy balance equation

In the analysis of fluid flow (in case of drum drying the fluid is liquid food material) one other important quantity is the energy balance. By the energy balance the energy quantities can be described. The main energy form considered in process design calculations is heat, and accordingly only heat balances should be determined. In practical applications by food drying processes the application of the energy balance request the focusing on heat, as a dominant energy form. Heat balances involve the enthalpy and specific heats of the various process and utility streams [19, 24].The energy balance can be calculated on the basis of external energy used per kilogram of product, or raw material processed, or on dry solids, or some key component [21].

Figure 2indicates the energy flows required to determine the overall heat balances, also. The overall thermal energy input to the dryer *Q (kW)* is used to heat the solid material Q_m *(kW)* and to evaporate the water Q_w *(kW)*. As already mentioned, it is assumed that drum dryer is an adiabatic dryer. Therefore, the overall energy balance for drum dryer can be depicted as follows [19]:

$$Q = Q_m + Q_w \tag{3}$$

thus,

$$Q_m = m_i (C_{pm} + X_i C_{pw})(T_o - T_i) \tag{4}$$

$$Q_w = m_i (X_i - X_o)(\Delta H_0 - (C_{pw} - C_{ps}) T_o) \tag{5}$$

whereas,

C_{pm},C_{pw}, C_{ps} –specific heat of material, water and steam (kJ/kg K),

ΔH_0 - latent heat of condensation (kJ/kg)

X_i, X_0 - initial and final material moisture content (%, dry basis)

Energy balances can be obtained by alternative formulation, taking into account enthalpy [19]. Enthalpy is always referred to some reference level, so that the quantities are relative to this reference level. Working out energy balances is then just a matter of considering the various quantities of materials involved, their specific heats, and their changes in temperature or state [21]. The heat can be absorbed or evolved by some reactions in food processing but usually the quantities are very small comparing with sensible heat and latent heat [21]. Sensible heat is that which when added or subtracted from food materials changes their temperature and thus can be sensed, whereas the latent heat is the heat required to change the physical state of materials [21].Considering the drum dryer as non-adiabatic dryer, differential dryer balances must include local heat losses and gains [18].

3.3. An example of simple mass and energy balance by baby food drum drying

Dehydrated baby food is one of the most important daily baby meals, which can be produced using various techniques like spray drying and drum drying [25].On example of drum drying of baby food wet mixtures the importance of mass and energy balance in practical applying was denoted.

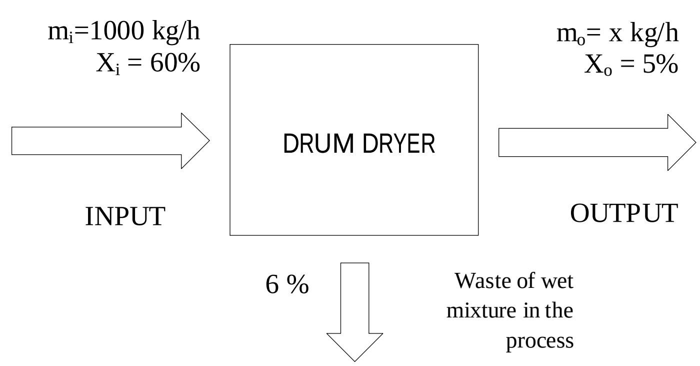

Figure 3 Schematic sketch of material flow of typical baby food drum drying process

Figure 3 represents an example of material flow by baby food drum drying. It is assumed, that the drum dryer is an adiabatic dryer, and that only physical material loss of 6% occurs. Using the very simple mass balance the following data can be obtained:

The mass of dry matter in wet mixture is940 kg *(1-0.6) = 376 kg and the mass of moisture in wet mixture is940 kg – 376 kg = 564 kg. Hence, the mass of the final product can be calculated in the following manner

376 kg : m_o = 0,95 : 1, resulting with m_o = 396 kg. Therefore, the mass of evaporated water is 940–396 = 544 kg

In practical applications there is very often the case that the mass balance can be presented following only particular components in the process. In this example the simple overall mass balance has been presented and the most important values were summarized in Table 1.

INPUT		OUTPUT	
Dry matter	**400 kg**	**Dried product**	**396 kg**
Water	**600 kg**		
		Waste	
		Water	**36 kg**
		Dry matter	**24 kg**
		Evaporated water	**544 kg**
TOTAL	**1000 kg**	**TOTAL**	**1000 kg**

Table 1 Asimple mass balance for baby food drum drying

On the other hand, the simple energy balances can be also very useful in food drying process. Assuming that the drum dryer from the above example utilizes the saturated steam (latent heat of condensation 2260 kJ/kg) for drying of the baby food (temperatures (T_i = 25°C, T_o=100 °C)) the overall heat requirement of the process can be calculated.

Using the Eq. 3 the overall thermal energy input can be easily calculated, having the value Q=392kW for given example.

4. DISCUSSION

Evidently, the above given calculations of mass and energy balance seems to be quite simple but at the same time they give a quantitative feeling for the presented situation and can be of high importance for using in design of equipment and processes, as well in the process control.

Many researchers [16, 18, 20, 21, 22] reported about the simple approach to mass and energy balance for practical applications, particularly in cases where the mass and energy balance should be estimated quickly. However, they showed the way to use simple mass and energy balances by process design and control.

The approach to mass and energy balance can be very complicated, as shown by reference [3]. The mass balance was included a large number of parameters such as moisture diffusivity, density, mass transfer coefficient, moisture molecular weight, saturation pressure at material surface, moisture partial pressure in the surrounding air, definition of initial and boundary conditions, drum rotation velocity, evaporation rate, etc. Hence, there is no doubt that using complicated mass balance the more accurate data can be obtained, but in industrial practice the estimation of all this variables and parameters can be redundant in daily operations. In this work the using of simple mass balance for obtaining quick process information was proposed.

More complicated is the issue of energy balance, where even more variables and parameters should be estimated. By using of more sophisticated energy balance, as shown in reference [3], the following parameters and variables have to be determined: material thermal conductivity, drum thermal conductivity, material heat capacity, moisture heat capacity, internal surface temperature, surrounding air convective heat transfer coefficient, density, film thickness, feed density, external drum diameter, powder heat capacity, Nusselt number, Prandtl number, Reynolds number, respectively. Additionally, by estimation of moisture transfer coefficient from the saturated film surface to the surroundings the Schmidt number, surrounding air molar flux and ambient pressure should be identified. By simple energy balance, as shown in this work, with only small number of parameters and variables the relevant information about the process can be obtained.

As indicated throughout the manuscript in literature can be found both, simple and sophisticated mass and energy balance equations for drum drying applications. For daily practical industrial applications and quick investigation of the process state the use of simple mass and energy balance is recommended. For full process control, it is recommended to conduct further process calculations and to master all crucial variables and parameters, mentioned earlier.

5. Conclusions

Mass and energy balance are of high importance and unavoidable step for process control and design of drying processes. As indicated in this work, the approach to mass and energy balance can be various, respectively, from very simple approach shown in this work and many authors, to very sophisticated approach reported by others. It can be concluded that using of simple approach is very useful in practical industrial application due to time sparing and obtaining of satisfied data that way.

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